Program Application Guide Volume 2
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Dynamic Simulation Principles

13.1. Basic Dynamic Simulation

The dynamic simulation of a physical process has three basic steps:

1. Construction of a set of differential equations describing the behavior of the physical system in general.
2. Determination of a set of values of constant and variable parameters describing, in detail, the condition of the physical system at some instant.
3. Integration of the differential equations with the values determined in Step 2 as initial conditions.

The overall process is best illustrated by an example.

A rocket, coasting after acceleration to a high velocity, would move around a heavenly body according to Newton's inverse square law as given by the four differential equations Equation 13.1 and Figure 13.1, "Diagram of a Simple Planetary System".

$$m\frac{dv_x}{dt} = \frac{-G}{x^2 + y^2}\,\frac{x}{\sqrt{x^2 + y^2}}$$

$$m\frac{dv_y}{dt} = \frac{-G}{x^2 + y^2}\,\frac{y}{\sqrt{x^2 + y^2}} \qquad (13.1)$$

$$\frac{dx}{dt} = v_x$$

$$\frac{dy}{dt} = v_y$$

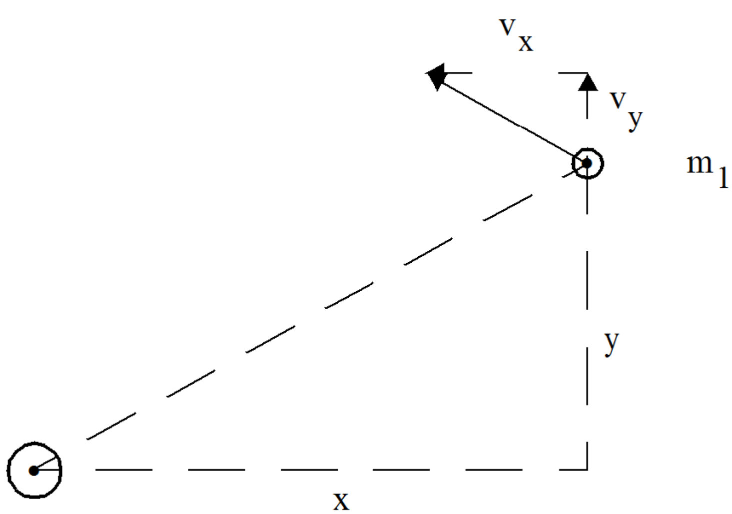


Figure 13.1. Diagram of a Simple Planetary System

If the values of the four variables x, y, v_x, v_y are known at some instant, t, their values at a later instant, t + Δ t, can be computed to first-order accuracy from Equation 13.2.

$$
\begin{aligned}
x^{new} &= x^{old} + \frac{dx}{dt}\Delta t \\
y^{new} &= y^{old} + \frac{dy}{dt}\Delta t \\
v_x^{new} &= v_x^{old} + \frac{dv_x}{dt}\Delta t \\
v_y^{new} &= v_y^{old} + \frac{dv_y}{dt}\Delta t
\end{aligned}
\tag{13.2}
$$

This process is illustrated in Figure 13.2, “Graphical Illustration of Simulation Process”. Numerical calculations are very simple because the four variables where instantaneous values are known (v_x, v_y, x, y) are all that is needed to complete the evaluation of the right-hand sides of Equation 13.1.

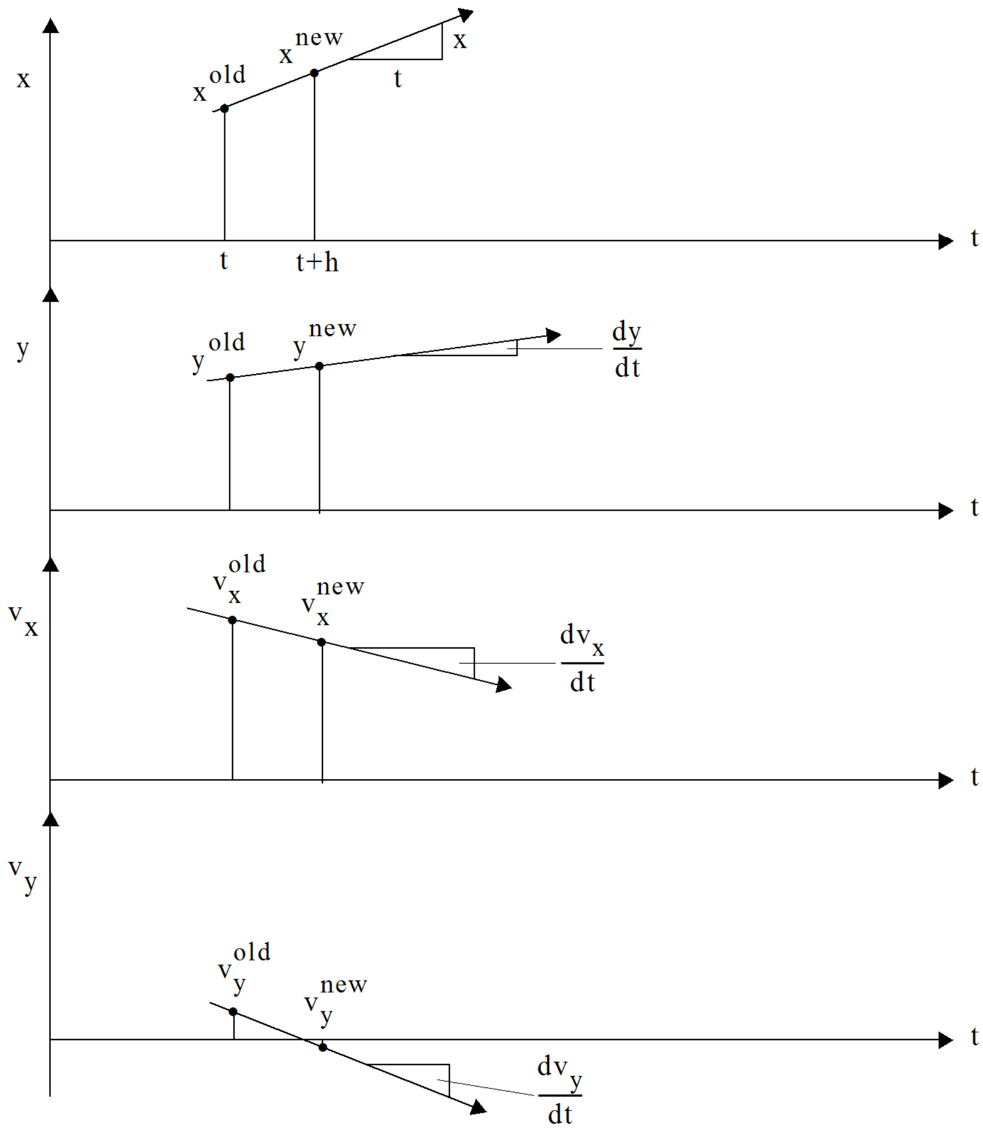


Figure 13.2. Graphical Illustration of Simulation Process

The flow chart of a digital computer program to execute the simulation of the rocket's motion is shown in Figure 13.3, "Simple Simulation of Planetary Motion Modeled as in Figure 13.1, "Diagram of a Simple Planetary System" ". Figure 13.4, "Simple Program to Simulate Motion of Rocket About a Heavenly Body" shows the Fortran listing of a very simple program to apply this calculation.

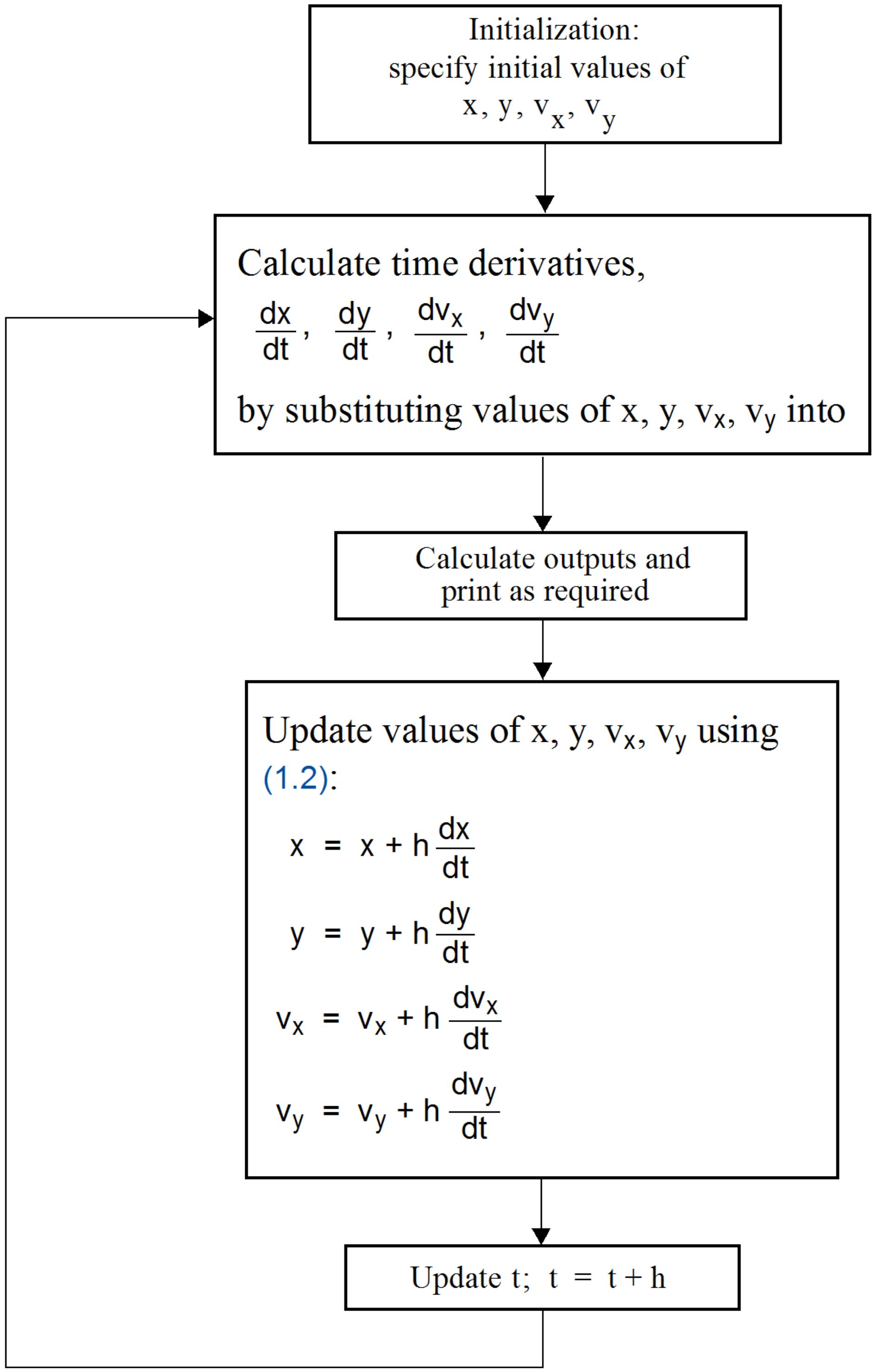


Figure 13.3. Simple Simulation of Planetary Motion Modeled as in Figure 13.1, "Diagram of a Simple Planetary System"

```
      REAL KG
C
C  ALLOW USER TO ENTER INITIAL VALUES OF POSITION AND VELOCITY
C
      WRITE(1,998)
 998  FORMAT(1X,'ENTER X Y VX VY KG H')
      READ(1,*)X,Y,VX,VY,KG,H
C
C  INITIALIZE VALUE OF TIME
C
      TIME=0.
C
C  START OF TIME ADVANCEMENT CALCULATION
C
 1     CONTINUE
C
C  CALCULATION OF VALUES OF ALL TIME DERIVATIVES
C
      DVXDT=-KG*X/((X**2+Y**2)**1.5)
      DVYDT=-KG*Y/((X**2+Y**2)**1.5)
      DXDT=VX                                      Process model
      DYDT=VY
C
C  OUTPUT PROCESSING.  CALCULATE VALUES OF ANY REQUIRED
C  VARIABLES AND PRINT RESULTS.  HERE WE CALCULATE RADIAL
C  DISTANCE AND ANGLE OF RADIUS ABOVE HORIZONTAL AXIS
C
      R=SQRT(X**2+Y**2)
      TH=ATAN2(Y,X)*57.2958                        Auxiliary output
      WRITE(1,999)TIME,R,TH,VX,VY                  calculations
 999  FORMAT(1X,5E14.4)
C
C  CALCULATION OF NEW VALUES OF ALL VARIABLES
C
      VX=VX+DVXDT*H                                Numerical
      VY=VY+DVYDT*H                                integration
      X=X+DXDT*H                                   calculation
      Y=Y+DYDT*H
C
C  INCREMENT TIME
C
      TIME=TIME+H
C
C  RECYCLE THE PROCESS AS LONG AS IT IS OF INTEREST
C
      IF(TIME.LT.1E6) GO TO 1
      STOP
      END
```

Figure 13.4. Simple Program to Simulate Motion of Rocket About a Heavenly Body

This example, and particularly the computer code in Figure 13.4, “Simple Program to Simulate Motion of Rocket About a Heavenly Body”, shows the three separate major elements of the dynamic simulation calculation:

- Calculation of time derivatives.
- Output processing.
- Numerical integration calculations.

It is apparent that no intelligence on the process being simulated other than numerical values of the four time derivatives is needed to apply the numerical integration calculations. If variables were renamed as follows, the program shown in Figure 13.4, “Simple Program to Simulate Motion of Rocket About a Heavenly Body” could be written as shown in Figure 13.5, “Rewritten Dynamic Simulation Program ”:

$v_x = s(1)$

$v_y = s(2)$

$x = s(3)$

$y = s(4)$

$r = v(1)$

$\theta = v(2)$

The program shown in Figure 13.5, “Rewritten Dynamic Simulation Program ” consists of two sections:

- A main program to handle data input, output, and numerical integration without specific information on the process being simulated
- A subroutine, ROCKET, to calculate numerical values of time derivatives from the process differential equations, and to calculate numerical values of auxiliary output variables

This example shows that the modeling of a specific process can be accomplished in a subroutine that is independent of the main dynamic simulation subroutine.

```
      REAL KG
      REAL S(4),DS(4),V(2)
C
C  ALLOW USER TO ENTER INITIAL VALUES OF POSITION AND VELOCITY
C
      WRITE(1,998)
 998  FORMAT(1X,'ENTER X Y VX VY KG H')
      READ(1,*)X,Y,VX,VY,KG,H
C
C  INITIALIZE VALUE OF ALL VARIABLES AND TIME
C
      TIME=0.
      S(1)=VX
      S(2)=VY
      S(3)=X
      S(4)=Y
C
C  START OF TIME ADVANCEMENT CALCULATION
C
 1      CONTINUE
C
C  CALCULATION OF VALUES OF ALL TIME DERIVATIVES
C
      CALL ROCKET(KG,S,DS,V)
C
C  WRITE OUT OUTPUT VARIABLES
C
      WRITE(1,999)TIME,V(1),V(2)
 999  FORMAT(1X,5E14,4)
C
C  CALCULATION OF NEW VALUES OF ALL VARIABLES
C
      DO 2 I=1,4
 2    S(I)=S(I)+DS(I)*H
C
C  INCREMENT TIME
C
      TIME=TIME+H
C
C  RECYCLE THE PROCESS AS LONG AS IT IS OF INTEREST
C
      IF(TIME.LT.1E6) GO TO 1
      STOP
      END
      SUBROUTINE ROCKET(KG,S,DS,V)
      REAL KG
      REAL S(4),DS(4),V(2)
C
C  CALCULATE TIME DERIVATIVES
C
      DS(1)=-KG*S(3)/((S(3)**2+S(4)**2)**1.5)
      DS(2)=-KG*S(4)/((S(3)**2+S(4)**2)**1.5)
      DS(3)=S(1)
      DS(4)=S(2)
C
C  CALCULATE AUXILIARY OUTPUT VARIABLES
C  V(1) IS RADIAL DISTANCE
C  V(2) IS ANGLE ABOVE HORIZONTAL AXIS
C
      V(1)=SQRT(S(3)**2+S(4)**2)
      V(2)=ATAN2(S(4),S(3))*57.2958
      RETURN
      END
```

Initialization

Dynamic Model Subroutine

Call to process model

Output

Numerical integration calculation

Process Model Subroutine

Figure 13.5. Rewritten Dynamic Simulation Program

with Process Model Isolated in Subroutine

13.2. Simulation Model Library

The dynamic simulation section of PSS®E has the basic structure illustrated by the foregoing example and shown in Figure 13.6, "Basic Program Structure of PSS®E Dynamic Simulation Section". The main skeleton of PSS®E contains logic for data input, output, numerical integration, and electric network solution, but contains no logic related to differential equations of specific equipment. The differential equation intelligence on the equipment to be simulated is contained in a library of subroutines; each subroutine contains logic to calculate time derivatives for one specific type of equipment. The model subroutines are called whenever the main skeleton logic needs numerical values of time derivatives. Most models are called directly by PSS®E. Others that may require user input or are called infrequently, such as switched shunt models, are called via linking subroutines CONEC and CONET.

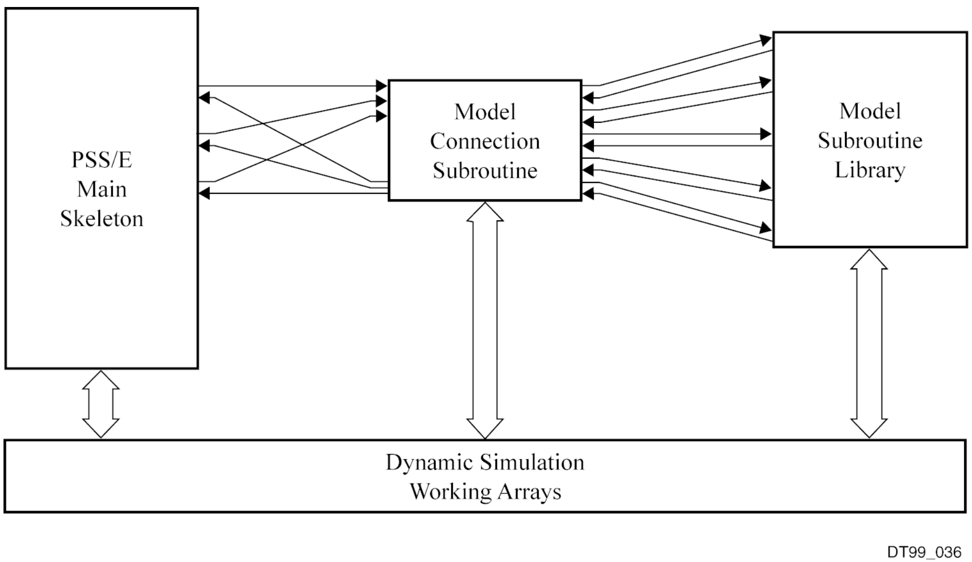


Figure 13.6. Basic Program Structure of PSS®E Dynamic Simulation Section

Each new dynamic simulation requires that new linkage subroutines, CONEC and CONET, be constructed and incorporated into the skeleton code. The construction and loading on CONEC and CONET is automated by the PSS®E skeleton, which is able to bootstrap itself into fully loaded condition. This process is covered in Section 14.2.6, "Dynamics Data Entry and CONEC, CONET Construction".

13.3. Numerical Integration Stability

A numerical integration process such as the one described by equations Equation 13.2 will function satisfactorily only if the time increment, $\Delta\, t$, is sufficiently small in relation to the time constants and natural frequencies of the process being simulated. Too long a step width, $\Delta\, t$, will lead to both inaccurate results and eventually to numerical instability of the calculation. To illustrate the phenomenon of numerical instability, consider the application of the simple first-order integration formula:

$$q^{new} = q^{old} + \frac{dq}{dt}\Delta t \tag{13.3}$$

to the very simple differential equation:

$$\frac{dq}{dt} = \frac{-q}{T} \tag{13.4}$$

Equation Equation 13.4 describes the discharge of a capacitor through a resistor; its exact solution is:

$q(t) = q(o)^{e-t/T}$

The numerical integration process of Figure 13.2, "Graphical Illustration of Simulation Process" is equivalent to rewriting Equation 13.4 as:

$$\frac{dq}{dt} = \frac{-q^{old}}{T}$$

and substituting this into Equation 13.3, with the result:

$$\begin{aligned} q^{new} &= q^{old} + \left(\frac{-q^{old}}{T}\right)\Delta t \\ q^{new} &= q^{old}\left(1 - \frac{\Delta t}{T}\right) \end{aligned} \tag{13.5}$$

which shows that:

- The sequence of *q* values will decrease monotonically if Δ t is less than the time constant, T.
- The sequence of *q* values will have alternating sign and increasing magnitude if Δ t is greater than 2 *T*.

It is apparent, then, that this numerical integration process can be accurate only when $\Delta\, t$ is small in relation to the time constant, T, and that it can exhibit an error that grows unstably if $\Delta\, t$ is excessive in relation to the process time constant. This behavior is shown graphically in Figure 13.7, "Comparison of Numerical Integrations of Equation Equation 13.4".

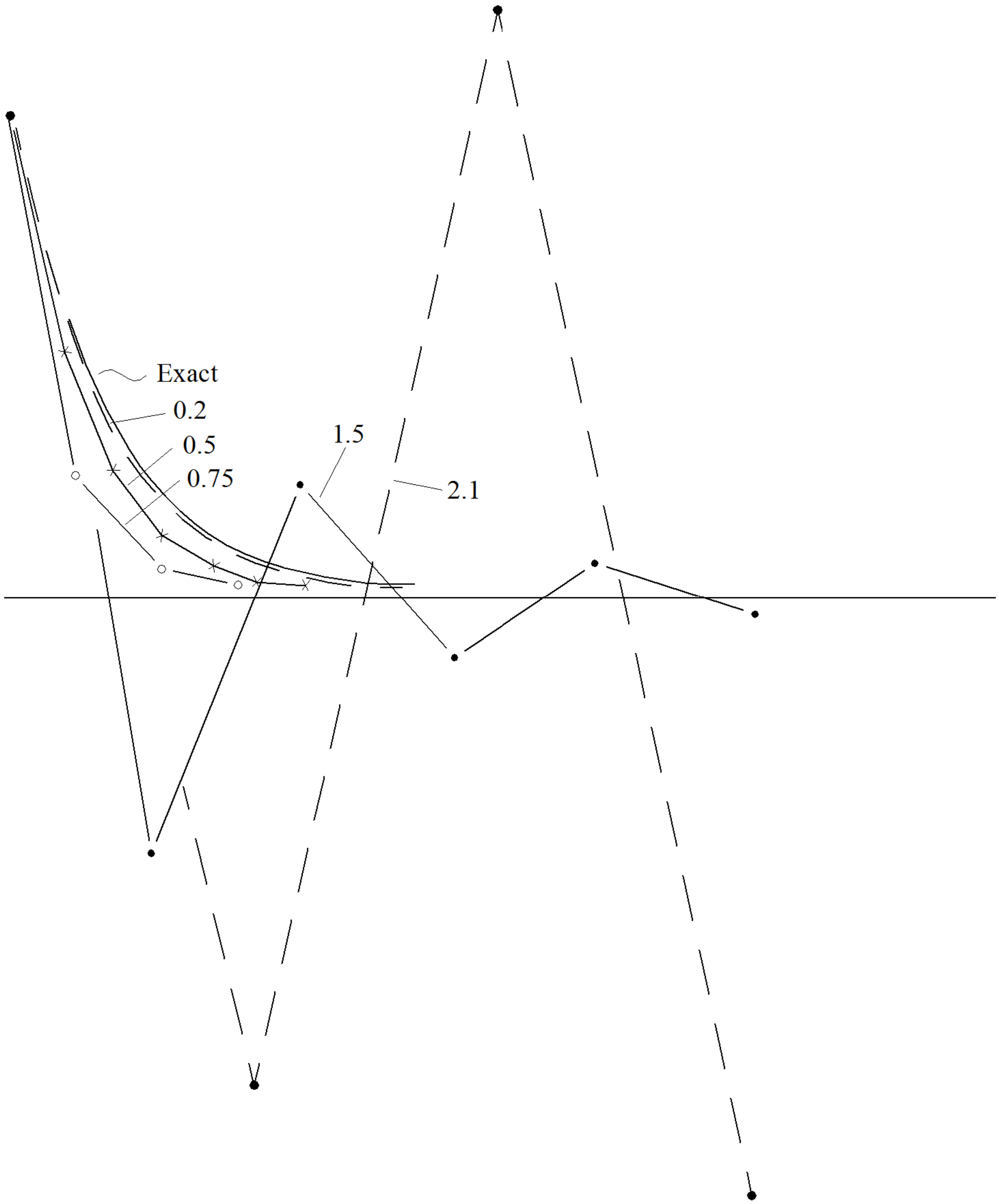


Figure 13.7. Comparison of Numerical Integrations of Equation Equation 13.4

for Varying Values of Δ t/T

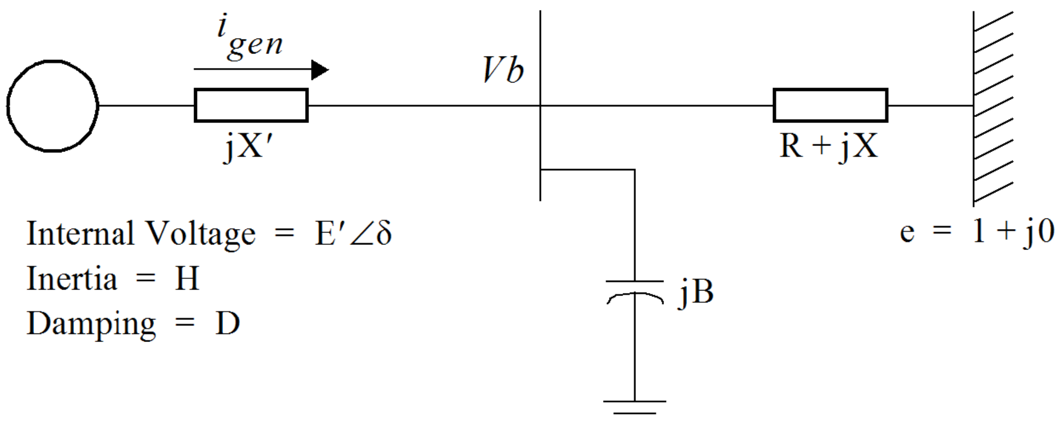
PSS®E does not use the simple first-order integration scheme analyzed above; it uses a second-order Euler numerical integration algorithm where accuracy is better than that of the simple first-order scheme. Long experience with this method indicates that numerical instability problems will normally be avoided, and accuracy will be adequate, if the integration time step, Δt, is kept smaller than about 1/5 to 1/4 of the shortest time constant in the process being simulated.

Numerical instability of the integration process usually results in a growing sequence of values in at least one system variable, with the sign alternating each time step. Numerical instability is most readily detected, therefore, by examining a plot of the variable at each time step. Conversely, a numerical instability can be present but may not be detected if the affected variable is plotted only every *n* time steps, where n is an even number. Hence, it is advisable always to use an odd number of time steps between each plotting of results from a dynamic simulation.

13.4. Classification of Variables

13.4.1. General Classification

The dynamic simulation example in the previous section was particularly simple in that each of the expressions for a time derivative (as shown in Figure 13.1, "Diagram of a Simple Planetary System") involved only the quantities where derivatives were being evaluated. Because the values of all of these quantities are known when the derivatives are to be evaluated, the derivatives can be calculated directly by numerical evaluation of the right-hand sides of the differential equations. This convenient state of affairs does not exist in power system dynamic simulations. The realistic situation is illustrated by the following example: a simulation of the motion of the rotor of a single generator connected to an infinite bus in accordance with the per unit differential equations shown in Figure 13.8, "Differential Equations for Generator Connected to Infinite Bus".



$$2H\frac{dn}{dt} = P_m - P_e - Dn$$

$$\frac{d\delta}{dt} = \omega_o n$$

Figure 13.8. Differential Equations for Generator Connected to Infinite Bus

The differential equations in Figure 13.8, "Differential Equations for Generator Connected to Infinite Bus" involve the constants H, D, and ω_o and, in addition, the first involves the generator electrical power, P_e. In the first equation in Figure 13.8, "Differential Equations for Generator Connected to Infinite Bus", the assumption is that the variation in speed is small. In view of this, power (instead of torque) is used in this equation. The evaluation of P_e at the instant for which the variables n, speed deviation, and δ, rotor angle, are given requires solution of the electric network for the generator current, i_{gen}. While it would be possible to write out an algebraic solution for the current and, subsequently, the power, it is more practical to handle the network solution and power calculation numerically. The evaluation of the time derivatives is then handled by the following sequence of calculations:

1. Calculate v_b from:

$$v_b - \left(\frac{E'\angle\delta}{jx'} + \frac{e}{R+jx} \right) / \left(jB + \frac{1}{jx'} + \frac{1}{R+jx} \right)$$

Calculate i_{gen} from:

$i_{gen} = (E' \angle \delta - v_b) / jx'$

2. Calculate P_{gen} from:

$P_{gen} = \mathrm{Real}\,(E' \angle \delta \times i_{gen})$

3. Calculate time derivatives:

$$\frac{dn}{dt} = (P_m - P_{gen} - Dn) / 2H$$

$$\frac{d\delta}{dt} = \omega_o n$$

The calculation of the time derivatives in this example involved the prior calculation of a set of quantities, v_b, i_{gen}, and P_{gen} that are related algebraically to the variables, n and δ , for which values are given by the numerical integration process. Variables such as v_b, i_{gen}, and P_{gen} are needed in the majority of dynamic simulations. It is convenient, therefore, to classify the quantities involved in a dynamic simulation as:

- *Constants:* Parameters that do not vary during the period to be simulated.
- *State Variables:* Variables for which instantaneous values are determined by differential equations.
- *Algebraic Variables:* Variables for which values can be determined if the values of all state variables, constants, and input variables are given.
- *Input Variables:* Quantities for which values are specified at any instant by logic outside the dynamic simulation.

13.4.2. PSS®E Parameter and Variable Classification

PSS®E is a general-purpose dynamic simulation tool that can handle any simulation task where formulation can be reduced to terms of constants, state variables, algebraic variables, and input variables as outlined in Section 13.4.1, “General Classification”. Because it is designed for power system work, PSS®E, has assigned named memory arrays to accommodate several specific groups of variables: constants, parameters, and variables, which are listed in Table 13.1, “Dynamic Simulation Arrays ”. This table lists four general-purpose arrays, CON, ICON, STATE, and VAR, together with the special arrays such as MBASE, VOLT, and VREF. The only distinction between the general-purpose and special-purpose arrays is that the latter accommodate quantities that are frequently wanted as input and output quantities in setting up and displaying the results of dynamic simulations. All arrays are used as constants, state variables, or algebraic variables in the same way.

Table 13.1. Dynamic Simulation Arrays

Array	Contents	Indexed By
Constants		
CON	General constants (real)	CON number
ICON	General constants (integer)	ICON number
CHRICN	General constants (character)	ICON number
MBASE	Machine base MVA	Machine index
ZSORCE	Machine impedance (complex)	Machine index
XTRAN	Step-up transformer impedance (complex)	Machine index
GENTAP	Step-up transformer tap ratio	Machine index
State Variables		
STATE	General state variable array	STATE number
Algebraic Variables		
VAR	General algebraic variable array	VAR number
VOLT	Bus per unit voltages (complex)	Bus sequence number
BSFREQ	Bus per unit frequency deviations	Bus sequence number
ANGLE	Machine relative rotor angle (degrees)	Machine index
PELEC	Machine electrical power (pu on SBASE)	Machine index
QELEC	Machine reactive power (pu on SBASE)	Machine index
ETERM	Machine terminal voltage (pu)	Machine index
EFD	Generator main field voltage (pu)	Machine index
PMECH	Turbine mechanical power (pu on MBASE)	Machine index
SPEED	Machine speed deviation from nominal (pu)	Machine index
XADIFD	Machine field current (pu)	Machine index
ECOMP	Voltage regulator compensated voltage (pu)	Machine index
VOTHSG	Stabilizer signal (pu)	Machine index
VUEL	Minimum excitation limiter signal (pu)	Machine index
VOEL	Maximum excitation limiter signal (pu)	Machine index
Input Variables		
VREF	Voltage regulator voltage setpoint (pu)	Machine index
Internal Arrays		
DSTATE	General state variable time derivatives	STATE number

Internal Arrays		
STORE	General state variable integrator memory	STATE number
BSFMEM	Memory for frequency calculation	Bus sequence number
STRTIN	Starting array indices for plant-related models	Array allocation index table
NUMTRM	Pointer to bus sequence number	Machine index
NUMBUS	External bus number	Bus sequence number
MACHID	Machine identifier	Machine index
INTICN	Integer memory array	ICON number

13.4.3. Data Space Allocation

The arrays summarized in Table 13.1, "Dynamic Simulation Arrays " are used by the dynamic simulation models to accommodate all input and output signals, constant parameters, and internal variables. The special-purpose arrays are indexed by either machine number or bus sequence number. Locations in the general-purpose arrays, CON, VAR, STATE, ICON, and DSTATE are allocated to equipment models on a first-come, first-served basis. The use of these arrays is illustrated by Figure 13.9, "Use of PSS®E Array Elements to Accommodate System Parameters and Variables".

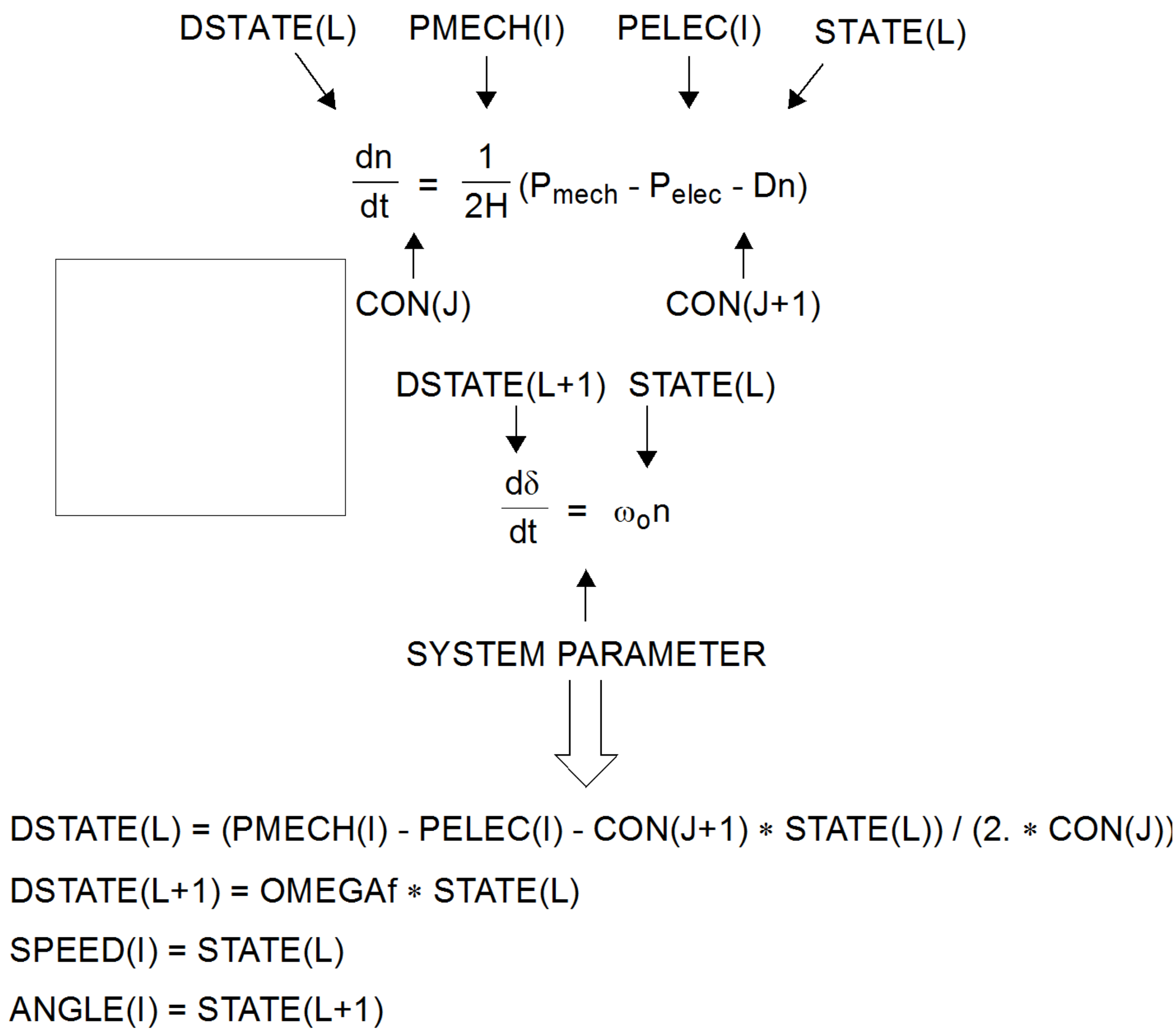


Figure 13.9. Use of PSS®E Array Elements to Accommodate System Parameters and Variables

Figure 13.9, “Use of PSS®E Array Elements to Accommodate System Parameters and Variables” shows the code implementing the two rotor dynamics differential equations shown in Figure 13.8, “Differential Equations for Generator Connected to Infinite Bus” within a subroutine named MODEL. The statement defining the model subroutine would be:

```
SUBROUTINE MODEL (I, J, L)
```

The values of *J* and *L* would be assigned to the next available locations in arrays CON and STATE as the MODEL subroutine calls are entered into subroutine CONEC. The arguments I, J, L are, then, pointers to the start of the data for the item of equipment being modeled in the PSS®E data arrays.

The use of the data arrays by a CONEC subroutine is indicated by Figure 13.10, “Assignment of PSS®E Array Space to Equipment Model Subroutines Called from Subroutine CONEC”.

Construction of subroutines CONEC and CONET require counting-off of the CONs, VARs, etc. used each time a model is called. The numbers of array elements used by each model are shown on the model data sheets. This process and the construction of CONEC and CONET can be handled manually, or can be automated by activities DYRE and CHAN, as shown in Section 14.2.6, “Dynamics Data Entry and CONEC, CONET Construction” and Section 14.2.7, “Output Channel Selection and CONET Construction”, respectively.

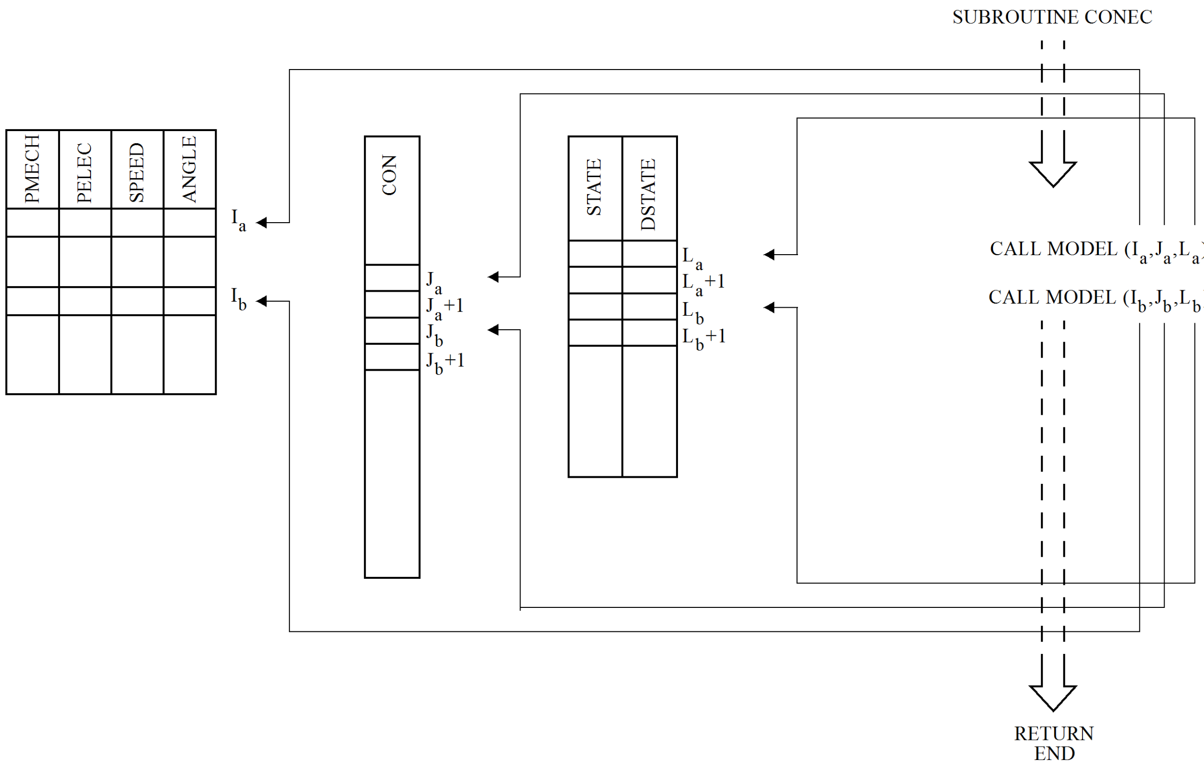


Figure 13.10. Assignment of PSS®E Array Space to Equipment Model Subroutines Called from Subroutine CONEC

13.5. PSS®E Dynamic Simulation Sequence

13.5.1. Overall Flow Chart

The overall flow of the dynamic simulation in PSS®E is shown in Figure 13.11, "Dynamic Simulation Basic Flow". The dynamic simulation functions are handled by activities DYRE, RSTR, STRT, RUN, and ALTR. These subroutines include logic to accept constant and parameter values, solve the electric network for its bus voltages, implement the numerical integration calculation, and display results. They do not, however, include logic relating to the algebraic and differential equations of any item of power system equipment. The logic required to inform PSS®E of the differential equations and other characteristics of the power system is provided by two libraries of subroutines:

- A library of subroutines handling models that involve state variables and differential equations.
- A library of subroutines handling models that involve only algebraic relationships between input and output signals, without reference to differential equations.

The linkage of the library subroutines into PSS®E is accomplished by four subroutines called TBLCNC, TBLCNT, CONEC, and CONET, which have the responsibilities outlined below. TBLCNC and TBLCNT are supplied by PSS®E and are never seen by the user.

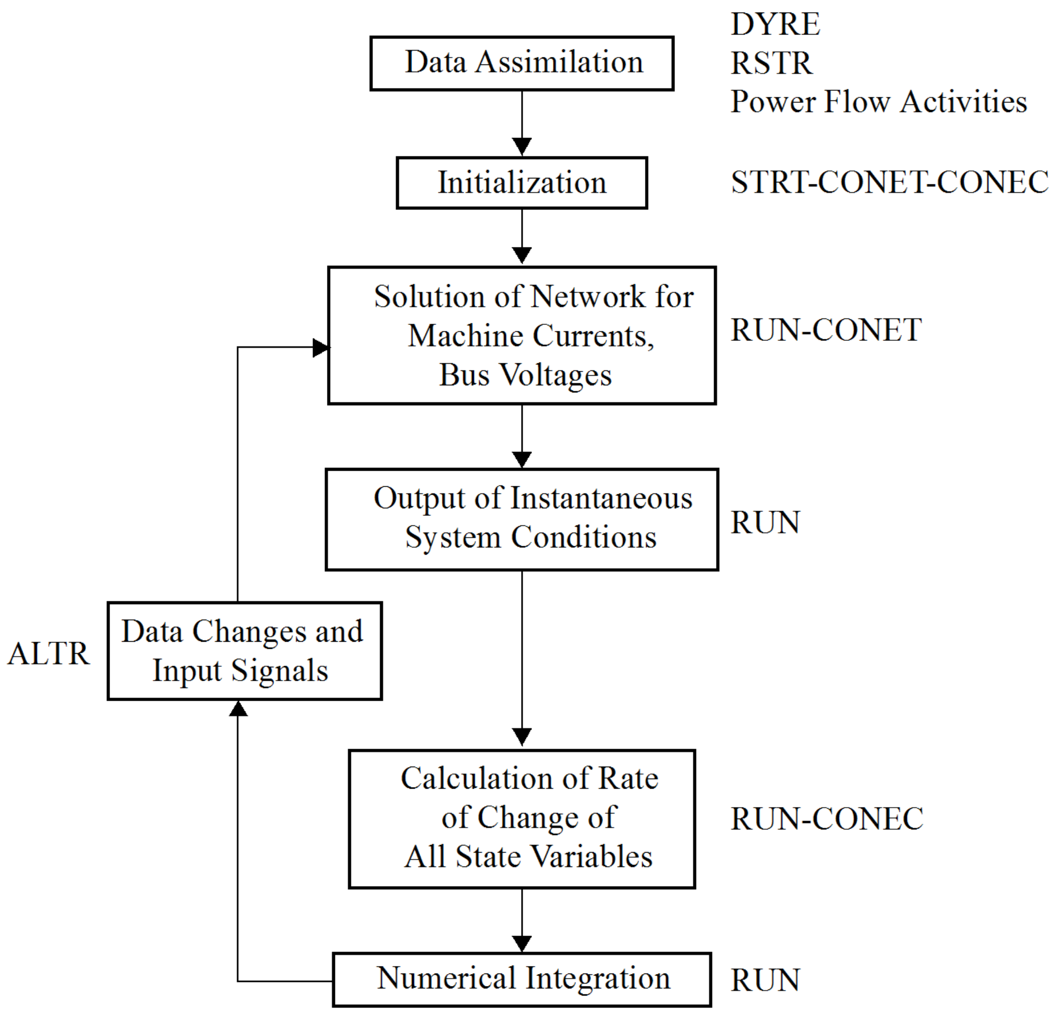


Figure 13.11. Dynamic Simulation Basic Flow

13.5.2. Subroutines TBLCNC and CONEC

Subroutines TBLCNC and CONEC are responsible for equipment models involving state variables and differential equations. TBLCNC is responsible for machines and their control systems; CONEC is responsible for all other models. Both have the responsibility of calculating the time derivative of every state variable used in modeling equipment, given the present values of all state variables and of all generator stator currents. In addition, both have the responsibility of calculating the values of all algebraic variables needed in the course of obtaining numerical values of the state variable time derivatives.

Subroutine CONEC could be written in Fortran by the user of PSS®E, much in the style of the modeling subroutine, ROCKET, shown in Figure 13.5, “Rewritten Dynamic Simulation Program ”. This is rarely done, however.

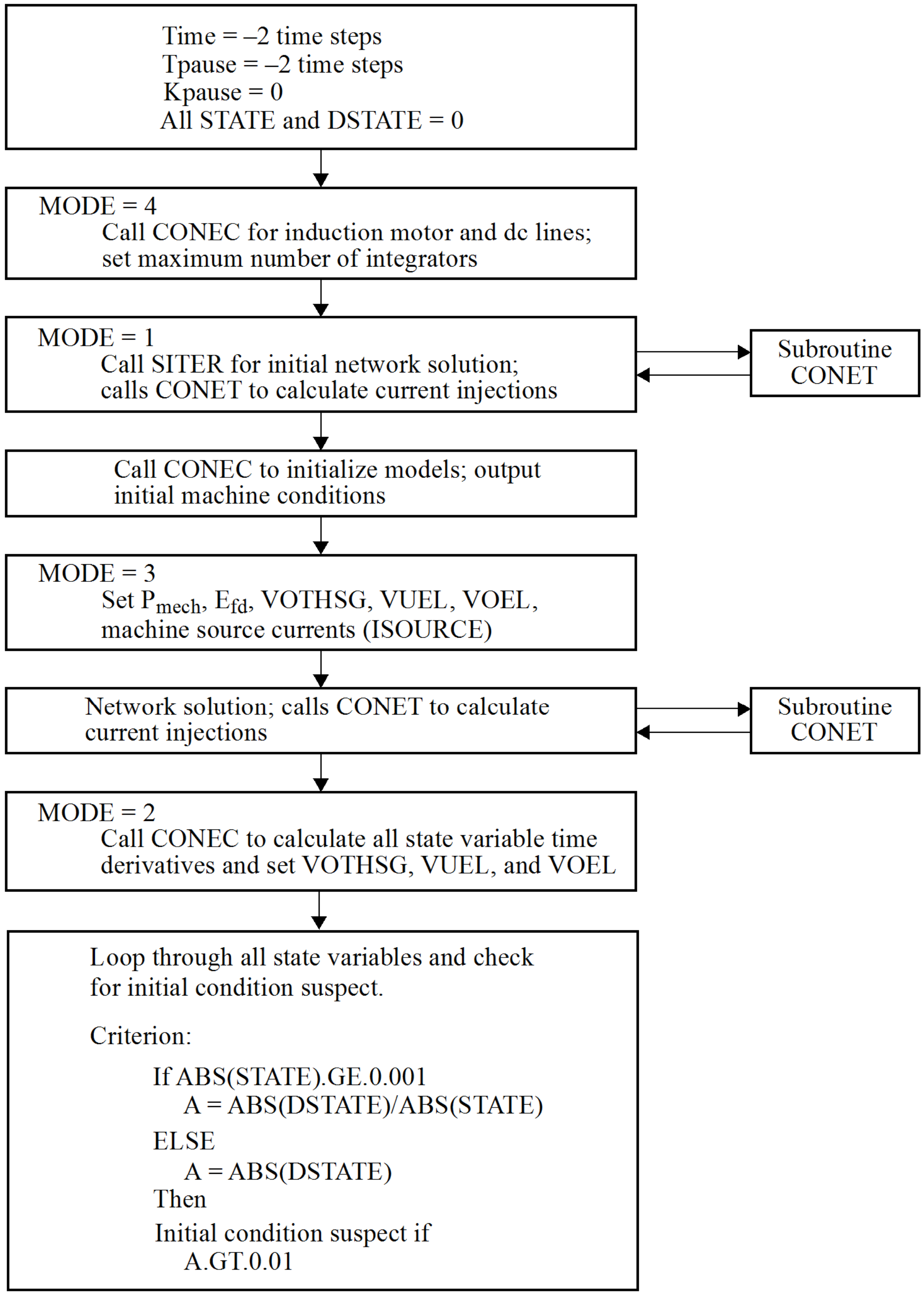
13.5.3. Subroutines TBLCNT and CONET

Subroutines TBLCNT and CONET are responsible for equipment models in which there is a purely algebraic relationship between the voltage at a bus and the current drawn by or key variable seen by a device. The principal equipment modeled in CONET are shunt load devices (such as reactors), relays, and meters.

As with subroutine CONEC, the user will rarely write the modeling code directly into CONET, but will normally establish a CONET subroutine that calls specialized equipment modeling subroutines from the PSS®E model subroutine library.

13.5.4. Program Control

The role of subroutines CONEC and CONET is shown by Figure 13.12, "Dynamic Simulation (Sheet 1 of 2)". CONEC and CONET are called at several points in the simulation process by several different activities. The specific actions of CONEC, CONET, and the model subroutines that they call are directed by a set of flags as defined in Table 13.2, "PSS®E Dynamic Simulation Control Flags ".



a. CONEC and CONET Calls on Initialization

Figure 13.12. Dynamic Simulation (Sheet 1 of 2)

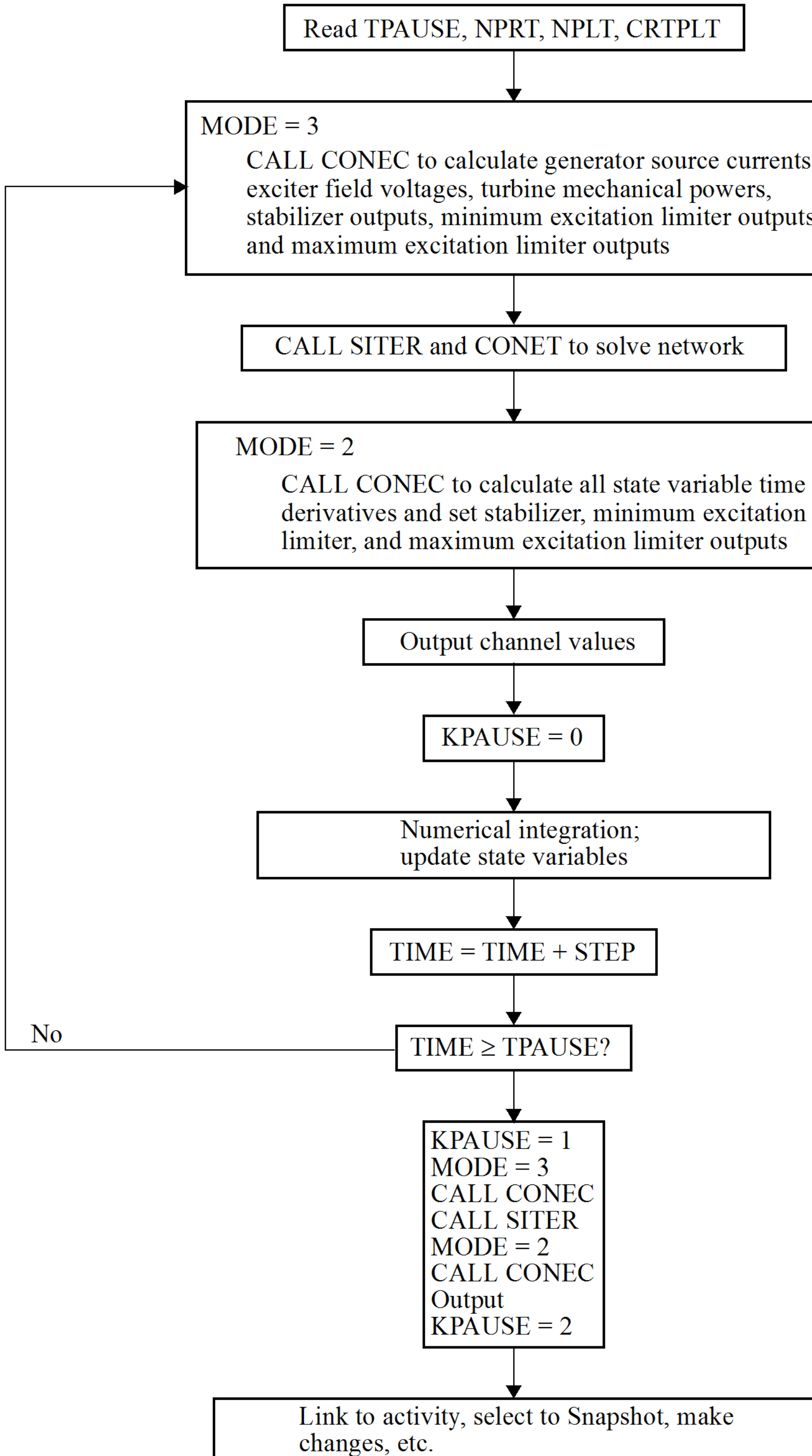


Figure 13.13. Dynamic Simulation (Sheet 2 of 2)

b. CONEC and CONET Calls During Activity RUN

Table 13.2. PSS®E Dynamic Simulation Control Flags

Flag Name	Value	Significance
MODE	1	Initialization: calculate initial condition values of all state variables and algebraic variables on the assumption that the system is in the steady state.
	2	The model must make all computations needed to place time derivatives into the DSTATE array; each stabilizer model must compute the present value of its output signal and place it in the appropriate entry in the VOTHSG array; each minimum excitation limiter model must compute the present value of its output signal and place it in the appropriate entry in the VUEL array; each maximum excitation limiter model must compute the present value of its output signal and place it in the appropriate entry in the VOEL array.
	3	Each stabilizer model must compute the present value of its output signal and place it in the appropriate entry in the VOTHSG array; each minimum excitation limiter model must compute the present value of its output signal and place it in the appropriate entry in the VUEL array; each maximum excitation limiter model must compute the present value of its output signal and place it in the appropriate entry in the VOEL array; a turbine-governor model must compute the present value of turbine mechanical power and place it in the PMECH array; other models written by users normally have no requirements in MODE three.
	4	Apply special calculations in initialization of induction motor and dc transmission models.
	5	Write model documentation when activity DOCU is run.

Flag Name	Value	Significance
	6	Write model input data when activity DYDA is run.
	7	Write model documentation when activity DOCU is run in its data checking mode.
IFLAG	False	Network iterations in progress; current injection models should update their contribution.
	True	Network solution is completed.
KPAUSE	1	Time = t^-: preswitching solution.
	2	Time = t^+: switching has been made, new solution needed.
	0	Time = t: routine step, no pause at time, t.
MSTATE	0	Standard simulation is being run.
	1	Excitation system response ratio test is being run.
	2	Excitation system open-circuit test is being run.
	3	Governor test is being run.
	4	Extended term dynamic simulation is being run.
	5	Dynamics data is present but an initialization activity has not been successfully run.

13.5.5. Simulation Output Channels

Any power system variable that can be represented by an element of an array appearing in Table 13.1, "Dynamic Simulation Arrays " may be selected as an output of a PSS®E dynamic simulation run. The handling of dynamic simulation output is shown in Figure 13.14, "PSS®E Output Channel Control". PSS®E places a set of output channel values in a Channel Output File at specified intervals of simulation time, building up a file containing a comprehensive history of the event being simulated.

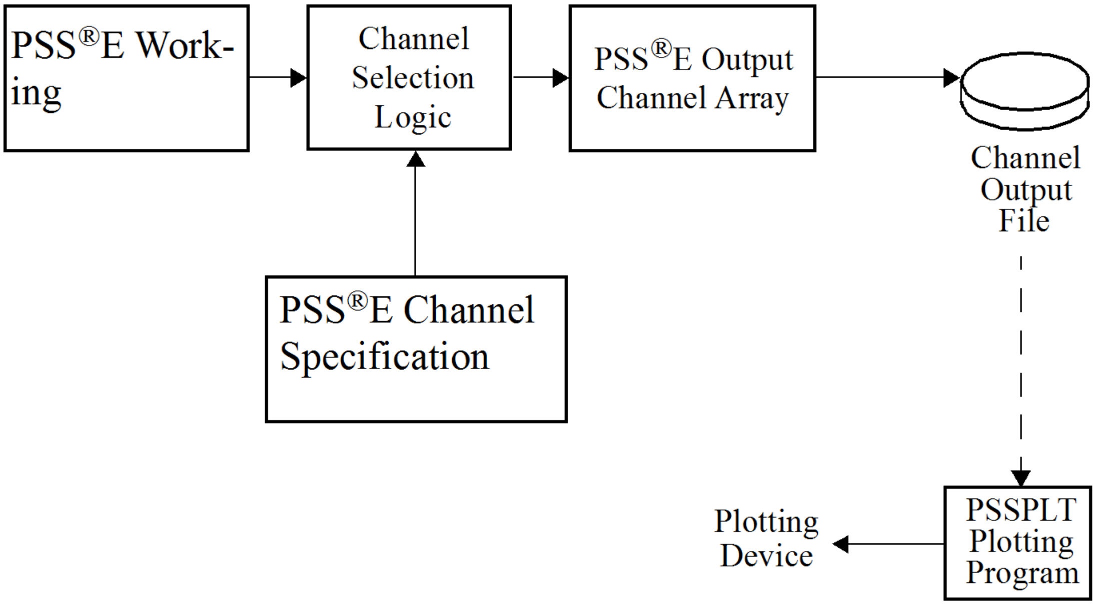


Figure 13.14. PSS®E Output Channel Control

The Channel Output File is a binary variable length record file for which the name is specified by the user when it is created in activity STRT. The PSS®E simulation activities do not plot or tabulate the output channels; these functions are handled by program PSSPLT.

The output channel values are obtained by copying designated variables from the dynamic simulation arrays into the output channel array, CHAN. This copying process is done every NPLT time steps, where NPLT is an integer specified by the user in the dialog of activity RUN. The selection of simulation variables for output via channels is controlled by the arrays summarized in Table 13.3, "Channel Specification Arrays". Array IPRINT contains the addresses of the output variables in the main dynamic simulation array space of PSS®E. Each output channel is given a 32-character alphanumeric identification. These are contained in the array, IDENT.

Table 13.3. Channel Specification Arrays

Array Name	Size	Function
IPRINT	n	Address of quantity to be displayed, relative to base of PSS®E array memory.
CHAN	n	Value of output channel.
IDENT	n	32-character channel identifier.
CRTCHN	6	Numbers of main channels in subset to be plotted during simulation on CRT.
CMAX	6	Upper limit for progress plot scaling.
CMIN	6	Lower limit for progress plot scaling.

PSS®E allows a subset of six of the output channels to be displayed by a progress output graph while activity RUN is being run. These six channels and their upper and lower scaling limits are specified by arrays CRTCHN, CMAX, and CMIN. The channel control arrays are established by the user through a dialog with activity CHAN. Any channel control parameter may be changed prior to a simulation run, via activity ALTR.

13.6. Overview of Simulation Procedure

13.6.1. Model Setup and Use

A dynamic simulation study involves two general phases:

1. Setup of a simulation model consisting of the following:

   Valid CONEC and CONET subroutines linking the required equipment dynamic models into PSS®E.

   Valid parameters and operating conditions for all items of equipment.

2. Execution of simulation runs using the model as setup in the first phase to show the effects of proposed events such as short circuit faults, generator trips, or motor starting.

PSS®E is used in both the setup phase and in the execution of simulation runs. The model setup phase is the more critical and involves the greater amount of work. A valid model setup with well-planned CONEC and CONET subroutines allows extensive series of simulation runs to be made with relatively little incremental work. A less-than-ideal model setup with unchecked data will not only make simulation runs more difficult, it will usually result in inaccurate results.

13.6.2. Simulation Model Setup

The principal steps in setting up a PSS®E dynamic simulation model are summarized in Table 13.4, "Overview of Steps in PSS®E Dynamic Simulation Model Setup " and detailed in later sections. The mechanics of setting up a system model are handled by PSS®E itself, including the construction of the CONEC and CONET subroutines and the establishment of output channel control tables. The bulk of the system model setup is automated, with handwork being reserved for special situations. A user with special requirements may, however, refine the CONEC and CONET subroutines to implement logic that is not provided by the standard model library subroutines.

Table 13.4. Overview of Steps in PSS®E Dynamic Simulation Model Setup

Step	PSS®E Activities Used	Files Used
Allocate a set of files for the simulation setup.	—	—
Establish base case power flow with generators and load models converted to their dynamic forms.	See Sections 5.2 and 13.3	Create a converted power flow Saved Case File.
Select the appropriate model for each item of equipment.	—	—
Create a PSS®E Dynamics Data File.	—	Dynamics Data File.
Use PSS®E in setup mode to create CONEC and CONET subroutines.	LOFL, CASE, ORDR, FACT, RTRN, DYRE	Read Dynamics Data File.
Use PSS®E in setup mode to create additional CONET model references to monitor transmission network via output channels.	CHAN	—
Make a Snapshot recording the parameter values and channel assignments.	SNAP	Initial condition Snapshot File.

Step	PSS® E Activities Used	Files Used
Stop PSS® E .	—	—
Edit manual refinements into CONEC and CONET as required.	—	Use text editor to alter CONEC and CONET Fortran source code files.
Compile CONEC and CONET and link into PSS® E by executing CLOAD4 command file.	—	CONEC and CONET relocatable code files.
Start PSS® E and recover the initial condition Snapshot File.	RSTR	Initial condition Snapshot File.
Retrieve power flow case corresponding to initial condition Snapshot File.	LOFL, CASE, FACT, RTRN	Converted power flow Saved Case File.
Enter any additional data values needed as a result to refinements to CONEC or CONET.	ALTR	—
Make an updated Snapshot.	SNAP	—
Set all VAR and STATE variables to their initial condition values.	STRT	Dynamics Channel Output File.
Check out all reported initial condition errors.	—	—
Make an updated initial condition Snapshot.	SNAP	Initial condition Snapshot File.
List all dynamic simulation data.	DOCU, DLST	—
Stop PSS® E .	—	—
Review all data for correctness.	—	—

Also, users may make their own special refinements to CONEC and CONET, because well-planned control logic in these subroutines often gives great simplifications in the execution of simulation runs. Examples of user-tailored logic in CONEC and CONET are given in Section 14.5, “Use of CONET in System Modeling”.

13.6.3. Execution of Simulation Runs

The steps involved in executing dynamic simulation runs vary depending on the details of the event being simulated. A sequence representative of a basic short circuit fault simulation is summarized in Table 13.5, “Representative Steps in a Dynamic Simulation Run”.

Table 13.5. Representative Steps in a Dynamic Simulation Run

Step	PSS® E Activities Used	Files Used
Recover initial condition Snapshot.	RSTR	Initial condition Snapshot File.
Recover initial condition converted power flow case.	LOFL, CASE, FACT, RTRN	Initial condition power flow Saved Case File.
Establish and confirm initial conditions in dynamic models (time initialized to t = -2 × DELT.	STRT	—
Select and initialize dynamics output file.	STRT	Channel Output File.

Step	PSS® E Activities Used	Files Used
Advance simulation with no disturbance to t = 0–, or some other appropriate time for first disturbing action.	RUN	Channel Output File.
Apply first action of disturbance, e.g., application of fault.	ALTR	—
Advance simulation to time of next change of applied disturbance.	RUN	Channel Output File.
Apply next change of applied disturbance, e.g., clear fault by opening a line.	ALTR	—
Advance simulation to time at which no additional results are currently needed.	RUN	Channel Output File.
Make a new Snapshot of conditions at the final instant of the run.	SNAP	New Snapshot File.
Make a new power flow Saved Case recording the network condition at the final instant of the run.	LOFL, SAVE	New power flow Saved Case File.
Stop PSS® E and plot, tabulate, or otherwise analyze the results.	STOP	—

13.6.4. Preservation of Simulation Setup – Snapshots

A complete dynamic simulation setup may be preserved at any time by making a Snapshot, which is a copy in a disk file of the current contents of dynamic simulation working memory. A Snapshot File contains a complete copy of the dynamic simulation arrays noted in Table 13.1, "Dynamic Simulation Arrays " and of all other arrays used internally by the dynamic simulation of PSS ®E.

A Snapshot may be used to preserve a dynamic simulation setup at any point from the early stages of data entry, through initialization, to any point during the integration of the differential equations. When made during the integration process, the Snapshot gives a complete statement of the instantaneous condition of all equipment where modeling is accommodated in the arrays listed in Table 13.1, "Dynamic Simulation Arrays ".

A Snapshot contains instantaneous values of bus voltages but does not contain transmission network impedance, status, load, and related data. This data must be preserved in power flow Saved Cases. The user may either make a new power flow Saved Case File to accompany each Snapshot or may rely on a single power flow Saved Case File that is used as the basis for all network data throughout a dynamic simulation (see the section called "Saved Case - Snapshot Pairs" and the section called "Restarting a Simulation Run").

Snapshots and associated power flow Saved Cases allow dynamic simulation work to be frozen at any point and to be restarted at the convenience of the user. They also allow in-progress conditions at key points in a simulation run to be preserved so that the effects of alternative switchings and perturbations can be investigated without having to rerun the simulation up to the point of the switching.

Chapter 14

Dynamic Simulation Setup

14.1. Overview

The dynamic simulation portion of the PSS®E program requires following a specific procedure to set up the system model. Chapter 13, *Dynamic Simulation Principles* covered the theory behind dynamic simulation and provided an outline for setting up a system. This section covers a specific procedure for taking a sample system, doing a study, expanding the modeling of the system, and doing another study. The description of specific modeling equipment is covered in Chapter 15, *Generator Modeling*.

14.2. Basic Setup Example

14.2.1. Files

The simulation setup procedure is outlined in Table 14.4, "Files to be Used in First Dynamic Simulation Setup Example". Table 14.2, "Application of Some Common Perturbations " shows the files to be used in this example. Files will be needed for raw data records, power flow Saved Cases, and dynamics Snapshots, as well as for the CONEC, CONET subroutines.

Table 14.1. Files to be Used in First Dynamic Simulation Setup Example

Power Flow Raw Data	SMALL
Solved Initial Condition (IC) Power Flow	SME1
Solved Converted IC Power Flow	SME2
Dynamics Raw Data	SMEDD
Initial Condition Snapshot	SSN1
First Plotting Output File	GOP1
Subroutine CONEC Source	CC1
Subroutine CONET Source	CT1
Response File for Channel Assignment	RC1
Progress Snapshot	SSN2
Progress Power Flow Case	SLF2

14.2.2. Example System

The setup of a dynamic simulation is illustrated in Figure 14.1, "Small Example System for Dynamic Simulation Setup Examples" using a simple example in which a small system is modeled for stability studies.

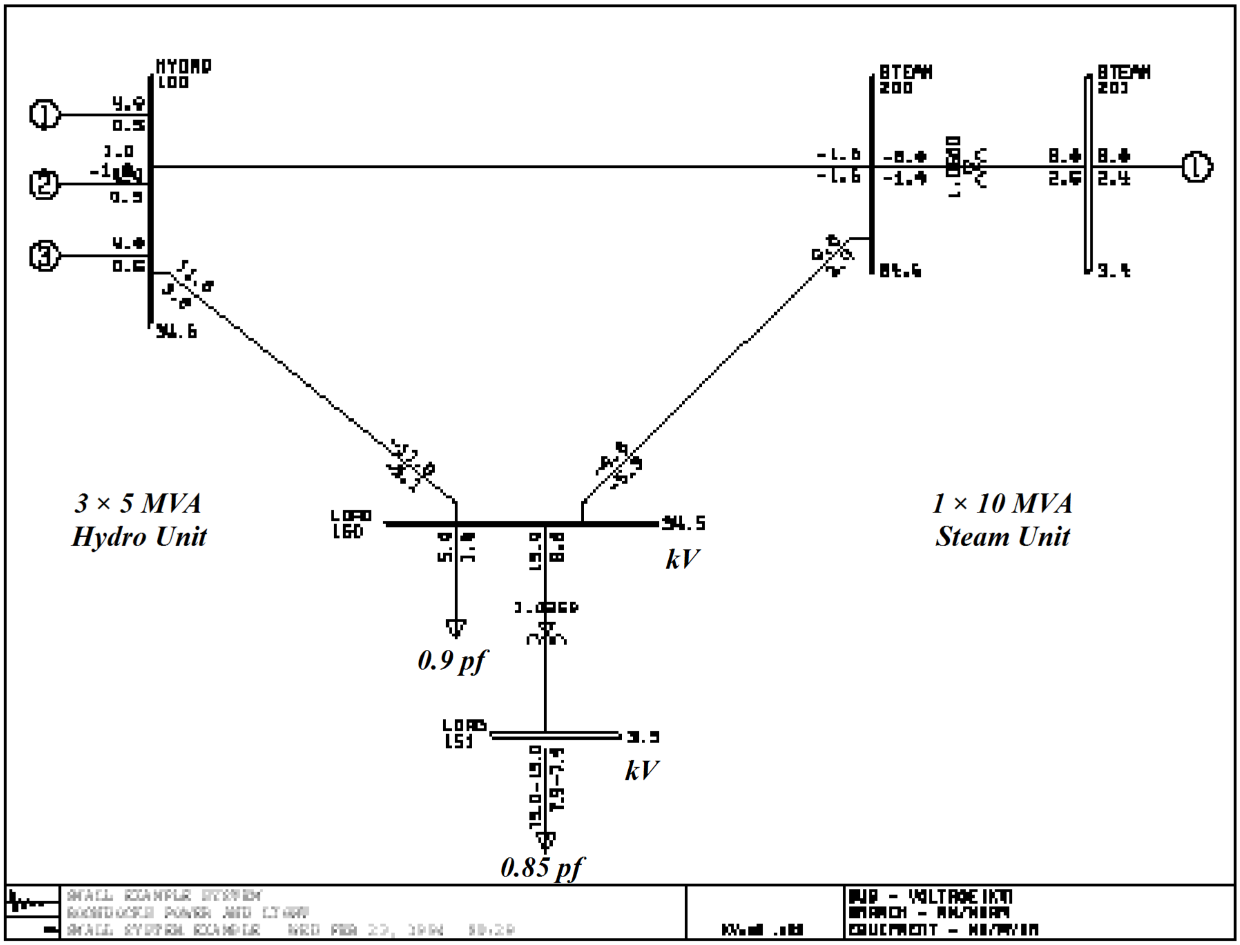


Figure 14.1. Small Example System for Dynamic Simulation Setup Examples

14.2.3. Power Flow Model

Every dynamic simulation is based on a power flow Saved Case that provides the required transmission network data, load data, and generator positive sequence model. The power flow Saved Case must have its generator models in the dynamic simulation form as outlined in Positive Sequence Representation of Generators, and its loads represented by a composite of the characteristics from Loads that is acceptable during excursions of bus voltages.

Figure 14.2, “Input Data for Small Example System” shows the basic power flow raw data file, SMALL, used to set up the power flow case.

```
0 100
SMALL EXAMPLE SYSTEM  ←  File SMALL
BOONDOCKS POWER AND LIGHT
100 3 0 0 0 0 1 1.05 0 'HYDRO' 33
150 1 5 1.56 0 0 2 1 0 'LOAD' 33
151 1 15 7.9 0 0 2 1 0 'LOAD' 3.3  ←  Bus Data
200 1 0 0 0 0 1 1 0 'STEAM' 33
201 2 0 0 0 0 1 1 0 'STEAM' 3.3
0
100 1 4 0 2 0 1.05 0 5 0 .25 0 .09 1.025  ←  Generator Data
100 2 4 0 2 0 1.05 0 5 0 .25 0 .09 1.025
100 3 4 0 2 0 1.05 0 5 0 .25 0 .09 1.025
201 1 8 0 4 0 1.05 200 10 0 .2
0
100 200 1 .02 .2 .03 15 17.5 20
100 150 1 .01 .1 .018 15 17.5 20  ←  Branch Data
150 200 1 .01 .1 .018 15 17.5 20
200 201 1 0 .8 0 10 12 15 1.05
150 151 1 0 .3 0 15 20 25 1.025
0  ←  Transformer Data
200 201 1 200 1.1 .9 1.1 .9
150 151 1 151 1.1 .9 1.1 .9
0
0
0  ←  No Other Data
0
0
0
0
```

Figure 14.2. Input Data for Small Example System

The steps in constructing the power flow case for dynamics use are shown in Figure 14.3, "Preparation of Power Flow Case for Use in Dynamic Simulation (Sheet 1 of 2)". The power flow case is first solved in the conventional manner to establish the initial condition values of all bus voltages, generator reactive outputs, and phase angles. The initial condition power flow, still in conventional form for power flow studies, is saved in file SME1, which is not useful for dynamics work.

The conversion of the power flow case so that its models are valid in dynamics ($t \le t^{+}$) rather than steady-state ($t \le t^{-}$) conditions is handled by activities CONL and CONG. These are spotted in Figure 14.4, "Preparation of Power Flow Case for Use in Dynamic Simulation (Sheet 2 of 2)". The dialog for CONL changes all loads from pure constant (MW, Mvar) to a composite characteristic in which 60% of the real power load follows a constant current characteristic and 40% behaves as a constant admittance. The split is designated as 50/50 in reactive power. This rearrangement of load characteristics may be made on a bus-by-bus basis, with different splits at different buses, by using CONL with its selection options, which are as outlined in Report Selection and Routing.

Activity CONG should always be followed by activity ORDR because the change of generator modeling to dynamic form removes all swing (Type 3) buses from the system, hence changing its topology with respect to optimal ordering.

The converted power flow case is saved in file SME2 for subsequent use as the source of network data in dynamic simulations. All generators will, then, be represented in the dynamic simulations by the dynamic impedance (normally the subtransient impedance) as contained in the power flow case SME2, and all loads will be modeled with the voltage dependence, as set up by CONL, unless this is specifically overridden in setting up the simulation.

Activities FACT and TYSL were used before the converted case was saved in file SME2. These steps give a refinement of the power flow solution to obtain the smallest possible mismatch at all buses. Such refinement is optional, but recommended, because:

1. The refinement's initial condition estimate of all generator currents is as perfect as possible. Therefore, the generator internal flux linkages calculated in the dynamics initialization will be, as nearly as possible, a perfect set of steady-state values.

2. Refining the power flow solution will reveal any significant imperfections. If activity TYSL takes more than two or three iterations to reach its tolerance, it is likely that the power flow case to which CONL and CONG were applied had not been brought to a small enough mismatch to provide a good set of initial conditions for dynamics work.

The converted saved case should always be reordered with ORDR after execution of CONG and before it is saved; otherwise, the ordering will have to be done each time a dynamic simulation is started.

Figure 14.5, "Data for Small Example System as Established in Power Flow Cases SME1 and SME2" shows a full data listing of the power flow case for reference purposes. This listing describes the solved, but unconverted, initial condition power flow as saved in file SME1.

```
$ psslf4
                POWER TECHNOLOGIES INCORPORATED

         12000 BUS POWER SYSTEM SIMULATOR--PSS®E-22.0

 INITIATED AT LOAD FLOW ENTRY POINT ON MON FEB 14, 1994  15:11

 ACTIVITY? read
 ENTER INPUT FILE NAME (0 TO EXIT, 1 FOR TERMINAL): SMALL

 ENTER IC, SBASE

 ENTER TWO LINE HEADING

 ENTER BUS DATA

 ENTER GENERATOR DATA

 ENTER BRANCH DATA

 ENTER TRANSFORMER ADJUSTMENT DATA

 ENTER AREA INTERCHANGE DATA

 ENTER TWO-TERMINAL DC LINE DATA

 ENTER SWITCHED SHUNT DATA

 ENTER TRANSFORMER IMPEDANCE CORRECTION DATA

 ENTER MULTI-TERMINAL DC LINE DATA

 ENTER MULTI-SECTION LINE DATA

 ENTER ZONE NAME DATA

 ENTER AREA TRANSACTION DATA

 BUILDING TABLES--WAIT...

 ACTIVITY? SOLV

 ITER DELTAV/TOL  BUS   REAL(DELTAV)    IMAG(DELTAV)
    1   984.908   201     0.2840E-01     0.9431E-01
    2   594.432   201     0.4574E-02    -0.5927E-01
    3   491.451   151    -0.4901E-01     0.3633E-02
    4   253.457   201     0.1111E-02    -0.2532E-01
    5    92.747   201    -0.3286E-02     0.8673E-02
    6    52.375   151     0.3459E-02    -0.3933E-02
    7    70.165   151    -0.5852E-02     0.3871E-02
    8    41.591   151     0.3665E-02    -0.1965E-02
    9    11.221   151    -0.8610E-03     0.7196E-03
   10    10.485   201    -0.3681E-03     0.9818E-03
   11     7.224   151    -0.6373E-03     0.3400E-03
   12     5.429   151     0.5383E-03    -0.7123E-04
   13     3.718   201    -0.2832E-03    -0.2409E-03
   14     3.091   201    -0.2623E-03     0.1636E-03
   15     2.446   201    -0.2378E-03    -0.5694E-04
   16     2.384   201    -0.2375E-03     0.2116E-04
   17     2.219   201    -0.2218E-03    -0.4107E-05
   18     2.038   201    -0.2037E-03     0.7415E-05
   19     1.954   201    -0.1953E-03     0.7045E-05
   20     1.831   201    -0.1831E-03    -0.1460E-05
   21     1.733   201    -0.1732E-03     0.6491E-05
   22     1.619   201    -0.1619E-03     0.1621E-05
   23     1.536   201    -0.1535E-03     0.4196E-05
   24     1.442   201    -0.1442E-03     0.1949E-05
   25     1.358   201    -0.1358E-03     0.2968E-05
   26     1.278   201    -0.1278E-03     0.2533E-05
   27     1.206   201    -0.1205E-03     0.2271E-05
   28     1.135   201    -0.1135E-03     0.2319E-05
   29     1.068   201    -0.1068E-03     0.1985E-05
   30     1.009   201    -0.1009E-03     0.2015E-05
   31     0.950   201    -0.9499E-04     0.1782E-05

 REACHED TOLERANCE IN   31 ITERATIONS
```

Figure 14.3. Preparation of Power Flow Case for Use in Dynamic Simulation (Sheet 1 of 2)

```
LARGEST MISMATCH:     0.00 MW    0.01 MVAR     0.01 MVA-BUS   150 [LOAD    33.0]
SYSTEM TOTAL ABSOLUTE MISMATCH:                0.02 MVA

ACTIVITY? ORDR
DIAGONALS =      4  OFF-DIAGONALS =      3  MAX SIZE =      6

ACTIVITY? FNSL

ENTER ITERATION NUMBER FOR VAR LIMITS
 0 FOR IMMEDIATELY, -1 TO IGNORE COMPLETELY: 0

ITER    DELTAP    BUS      DELTAQ    BUS      DELTA/V/   BUS   DELTAANG   BUS
  0     0.0000(  200)     0.0002(  200)
                                               0.00017(  200)    0.00003(  201)
  1     0.0000(  200)     0.0018(  201)
                                               0.00135(  201)    0.00008(  201)
  2     0.0000(  200)     0.0001(  201)


REACHED TOLERANCE IN    2 ITERATIONS

LARGEST MISMATCH:     0.00 MW   -0.01 MVAR     0.01 MVA-BUS   200 [STEAM   33.0]
SYSTEM TOTAL ABSOLUTE MISMATCH:                0.01 MVA

ACTIVITY? SAVE SME1

CASE SAVED IN FILE SME1.SAV ON MON FEB 14, 1994  15:12

ACTIVITY? CONL ALL
ENTER % CONSTANT I, % CONSTANT G FOR REAL POWER: 100 0
ENTER % CONSTANT I, % CONSTANT B FOR REACTIVE POWER: 0 100

LOAD TO BE REPRESENTED AS:
   REAL   REACTIVE
  0.00%       0.00% CONSTANT POWER
100.00%       0.00% CONSTANT CURRENT
  0.00%     100.00% CONSTANT ADMITTANCE
ENTER 1 IF O.K., 0 OTHERWISE:

LOADS CONVERTED AT      2 OF      2 LOAD BUSES

ACTIVITY? CONG

GENERATORS CONVERTED

ACTIVITY? ORDR
DIAGONALS =      5  OFF-DIAGONALS =      5  MAX SIZE =     10

ACTIVITY? FACT

    5 DIAGONAL AND      5 OFF-DIAGONAL ELEMENTS

ACTIVITY? TYSL

ITER DELTAV/TOL  BUS    REAL(DELTAV)    IMAG(DELTAV)
  1       2.161   200     0.2134E-04     -0.3395E-05
  2       0.060   151    -0.5960E-06      0.6706E-07

REACHED TOLERANCE IN    2 ITERATIONS

LARGEST MISMATCH:     0.00 MW    0.00 MVAR     0.00 MVA-BUS   100 [HYDRO   33.0]
SYSTEM TOTAL ABSOLUTE MISMATCH:                0.00 MVA

ACTIVITY? SAVE SME2

CASE SAVED IN FILE SME2.SAV ON MON FEB 14, 1994  17:05
```

Save unconverted initial condition power flow

Convert load characteristics to form needed in dynamic simulation

Convert generators for dynamic simulation.

Reordering is essential after converting generators

Refine solution with generator flux linkage fixed

Save converted case for use in dynamic simulation

Figure 14.4. Preparation of Power Flow Case for Use in Dynamic Simulation (Sheet 2 of 2)

```
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      MON FEB 14, 1994  17:17
SMALL EXAMPLE SYSTEM                                             SYSTEM SUMMARY
BOONDOCKS POWER AND LIGHT

---------------------BUSES---------------------  GENERATION AREAS ZONES SYSTEM
TOTAL  PQ<>0.  PQ=0.  PE/E   PE/Q  SWING  OTHER PLANTS MACHS USED  USED   BASE
    5      2      1      1      0      1      0      2     4     2     1  100.0
------------------AC BRANCHES------------------MULTI-SECTION    DC LINES TRANS
TOTAL    RXB     RX    RXT   RX=0.    IN    OUT LINES SECTNS  2-TRM N-TRM ACTN
    5      3      0      2      0      5      0      0      0      0     0    0

TOTAL GENERATION PQLOAD   I LOAD   Y LOAD   SHUNTS  CHARGING  LOSSES    SWING
MW         20.0     20.0      0.0      0.0      0.0      0.0      0.0     12.0
MVAR        3.8      9.5      0.0      0.0      0.0      7.3      1.6      1.5

TOTAL SYSTEM MISMATCH =    0.01 MVA X-----AT BUS-----X     X------SWING-----X
LARGEST BUS  MISMATCH =    0.01 MVA   200 STEAM   33.0       100 HYDRO   33.0
         HIGH VOLTAGE =  1.0500 PU    100 HYDRO   33.0
         LOW  VOLTAGE =  0.9947 PU    151 LOAD    3.30                  THRSHZ
                                                                      0.000100
X-------SOLV AND MSLV-------X   X---NEWTON---X   X------TYSL------X BLOW  PQ
 ACCP  ACCQ  ACCM   TOL  ITER   ACCN  TOL ITER   ACCTY    TOL  ITER  UP  BRAK
1.600 1.600 1.000 0.00010 100   1.00 0.100  20   1.000 0.000010  20  3.0 0.70
ENTER 0 TO EXIT, 1 FOR NEXT PAGE, 2 FOR NEXT DATA CATEGORY:

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      MON FEB 14, 1994  17:17
SMALL EXAMPLE SYSTEM                                                    WORST
BOONDOCKS POWER AND LIGHT                                          MISMATCHES
 BUS#    NAME  BSKV        MW       MVAR        MVA
  200  STEAM   33.0      0.00       0.01       0.01
  201  STEAM   3.30      0.00      -0.01       0.01
ENTER 0 TO EXIT, 1 FOR NEXT PAGE:

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      MON FEB 14, 1994  17:17
SMALL EXAMPLE SYSTEM                                                 BUS DATA
BOONDOCKS POWER AND LIGHT
 BUS#   NAME  BSKV CODE   VOLT  ANGLE   PLOAD   QLOAD      S H U N T  AREA ZONE
  100 HYDRO   33.0   3  1.0500    0.0     0.0     0.0     0.0     0.0    1    1
  150 LOAD    33.0   1  1.0450   -0.6     5.0     1.6     0.0     0.0    2    1
  151 LOAD    3.30   1  0.9947   -3.1    15.0     7.9     0.0     0.0    2    1
  200 STEAM   33.0   1  1.0500   -0.1     0.0     0.0     0.0     0.0    1    1
  201 STEAM   3.30   2  1.0168    3.5     0.0     0.0     0.0     0.0    1    1
ENTER 0 TO EXIT, 1 FOR NEXT PAGE:

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      MON FEB 14, 1994  17:17
SMALL EXAMPLE SYSTEM                                                 SWITCHED
BOONDOCKS POWER AND LIGHT                                          SHUNT DATA
 BUS# MOD  VHI    VLO     SHUNT  X-------X X-------X X-------X X-------X REMOTE

                                  * NONE *
ENTER 0 TO EXIT, 1 FOR NEXT PAGE:

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      MON FEB 14, 1994  17:17
SMALL EXAMPLE SYSTEM                                               GENERATING
BOONDOCKS POWER AND LIGHT                                          PLANT DATA
 BUS#   NAME  BSKV COD MCNS PGEN   QGEN   QMAX   QMIN VSCHED  VACT. REMOT PCT Q
  100 HYDRO   33.0  3   3   12.0    1.5    6.0    0.0 1.0500 1.0500
  201 STEAM   3.30  2   1    8.0    2.4    4.0    0.0 1.0500 1.0500   200 100.0
ENTER 0 TO EXIT, 1 FOR NEXT PAGE:

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      MON FEB 14, 1994  17:17
SMALL EXAMPLE SYSTEM                                                GENERATOR
BOONDOCKS POWER AND LIGHT                                           UNIT DATA
 BUS#   NAME  BSKV COD ID ST PGEN QGEN QMAX QMIN PMAX PMIN MBASE Z S O R C E    X T R A N   GENTAP
  100 HYDRO   33.0  3   1  1    4    0    2    0 9999-9999    5 0.0000 0.2500 0.0000 0.0900 1.0250
  100 HYDRO   33.0  3   2  1    4    0    2    0 9999-9999    5 0.0000 0.2500 0.0000 0.0900 1.0250
  100 HYDRO   33.0  3   3  1    4    0    2    0 9999-9999    5 0.0000 0.2500 0.0000 0.0900 1.0250
  201 STEAM   3.30  2   1  1    8    2    4    0 9999-9999   10 0.0000 0.2000
ENTER 0 TO EXIT, 1 FOR NEXT PAGE:

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      MON FEB 14, 1994  17:17
SMALL EXAMPLE SYSTEM                                              BRANCH DATA
BOONDOCKS POWER AND LIGHT
 FROM      TO CKT NAME     NAME       LINE R  LINE X CHRGING TP ST RATA RATB RATC
  100*    150  1  HYDRO    LOAD       0.0100  0.1000  0.0180     1   15   18   20
  100*    200  1  HYDRO    STEAM      0.0200  0.2000  0.0300     1   15   18   20
  150*    151  1  LOAD     LOAD       0.0000  0.3000  0.0000  F  1   15   20   25
  150*    200  1  LOAD     STEAM      0.0100  0.1000  0.0180     1   15   18   20
  200*    201  1  STEAM    STEAM      0.0000  0.8000  0.0000  F  1   10   12   15
ENTER 0 TO EXIT, 1 FOR NEXT PAGE:

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      MON FEB 14, 1994  17:17
SMALL EXAMPLE SYSTEM                                         TRANSFORMER DATA
BOONDOCKS POWER AND LIGHT
 FROM     TO CKT TP RATIO   ANGLE RG   CONT   RMAX    RMIN    VMAX    VMIN   STEP TABLE    CR        CX
  150    151   1  F 1.0250   0.00 1    151 1.1000  0.9000  1.1000  0.9000 0.00625
  200    201   1  F 1.0500   0.00 1   -200 1.1000  0.9000  1.1000  0.9000 0.00625
```

Figure 14.5. Data for Small Example System as Established in Power Flow Cases SME1 and SME2

14.2.4. Equipment Model Selection

A model must be selected from the library for each piece of equipment to be represented in the simulation. One convenient way of recording the model selection is to fill out a data form for each item of equipment, as shown in Sample Dynamic Data Sheet, for the sample case. Each model data sheet contains spaces for parameter and bus number values describing the equipment and its location, and index values indicating the elements of the CON, VAR, STATE, and ICON arrays assigned to the equipment model. Only the first category of entries is required for a basic system model setup, and only these basic entries are completed in Sample Dynamic Data Sheet.

All data entered in dynamic simulation tables are expressed with respect to the base MVA of the equipment described. The generator data sheets, in particular, require the user to identify MVA. Dynamic Data used for representation of One Hydro unit , which pertains to a hydro plant with three units of 5 MVA each, represents only one unit at bus 100. The constant data values, indicated by a star, are the parameters of one 5-MVA generator expressed with respect to a 5-MVA base. The value of ZSORCE is, similarly, the subtransient impedance of one 5-MVA generator expressed with respect to a 5-MVA base. The fact that there are three identical units connected on the bus is handled by setting the MBASE parameter to 3 × 5 = 15 MVA. The behavior of three identical 5-MVA units is the same, mathematically, as that of one 15-MVA unit where per unit data on a 15-MVA base is the same as the per unit data of the 5-MVA units on 5-MVA base. The value of X''_d entered on GENSAL, GENROU, and GENDCO data sheets must be identical to the imaginary part of ZSORCE, which is entered in the power flow.

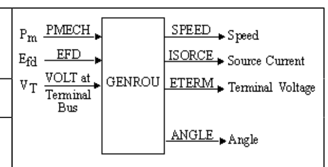
14.2.5. PSS®E Dynamics Data File

The parameters chosen when the models were selected and entered on the data sheets, must be entered in the Dynamics Data File, SMEDD, shown in Figure 14.14, "Basic Dynamics Data File for Setup of Simulation Model". (Refer to Reading Dynamics Model Data of the *PSS® E Program Operation Manual* for details of the raw data file.) Each record contains equipment bus number, model name, and the parameter list in the same order as it appears in the data sheet. The order in which records appear in the Dynamics Data File is not important.

It may be desirable to include entries in the Dynamics Data File for items of equipment that are not in service in the initial condition power flow case (SME2 in this example), so that the file can be held as a complete record of system data for studies of a variety of system conditions. Unneeded records will simply be ignored when the file is used by activity DYRE.

GENROU

Round Rotor Generator Model (Quadratic Saturation)

This model is located at system bus	# 201* [a]	IBUS,	
machine	# 1*	I,	
This model uses CONs starting with	#____	J,	
and STATEs starting with	#____	K.	
The machine MVA is 10* for each of 1* unit = 5* MBASE.			
ZSORCE for this machine is 0 + j 0.2 on the above MBASE			

[a]See power flow data, Figure 14.5, "Data for Small Example System as Established in Power Flow Cases SME1 and SME2".

CONs	#	Value	Description
J		6	T'_{do} (>0) (sec)
J+1		0.05	T''_{do} (>0) (sec)
J+2		1	T'_{qo} (>0) (sec)
J+3		0.05	T''_{qo} (>0) (sec)
J+4		3	Inertia, H
J+5		0	Speed damping, D
J+6		1.4	X_d
J+7		1.35	X_q
J+8		0.3	X'_d
J+9		0.6	X'_q
J+10		0.2	$X''_d = X''_q$
J+11		0.1	X_l
J+12		0.03	S(1.0)
J+13		0.4	S(1.2)

X_d, X_q, X'_d, X'_q, X''_d, X''_q, X_l, H, and D are in pu, machine MVA base.

X''_q must be equal to X''_d.

STATEs	#	Description
K		E'_q
K+1		E'_d
K+2		ψ kd
K+3		ψ kq
K+4		Δ speed (pu)
K+5		Angle (radians)

IBUS, 'GENROU', I, T'_{do}, T'_{do}, T''_{qo}, T''_{qo}, H, D, X_d , X_q, X'_d, X'_q , X''_d, X_l, S(1.0), S(1.2)/

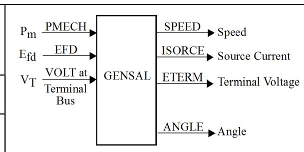
Sample Dynamic Data Sheet

(Sheet 1 of 12)

GENSAL

Salient Pole Generator Model (Quadratic Saturation on d-Axis)

This model is located at system bus	# 100* [a]	IBUS,
machine	# 1*	I.
This model uses CONs starting with	#____	J,
and STATEs starting with	#____	K.
The machine MVA is 5* for each of 1* units = 5* MBASE.		
ZSORCE for this machine is 0* + j 0.25* on the above MBASE.		



[a]See power flow data, Figure 14.5, “Data for Small Example System as Established in Power Flow Cases SME1 and SME2”.

CONs	#	Value	Description
J		5	T'_{do} (>0) (sec)
J+1		0.05	T''_{do} (>0) (sec)
J+2		0.06	T''_{qo} (>0) (sec)
J+3		5.084	Inertia, H
J+4		1	Speed damping, D
J+5		1.5	X_d
J+6		1.2	X_q
J+7		0.4	X'_d
J+8		0.25	$X''_d = X''_q$
J+9		0.12	X_l
J+10		0.03	S(1.0)
J+11		0.25	S(1.2)

X_d, X_q, X'_d, X''_d, X''_q, X_l, H, and D are in pu, machine MVA base.

X''_q must be equal to X''_d.

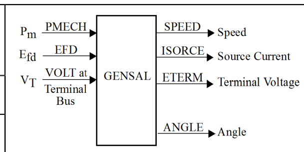
STATEs	#	Description
K		E'_q
K+1		ψ''_q
K+2		ψ kd
K+3		Δ speed (pu)
K+4		Angle (radians)

IBUS, 'GENSAL', I, T'_{do}, T''_{do}, T''_{qo}, H, D, X_d, X_q, X'_d, X''_d, X_l, S(1.0), S(1.2)/

Sample Dynamic Data Sheet (Sheet 2 of 12)

GENSAL

Salient Pole Generator Model (Quadratic Saturation on d-Axis)

This model is located at system bus	# 100* [a]	IBUS,	
machine	# 2*	I.	
This model uses CONs starting with	#____	J,	
and STATEs starting with	#____	K.	
The machine MVA is 5* for each of 1* units = 5* MBASE.			
ZSORCE for this machine is 0* + j 0.25* on the above MBASE.			

[a]See power flow data, Figure 14.5, “Data for Small Example System as Established in Power Flow Cases SME1 and SME2”.

CONs	#	Value	Description
J		5	T'_{do} (>0) (sec)
J+1		0.05	T''_{do} (>0) (sec)
J+2		0.06	T''_{qo} (>0) (sec)
J+3		5.084	Inertia, H
J+4		1	Speed damping, D
J+5		1.5	X_d
J+6		1.2	X_q
J+7		0.4	X'_d
J+8		0.25	$X''_d = X''_q$
J+9		0.12	X_l
J+10		0.03	S(1.0)
J+11		0.25	S(1.2)

X_d, X_q, X'_d, X''_d, X''_q, X_l, H, and D are in pu, machine MVA base.

X''_q must be equal to X''_d.

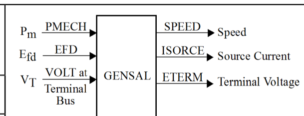
STATEs	#	Description
K		E'_q
K+1		ψ''_q
K+2		ψ kd
K+3		Δ speed (pu)
K+4		Angle (radians)

IBUS, 'GENSAL', I, T'_{do}, T''_{do}, T''_{qo}, H, D, X_d , X_q, X'_d, X''_d, X_l , S(1.0), S(1.2)/

Sample Dynamic Data Sheet (Sheet 3 of 12)

GENSAL

Salient Pole Generator Model (Quadratic Saturation on d-Axis)

This model is located at system bus	# 100* [a]	IBUS,	
machine	# 3*	I.	
This model uses CONs starting with	#_____	J,	
and STATEs starting with	#_____	K.	
The machine MVA is 5* for each of 1* units = 5* MBASE.			
ZSORCE for this machine is 0* + j 0.25* on the above MBASE.			

[a]See power flow data, Figure 14.5, "Data for Small Example System as Established in Power Flow Cases SME1 and SME2".

CONs	#	Value	Description
J		5	T'_{do} (>0) (sec)
J+1		0.05	T''_{do} (>0) (sec)
J+2		0.06	T''_{qo} (>0) (sec)
J+3		5.084	Inertia, H
J+4		1	Speed damping, D
J+5		1.5	X_d
J+6		1.2	X_q
J+7		0.4	X'_d
J+8		0.25	$X''_d = X''_q$
J+9		0.12	X_l
J+10		0.03	S(1.0)
J+11		0.25	S(1.2)

X_d, X_q, X'_d, X''_d, X''_q, X_l, H, and D are in pu, machine MVA base.

X''_q must be equal to X''_d.

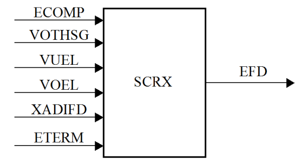
STATEs	#	Description
K		E'_q
K+1		ψ''_q
K+2		ψ kd
K+3		Δ speed (pu)
K+4		Angle (radians)

IBUS, 'GENSAL', I, T'_{do}, T''_{do}, T''_{qo}, H, D, X_d, X_q, X'_d, X''_d, X_l, S(1.0), S(1.2)/

Sample Dynamic Data Sheet (Sheet 4 of 12)

SCRX

Bus Fed or Solid Fed Static Exciter

This model is located at system bus	# 100	IBUS,	
machine	# 1	I,	
This model uses CONs starting with	#____	J,	
and STATEs starting with	#____	K.	

CONs	#	Value	Description
J		0.1	T_A/T_B
J+1		10	T_B (>0) (sec)
J+2		200	K
J+3		0.05	T_E (sec)
J+4		0	E_{MIN} (pu EFD base)
J+5		5	E_{MAX} (pu EFD base)
J+6		0	C_{SWITCH}
J+7		0	r_c/r_{fd}

Set C_{SWITCH} = 0 for bus fed.

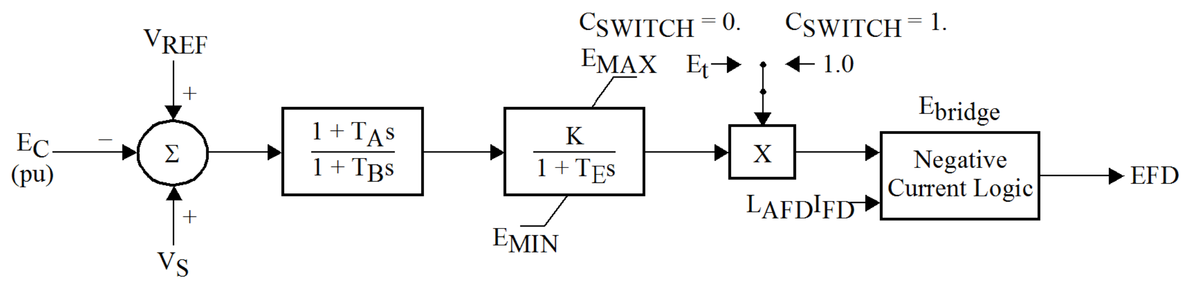
Set C_{SWITCH} = 1. for solid fed.

Set CON(J+7) = 0 for exciter with negative field current capability.

Set CON(J+7) > 0 for exciter without negative field current capability. (Typical CON(J+7) = 10.)

STATEs	#	Description
K		First integrator
K+1		Second integrator

IBUS, 'SCRX', I, T_A /T_B, T_B, K, T_E , E_{MIN}, E_{MAX}, C_{SWITCH} , r_c/r_{fd}/

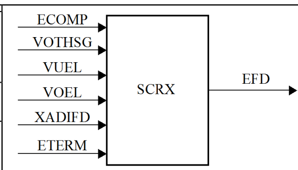


V_S = VOTHSG + VUEL + VOEL

Figure 14.6. Sample Dynamic Data Sheet (Sheet 5 of 12)

SCRX

Bus Fed or Solid Fed Static Exciter

This model is located at system bus	# 100	IBUS,	
machine	# 2	I,	
This model uses CONs starting with	#____	J,	
and STATEs starting with	#____	K.	

CONs	#	Value	Description
J		0.1	T_A/T_B
J+1		10	T_B (>0) (sec)
J+2		200	K
J+3		0.05	T_E (sec)
J+4		0	E_{MIN} (pu EFD base)
J+5		5	E_{MAX} (pu EFD base)
J+6		0	C_{SWITCH}
J+7		0	r_c/r_{fd}

Set C_{SWITCH} = 0 for bus fed.

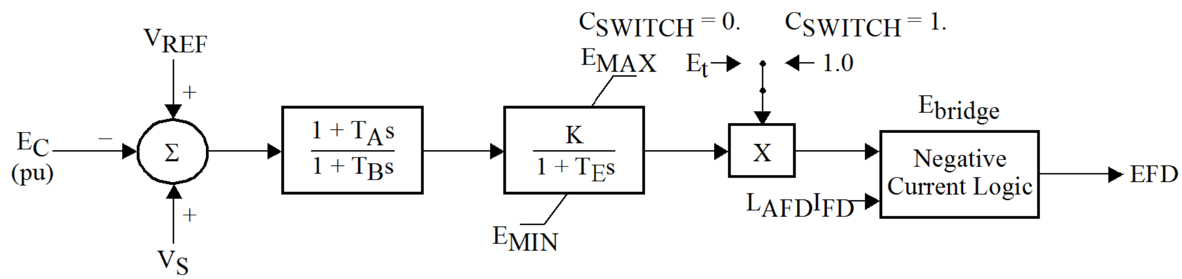
Set C_{SWITCH} = 1. for solid fed.

Set CON(J+7) = 0 for exciter with negative field current capability.

Set CON(J+7) > 0 for exciter without negative field current capability. (Typical CON(J+7) = 10.)

STATEs	#	Description
K		First integrator
K+1		Second integrator

IBUS, 'SCRX', I, T_A /T_B, T_B, K, T_E , E_{MIN}, E_{MAX}, C_{SWITCH} , r_c/r_{fd}/

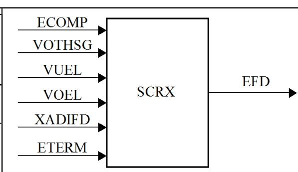


V_S = VOTHSG + VUEL + VOEL

Figure 14.7. Sample Dynamic Data Sheet (Sheet 6 of 12)

SCRX

Bus Fed or Solid Fed Static Exciter

This model is located at system bus	# 100	IBUS,	
machine	# 3	I,	
This model uses CONs starting with	#_____	J,	
and STATEs starting with	#_____	K.	

CONs	#	Value	Description
J		0.1	T_A/T_B
J+1		10	T_B (>0) (sec)
J+2		200	K
J+3		0.05	T_E (sec)
J+4		0	E_{MIN} (pu EFD base)
J+5		5	E_{MAX} (pu EFD base)
J+6		0	C_{SWITCH}
J+7		0	r_c/r_{fd}

Set C_{SWITCH} = 0 for bus fed.

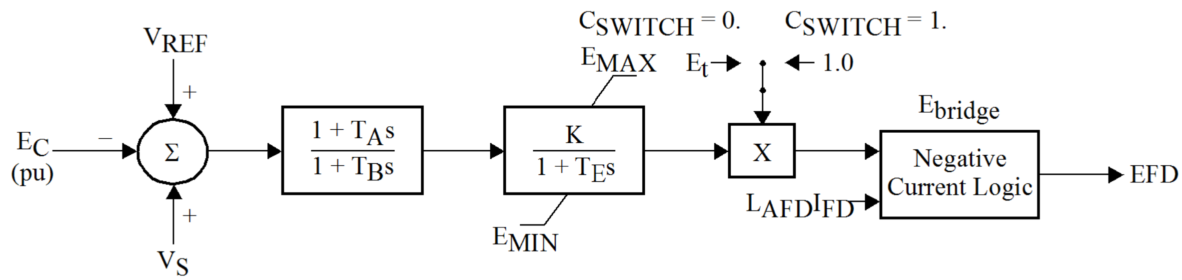
Set C_{SWITCH} = 1. for solid fed.

Set CON(J+7) = 0 for exciter with negative field current capability.

Set CON(J+7) > 0 for exciter without negative field current capability. (Typical CON(J+7) = 10.)

STATEs	#	Description
K		First integrator
K+1		Second integrator

IBUS, 'SCRX', I, T_A/T_B, T_B, K, T_E, E_{MIN}, E_{MAX}, C_{SWITCH}, r_c/r_{fd}/



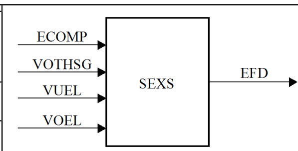
V_S = VOTHSG + VUEL + VOEL

Figure 14.8. Sample Dynamic Data Sheet (Sheet 7 of 12)

SEXS

Simplified Excitation System

This model is located at system bus	# 201	IBUS,	
machine	# 1	I,	
This model uses CONs starting with	#____	J,	
and STATEs starting with	#____	K.	

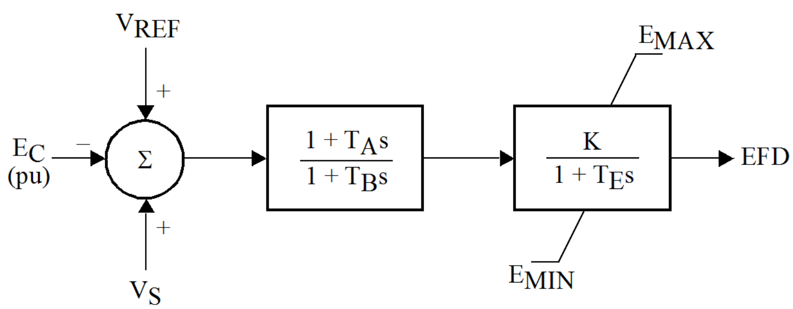


CONs	#	Value	Description
J		0.1	T_A/T_B
J+1		10	T_B (>0) (sec)

CONs	#	Value	Description
J+2		100	K
J+3		0.1	T_E (sec)
J+4		0	E_{MIN} (pu EFD base)
J+5		3	E_{MAX} (pu EFD base)

STATEs	#	Description
K		First integrator
K+1		Second integrator

IBUS, 'SEXS', I, T_A /T_B, T_B, K, T_E , E_{MIN}, E_{MAX}/

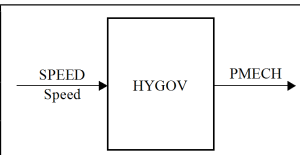


V_S = VOTHSG + VUEL + VOEL

Figure 14.9. Sample Dynamic Data Sheet (Sheet 8 of 12)

HYGOV

Hydro Turbine-Governor

This model is located at system bus	# 100	IBUS,	
machine	# 1	I,	
This model uses CONs starting with	#____	J,	
and STATEs starting with	#____	K,	
and VARs starting with	#____	L.	

CONs	#	Value	Description
J		0.05	R, permanent droop
J+1		0.75	r, temporary droop
J+2		8	T_r (>0) governor time constant

CONs	#	Value	Description
J+3		0.05	T_f (>0) filter time constant
J+4		0.5	T_g (>0) servo time constant
J+5		0.2	+VELM, gate velocity limit
J+6		1	G_{MAX}, maximum gate limit
J+7		0	G_{MIN}, minimum gate limit
J+8		1.3	T_W (>0) water time constant
J+9		1.1	A_t, turbine gain
J+10		0.5	D_{turb}, turbine damping
J+11		0.8	q_{NL}, no power flow

STATEs	#	Description
K		e, filter output
K+1		c, desired gate
K+2		g, gate opening
K+3		q, turbine flow

VARs	#	Description
L		Speed reference
L+1		h, turbine head

IBUS, 'HYGOV', I, R, r, Tr, Tf, Tg, VELM, GMAX, GMIN, TW, At, Dturb, qNL/

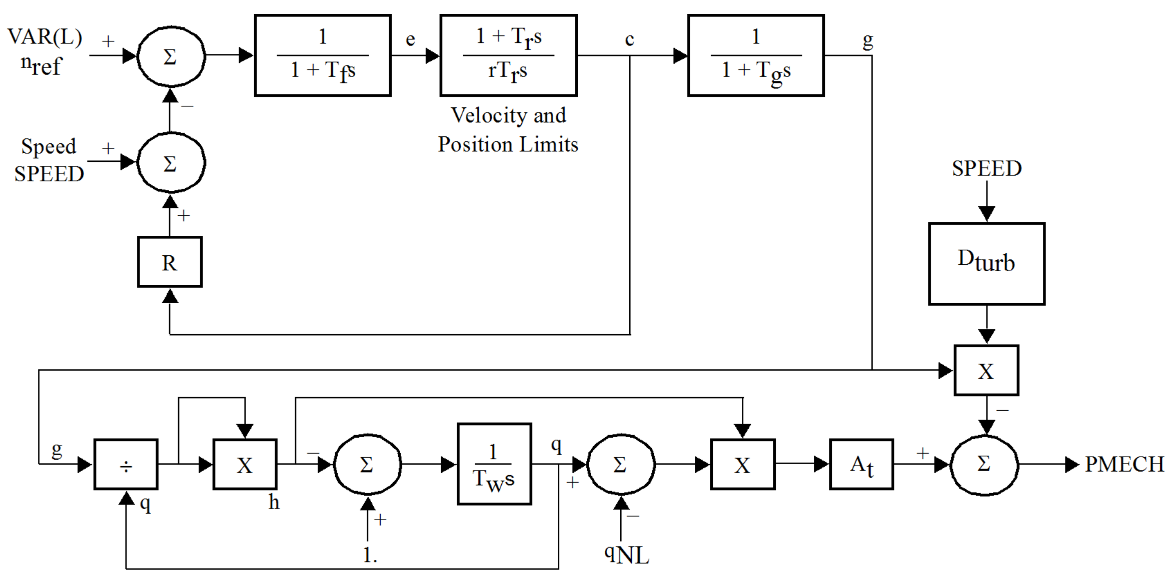
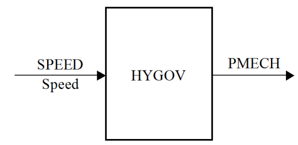


Figure 14.10. Sample Dynamic Data Sheet (Sheet 9 of 12)

HYGOV

Hydro Turbine-Governor

This model is located at system bus	# 100	IBUS,
machine	# 2	I,
This model uses CONs starting with	#_____	J,
and STATEs starting with	#_____	K,
and VARs starting with	#_____	L.



CONs	#	Value	Description
J		0.05	R, permanent droop
J+1		0.75	r, temporary droop
J+2		8	T_r (>0) governor time constant
J+3		0.05	T_f (>0) filter time constant
J+4		0.5	T_g (>0) servo time constant
J+5		0.2	+ VELM, gate velocity limit
J+6		1	G_{MAX}, maximum gate limit
J+7		0	G_{MIN}, minimum gate limit
J+8		1.3	T_W (>0) water time constant
J+9		1.1	A_t, turbine gain
J+10		0.5	D_{turb}, turbine damping
J+11		0.08	q_{NL}, no power flow

STATEs	#	Description
K		e, filter output
K+1		c, desired gate
K+2		g, gate opening
K+3		q, turbine flow

VARs	#	Description
L		Speed reference
L+1		h, turbine head

IBUS, 'HYGOV', I, R, r, Tr, Tf, Tg, VELM, GMAX, GMIN, TW, At, Dturb, qNL/

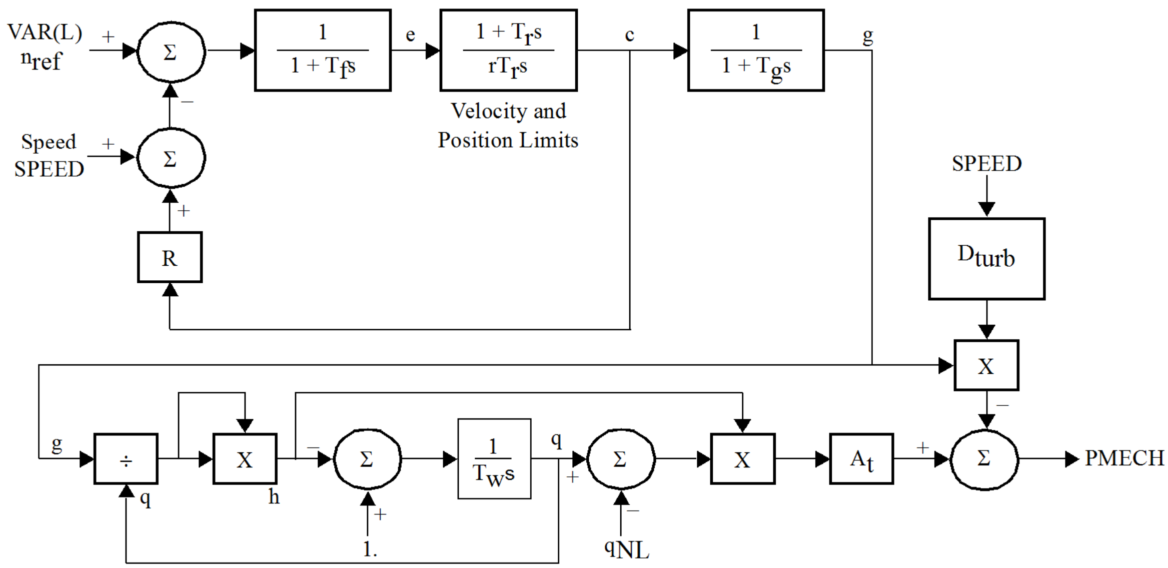
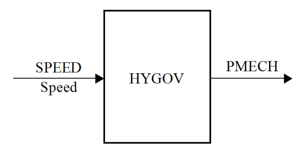


Figure 14.11. Sample Dynamic Data Sheet (Sheet 10 of 12)

HYGOV

Hydro Turbine-Governor

This model is located at system bus	# 100	IBUS,	
machine	# 2	I,	
This model uses CONs starting with	#_____	J,	
and STATEs starting with	#_____	K,	
and VARs starting with	#_____	L.	

CONs	#	Value	Description
J		0.05	R, permanent droop
J+1		0.75	r, temporary droop
J+2		8	T_r (>0) governor time constant
J+3		0.05	T_f (>0) filter time constant
J+4		0.5	T_g (>0) servo time constant
J+5		0.2	+ VELM, gate velocity limit
J+6		1	G_{MAX}, maximum gate limit
J+7		0	G_{MIN}, minimum gate limit
J+8		1.3	T_W (>0) water time constant
J+9		1.1	A_t, turbine gain

CONs	#	Value	Description
J+10		0.5	D_{turb}, turbine damping
J+11		0.08	q_{NL}, no power flow

STATEs	#	Description
K		e, filter output
K+1		c, desired gate
K+2		g, gate opening
K+3		q, turbine flow

VARs	#	Description
L		Speed reference
L+1		h, turbine head

IBUS, 'HYGOV', I, R, r, Tr, Tf, Tg, VELM, GMAX, GMIN, TW, At, Dturb, qNL/

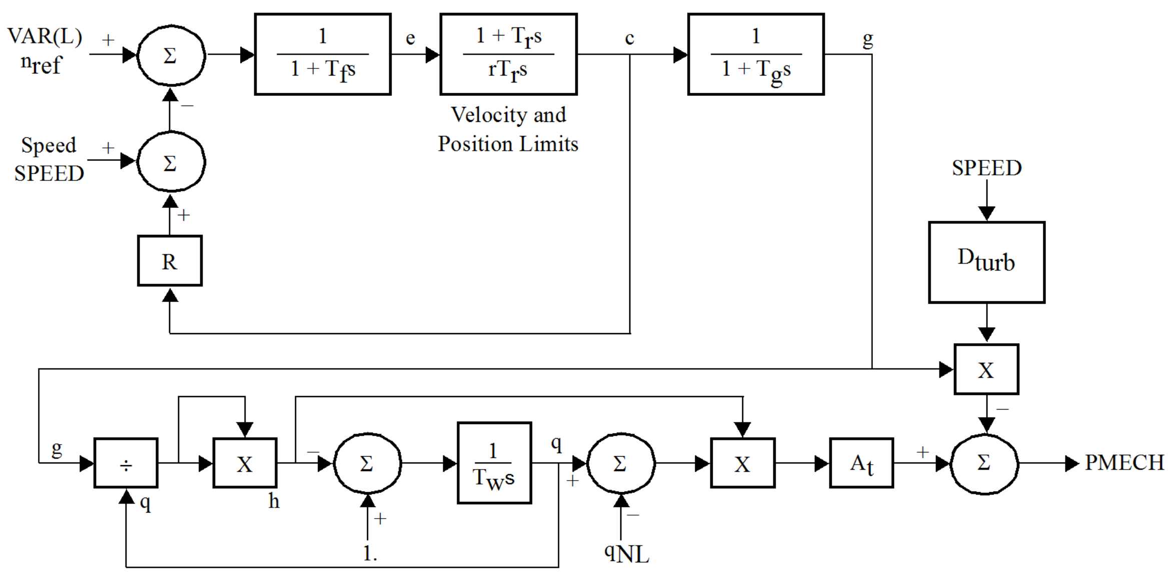
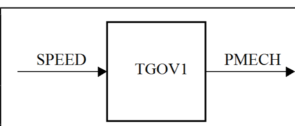


Figure 14.12. Sample Dynamic Data Sheet (Sheet 11 of 12)

TGOV1

Steam Turbine-Governor

This model is located at system bus	# 201	IBUS,	
machine	# 1	I,	
This model uses CONs starting with	#_____	J,	

and STATEs starting with	#____	K,	
and VAR	#____	L.	

CONs	#	Value	Description
J		0.05	R
J+1		0.5	T_1 (>0) (sec)
J+2		1.0	V_{MAX}
J+3		0.3	V_{MIN}
J+4		1.0	T_2 (sec)
J+5		1.0	T_3 (>0) (sec)
J+6		0.	D_t

Note: V_{MAX}, V_{MIN}, D_t are in per unit on generator base.

T_2/T_3 = high-pressure fraction.

T_3 = reheater time constant.

STATEs	#	Description
K		Valve opening
K+1		Turbine power

VAR	#	Description
L		Reference

IBUS, 'TGOV1', I, R, T_1 , V_{MAX}, V_{MIN}, T_2 , T_3, D_t/

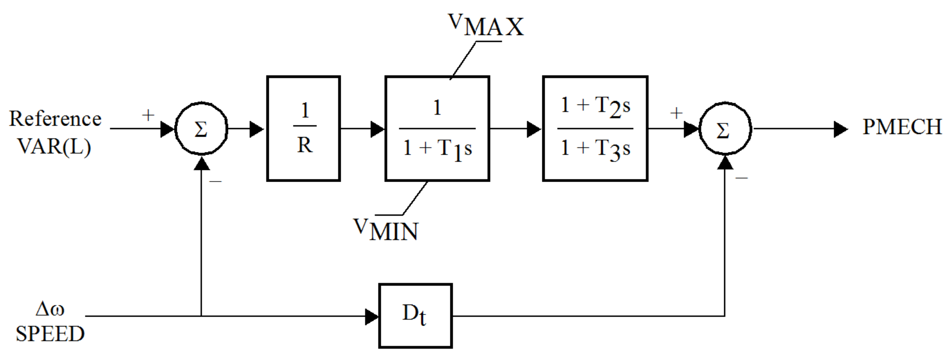
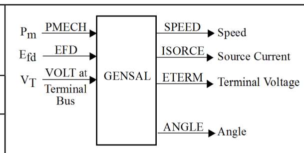


Figure 14.13. Sample Dynamic Data Sheet (Sheet 12 of 12)

GENSAL

Salient Pole Generator Model (Quadratic Saturation on d-Axis)

This model is located at system bus	# 100* [a]	IBUS,
machine	# 1*	I,
This model uses CONs starting with	#____	J,
and STATEs starting with	#____	K,
The machine MVA is 5* for each of 3* units = 15* MBASE.		
ZSORCE for this machine is 0* + j 0.25* on the above MBASE.		



[a]Power flow quantities.

CONs	#	Value	Description
J		5	T'_{do} (>0) (sec)
J+1		0.05	T''_{do} (>0) (sec)
J+2		0.06	T''_{qo} (>0) (sec)
J+3		3.05	Inertia, H
J+4		0	Speed damping, D
J+5		1.5	X_d
J+6		1.2	X_q
J+7		0.4	X'_d
J+8		0.25	$X''_d = X''_q$
J+9		0.12	X_l
J+10		0.03	S(1.0)
J+11		0.25	S(1.2)

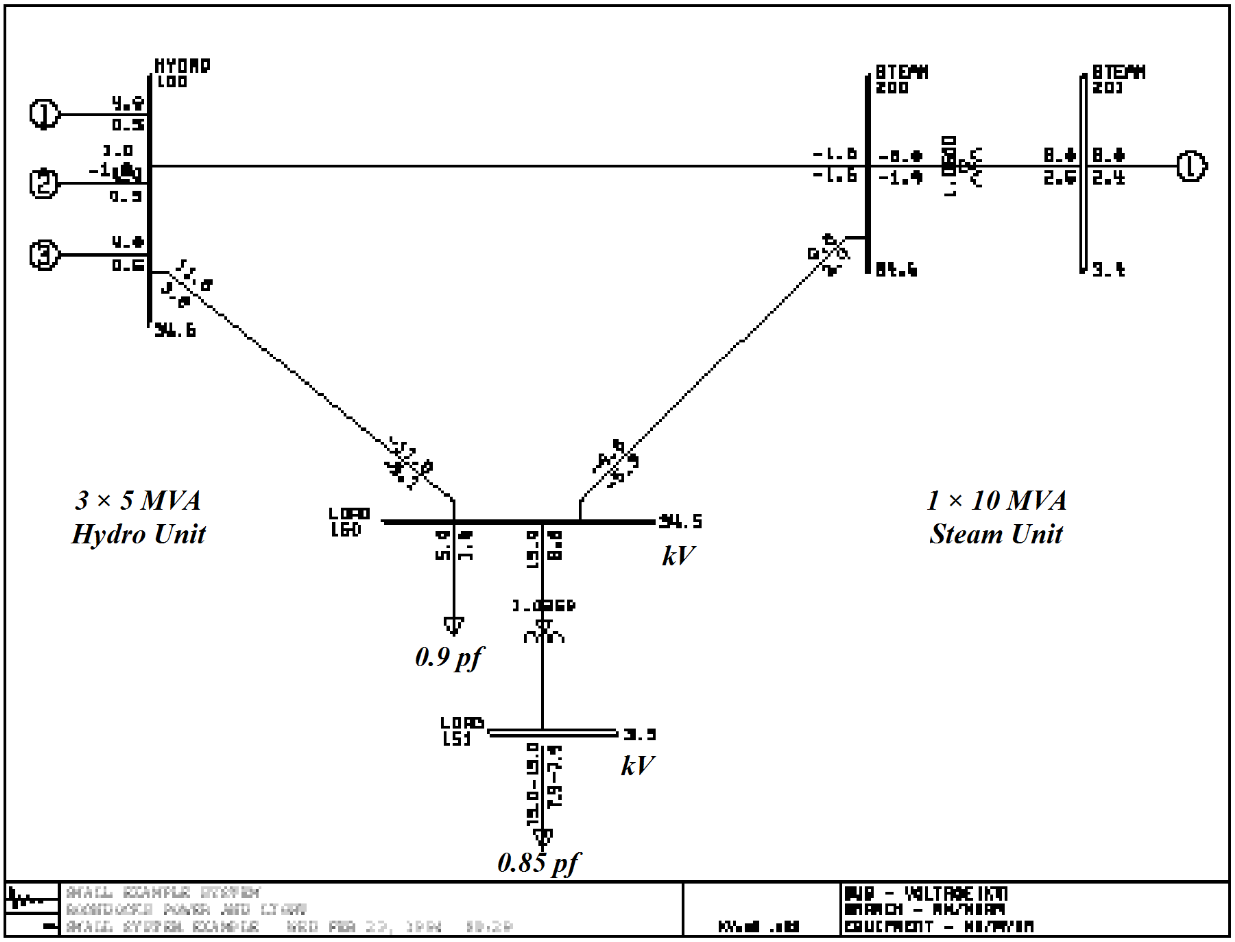
X_d, X_q, X'_d, X''_d, X''_q, X_l, H, and D are in pu, machine MVA base.

X''_q must be equal to X''_d.

STATEs	#	Description
K		E'_q
K+1		ψ''_q
K+2		ψ_{kd}
K+3		Δ speed (pu)
K+4		Angle (radians)

IBUS, 'GENSAL', I, T'_{do}, T''_{do}, T''_{qo}, H, D, X_d, X_q, X'_d, X''_d, X_l, S(1.0), S(1.2)/

Dynamic Data Used for Representation of One Hydro Unit




```
FILE SMEDD

100 'GENSAL' 1 5 .05 .06 5.084 1 1.5 1.2 .4 .25 .12 .03 .25/
100 'GENSAL' 2 5 .05 .06 5.084 1 1.5 1.2 .4 .25 .12 .03 .25/
100 'GENSAL' 3 5 .05 .06 5.084 1 1.5 1.2 .4 .25 .12 .03 .25/
201 'GENROU' 1 6 .05 1 .05 3 0 1.4 1.35 .3 .6 .2 .1 .03 .4/
100 'SCRX' 1 .1 10 200 .05 0 5 0 0/
100 'SCRX' 2 .1 10 200 .05 0 5 0 0/
100 'SCRX' 3 .1 10 200 .05 0 5 0 0/
201 'SEXS' 1 .1 .1 100 .1 0 3/
100 'HYGOV' 1 .05 .75 8 .05 .5 .2 1 0 1.3 1.1 0 .08/
100 'HYGOV' 2 .05 .75 8 .05 .5 .2 1 0 1.3 1.1 0 .08/
100 'HYGOV' 3 .05 .75 8 .05 .5 .2 1 0 1.3 1.1 0 .08/
201 'TGOV1' 1 .05 .5 1. .3 1. 1. 0./
```

Figure 14.14. Basic Dynamics Data File for Setup of Simulation Model

of Small Example System

14.2.6. Dynamics Data Entry and CONEC, CONET Construction

Until valid subroutines CONEC and CONET have been loaded, the dynamic simulation section of PSS®E is only a skeleton, used to bootstrap itself into the fully setup form. The first step in the bootstrap process is the entry of dynamics data and construction of subroutines CONEC and CONET.

Sheet 1,Figure 14.15, “Dialog of Basic PSS®E Dynamic Simulation Model Setup (Sheet 1 of 4)” shows the dialog of this process. First, the PSS ®E link activity LOFL is used to gain access to power flow activities. The converted saved case file, SME2, is retrieved with activity CASE, and activity FACT is used to establish the required factors of the network admittance matrix. Recovery and preparation of the network data is completed by activity RTRN, which regains access to dynamic simulation activities.

The reading of CON data values, assignment of storage in the dynamics data arrays (see Table 13.1, “Dynamic Simulation Arrays ” and Section 13.4.3, “Data Space Allocation”), and construction of subroutines CONEC and CONET, is handled by activity DYRE on Sheet 1,Figure 14.15, “Dialog of Basic PSS®E Dynamic Simulation Model Setup (Sheet 1 of 4)”. DYRE is instructed to place the CONEC subroutine in file CC1 and the CONET subroutine in file CT1, respectively, as it builds them.

The summary output produced by DYRE shows the number of CON, STATE, VAR, and ICON array elements used by the models included in subroutines CONEC and CONET. Figure 14.19, “Basic CONEC and CONET Subroutines as Built by Activity DYRE” shows files CC1 and CT1, the CONEC and CONET subroutines constructed by DYRE. In the file with CONEC is a routine USRXXX. Any user-written models would be called here. The user should not modify this routine.

The last line printed by DYRE, at the bottom of Sheet 2 of Figure 14.16, “Dialog of Basic PSS®E Dynamic Simulation Model Setup (Sheet 2 of 4)”, shows that the simulation setup produced by DYRE uses CONS 1 through 123, STATES 1 through 43, VARs 1 through 7, and no ICONs. These numbers are stored in the Snapshot for future reference because later steps of the simulation setup will require the assignment of additional space in the CON, STATE, VAR, and ICON arrays.

Before exiting activity DYRE, the user is asked for a compiling command file for subroutine CONEC and CONET, so the proper compile options are used.

While DYRE was executing, it ran certain data checks regarding the number of input values and whether the expected value was real or a character. The user should run DYCH next to look for any model calling inconsistencies. This activity looks for items such as an exciter on an SVS or a stabilizer on a machine with no exciter. This function was not run in this example as there are no inconsistencies in the data. DYCH can also be used later to remove or disconnect equipment for certain simulations.

14.2.7. Output Channel Selection and CONET Construction

Output channel selection is handled by activity CHAN and should be done immediately after activity DYRE. Sheet 2,Figure 14.16, “Dialog of Basic PSS®E Dynamic Simulation Model Setup (Sheet 2 of 4)” shows the dialog of activity CHAN. Activity CHAN first asks the user to specify the first channel, VAR and ICON to be assigned in setting up output channels. These channels will normally be the next available elements when assigning channels in an initial simulation setup. Because the program keeps track of these values, the user will usually just hit the carriage return key.

The CHAN dialog assigns 19 variables from the simulation to the first 19 output channels. The final summary output of activity CHAN, as spotted on Sheet 4 of Figure 14.18, “Dialog of Basic PSS®E Dynamic Simulation Model Setup (Sheet 4 of 4)”, shows the next available entry in the channel arrays of Table 14.3, “Sequence of Activities to Recover Prefault System Data and Status” and in VAR and ICON to be 25, 17, and 13, respectively.

```
$ pssds4
```

Start PSS®E skeleton to initiate setup process

```
Starting skeleton PSSDS...

                POWER TECHNOLOGIES INCORPORATED

         12000 BUS POWER SYSTEM SIMULATOR--PSS®E-22.0

 INITIATED AT DYNAMICS ENTRY POINT ON TUE FEB 15, 1994  10:08

 ACTIVITY? LOFL

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? CASE SME2

 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 CASE SME2.SAV WAS SAVED ON MON FEB 14, 1994  17:05

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? FACT

     5 DIAGONAL AND      5 OFF-DIAGONAL ELEMENTS

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? RTRN
```

Pick up initial condition power flow

```
 ACTIVITY? DYRE
```

DYRE to read data and build subroutines

```
 ENTER DYNAMICS DATA SOURCE FILENAME: SMEDD
```

Dynamics Data File

```
 ENTER FILENAME FOR SUBROUTINE CONEC: CC1
```

Place CONEC source in file CC1

```
 ENTER FILENAME FOR SUBROUTINE CONET: CT1
```

Place CONET source in file CT1

```
 ENTER FILENAME FOR PSSPLT RELAY CHARACTERISTIC DATA: CR1
```

File for relay characteristic data: CR1

```
 NEXT AVAILABLE ADDRESSES ARE:
    CON   STATE     VAR    ICON
     1       1       1       1
 ENTER STARTING CON, STATE, VAR, ICON OR CARRIAGE RETURN

 OUT OF FILE DATA--SWITCH TO TERMINAL INPUT MODE

 GENERATOR MODELS USE:
  CONS         1-    50
  STATES       1-    21

 EXCITER MODELS USE:
  CONS        51-    80
  STATES      22-    29

 GOVERNOR MODELS USE:
  CONS        81-   123
  STATES      30-    43
  VARS         1-     7


 SUMMARY OF MODELS READ:

 GENS:   GENROU GENSAL
              1      3

 EXSYS:  SCRX   SEXS
              3      1

 GOVS:   TGOV1  HYGOV
              1      3

 NEXT AVAILABLE ADDRESSES ARE:
    CON   STATE     VAR    ICON
    124     44       8       1
```

Storage locations assigned by DYRE

Figure 14.15. Dialog of Basic PSS®E Dynamic Simulation Model Setup (Sheet 1 of 4)

```
NO MODEL CALLS IN CONEC/CONET/USRXXX--DYNAMICS SKELETON MAY BE USED

ENTER FILENAME FOR COMPILING FILE (0 TO EXIT): COMPILE

ACTIVITY? CHAN

NEXT AVAILABLE ADDRESSES ARE:
  CHANNEL    VAR    ICON
       1       8       1
ENTER STARTING CHANNEL, VAR, ICON INDICES OR CARRIAGE RETURN


ENTER OUTPUT CATEGORY:
 0 = EXIT             1 = ANGLE            2 = PELEC
 3 = QELEC            4 = ETERM            5 = EFD
 6 = PMECH            7 = SPEED            8 = XADIFD
 9 = ECOMP           10 = VOTHSG          11 = VREF
12 = BSFREQ          13 = VOLTAGE         14 = VOLT & ANG
15 = FLOW (P)        16 = FLOW (P&Q)      17 = FLOW (MVA)
18 = RELAY2 (R&X)    19 = VAR             20 = STATE
21 = MACH ITERM      22 = MACH APP IMP: 1
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 100,1
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 100,2
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 201
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 0

ENTER OUTPUT CATEGORY:
 0 = EXIT             1 = ANGLE            2 = PELEC
 3 = QELEC            4 = ETERM            5 = EFD
 6 = PMECH            7 = SPEED            8 = XADIFD
 9 = ECOMP           10 = VOTHSG          11 = VREF
12 = BSFREQ          13 = VOLTAGE         14 = VOLT & ANG
15 = FLOW (P)        16 = FLOW (P&Q)      17 = FLOW (MVA)
18 = RELAY2 (R&X)    19 = VAR             20 = STATE
21 = MACH ITERM      22 = MACH APP IMP: 2
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 100,1
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 100,2
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 201
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 0

ENTER OUTPUT CATEGORY:
 0 = EXIT             1 = ANGLE            2 = PELEC
 3 = QELEC            4 = ETERM            5 = EFD
 6 = PMECH            7 = SPEED            8 = XADIFD
 9 = ECOMP           10 = VOTHSG          11 = VREF
12 = BSFREQ          13 = VOLTAGE         14 = VOLT & ANG
15 = FLOW (P)        16 = FLOW (P&Q)      17 = FLOW (MVA)
18 = RELAY2 (R&X)    19 = VAR             20 = STATE
21 = MACH ITERM      22 = MACH APP IMP: 4
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 100,1
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 100,2
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 201
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 0


ENTER OUTPUT CATEGORY:
 0 = EXIT             1 = ANGLE            2 = PELEC
 3 = QELEC            4 = ETERM            5 = EFD
 6 = PMECH            7 = SPEED            8 = XADIFD
 9 = ECOMP           10 = VOTHSG          11 = VREF
12 = BSFREQ          13 = VOLTAGE         14 = VOLT & ANG
15 = FLOW (P)        16 = FLOW (P&Q)      17 = FLOW (MVA)
18 = RELAY2 (R&X)    19 = VAR             20 = STATE
21 = MACH ITERM      22 = MACH APP IMP: 5
```

Creates command file for proper options

Use CHAN to set up outputs and to add to subroutine CONET

Program keeps locations used

First three channels will show rotor angle

Channels 4, 5, 6 will show machine electrical power

Channels 7, 8, 9 will show machine terminal voltage

Figure 14.16. Dialog of Basic PSS®E Dynamic Simulation Model Setup (Sheet 2 of 4)

```
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 100,1
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 100,2
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 201
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 0
```

Channels 10, 11, 12 will show machine field voltage

```
ENTER OUTPUT CATEGORY:
 0 = EXIT            1 = ANGLE          2 = PELEC
 3 = QELEC           4 = ETERM          5 = EFD
 6 = PMECH           7 = SPEED          8 = XADIFD
 9 = ECOMP          10 = VOTHSG        11 = VREF
12 = BSFREQ         13 = VOLTAGE       14 = VOLT & ANG
15 = FLOW (P)       16 = FLOW (P&Q)    17 = FLOW (MVA)
18 = RELAY2 (R&X)   19 = VAR           20 = STATE
21 = MACH ITERM     22 = MACH APP IMP: 6
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 100,1
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 100,2
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 201
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 0
```

Channels 13, 14, 15 will show turbine mechanical power

```
ENTER OUTPUT CATEGORY:
 0 = EXIT            1 = ANGLE          2 = PELEC
 3 = QELEC           4 = ETERM          5 = EFD
 6 = PMECH           7 = SPEED          8 = XADIFD
 9 = ECOMP          10 = VOTHSG        11 = VREF
12 = BSFREQ         13 = VOLTAGE       14 = VOLT & ANG
15 = FLOW (P)       16 = FLOW (P&Q)    17 = FLOW (MVA)
18 = RELAY2 (R&X)   19 = VAR           20 = STATE
21 = MACH ITERM     22 = MACH APP IMP: 13
ENTER BUS NUMBER, 'IDENTIFIER': 150
ENTER BUS NUMBER, 'IDENTIFIER': 151
ENTER BUS NUMBER, 'IDENTIFIER': 200
ENTER BUS NUMBER, 'IDENTIFIER': 0
```

Channels 16, 17, 18 will contain bus voltages

```
ENTER OUTPUT CATEGORY:
 0 = EXIT            1 = ANGLE          2 = PELEC
 3 = QELEC           4 = ETERM          5 = EFD
 6 = PMECH           7 = SPEED          8 = XADIFD
 9 = ECOMP          10 = VOTHSG        11 = VREF
12 = BSFREQ         13 = VOLTAGE       14 = VOLT & ANG
15 = FLOW (P)       16 = FLOW (P&Q)    17 = FLOW (MVA)
18 = RELAY2 (R&X)   19 = VAR           20 = STATE
21 = MACH ITERM     22 = MACH APP IMP: 16
ENTER FROM BUS, TO BUS, CIRCUIT ID, 'IDENTIFIER': 100 200 1
ENTER SECOND 'IDENTIFIER':
ENTER FROM BUS, TO BUS, CIRCUIT ID, 'IDENTIFIER': 100 150 1
ENTER SECOND 'IDENTIFIER':
ENTER FROM BUS, TO BUS, CIRCUIT ID, 'IDENTIFIER': 200 150 1
ENTER SECOND 'IDENTIFIER':
ENTER FROM BUS, TO BUS, CIRCUIT ID, 'IDENTIFIER': 0
```

Channels 19 through 24 contain line P, Q flows

```
ENTER OUTPUT CATEGORY:
 0 = EXIT            1 = ANGLE          2 = PELEC
 3 = QELEC           4 = ETERM          5 = EFD
 6 = PMECH           7 = SPEED          8 = XADIFD
 9 = ECOMP          10 = VOTHSG        11 = VREF
12 = BSFREQ         13 = VOLTAGE       14 = VOLT & ANG
15 = FLOW (P)       16 = FLOW (P&Q)    17 = FLOW (MVA)
18 = RELAY2 (R&X)   19 = VAR           20 = STATE
21 = MACH ITERM     22 = MACH APP IMP: 0

NEXT AVAILABLE ADDRESSES ARE:
  CHANNEL    VAR    ICON
      25      17      13
```

Figure 14.17. Dialog of Basic PSS®E Dynamic Simulation Model Setup (Sheet 3 of 4)

```
 ACTIVITY? SNAP SSN1 <------------- Record setup progress to date

NUMBER OF ELEMENTS IN USE ARE:
  CONS STATES   VARS  ICONS CHANNELS
   123     43     16     12      24
ENTER NUMBER TO BE SAVED OR CARRIAGE RETURN FOR ABOVE VALUES

SNAPSHOT STORED IN FILE SSN1.SNP AT TIME =  0.000

ACTIVITY? STOP <------------------- End of initial setup process with PSS®E skeleton
```

Figure 14.18. Dialog of Basic PSS®E Dynamic Simulation Model Setup (Sheet 4 of 4)

```
      SUBROUTINE CONEC
C
$INSERT COMON4.INS
C
C
      RETURN
      END
      SUBROUTINE USRXXX(MC,SLOT,IT)                  File CC1
      INTEGER MC,SLOT,IT
      SELECT (IT)
      FIN
      RETURN
      END
```

```
      SUBROUTINE CONET
C
$INSERT COMON4.INS
C
C
      IF (.NOT. IFLAG) GO TO 9000
C
C   NETWORK MONITORING MODELS                        File CT1
C
C
 9000 CONTINUE
C
      RETURN
      END
```

Figure 14.19. Basic CONEC and CONET Subroutines as Built by Activity DYRE

14.2.8. Initial Condition Snapshot

Completion of activities DYRE and CHAN leaves completed dynamic simulation data arrays in the PSS®E working files. These arrays must be preserved for use in the next stages of the simulation work by making a Snapshot *before* PSS®E is stopped. Activity SNAP is instructed to save the elements of arrays CON, STATE, VAR, and ICON being used. By hitting the carriage return, the user saves only the arrays being used and does not waste disk memory space.

14.2.9. End of Skeleton PSS®E Execution

Storage of the Snapshot completes the first part of the setup process. It is now necessary to stop PSS®E, add any user code, compile CONEC and CONET, and load these into the PSS®E skeleton to produce a completed PSS®E setup.

14.2.10. Refinement of CONEC and CONET

Subroutines CONEC and CONET, as built by activity DYRE, provide the basic level of system modeling. The statements built into CONEC and CONET by this activity usually represent the major bulk of the required code. In many applications, however, it is advantageous to insert special Fortran logic into CONEC and/or CONET. The user may insert any meaningful Fortran statements into these subroutines before compiling them and linking them into PSS®E. It is suggested that the CONEC and CONET subroutines be left in files with names related to their application (e.g., CC1 and CT1 in this case).

Advanced uses of this capability are demonstrated in Advanced Uses of CONEC and CONET of the *PSS ® E Program Operation Manual*.

14.2.11. Compilation and Linking of CONEC/CONET

The CONEC and CONET subroutines must be compiled and linked into the PSS®E skeleton.

Successful execution of these steps leaves a completed copy of the PSS®E dynamic simulation code in the user's User File Directory. This copy of PSS®E will carry out dynamic simulations of the power system described by the CONEC and CONET subroutines with which it was loaded.

A user may keep any number of pairs of CONEC and CONET subroutines in differently named files in a User File Directory. The loaded copy of PSS®E in the User File Directory includes only the intelligence from the CONEC and CONET subroutines last loaded with the CLOAD4 command, however. Because the CLOAD4 procedure always links the subroutines for which compiled codes are held in files, CONEC and CONET, filenames must be reassigned as necessary. One convenient arrangement is to keep all CONEC and CONET subroutines in source file form only, and to compile each with the commands specified above each time it is needed.

14.2.12. Start PSS®E

After PSS®E has been loaded with the appropriate CONEC and CONET subroutines, it is ready for use in the checkout and execution of dynamic simulations. The dialog needed to start PSS®E and initialize a dynamic simulation is shown in the first page of Figure 14.20, "Checkout of Dynamics Simulation Setup (Sheet 1 of 5)".

```
$ pssds4
Starting your PSSDS...
```

Restore Snapshot made during CONEC construction

```
                POWER TECHNOLOGIES INCORPORATED

         12000 BUS POWER SYSTEM SIMULATOR--PSS/E-22.0

 INITIATED AT DYNAMICS ENTRY POINT ON TUE FEB 15, 1994  15:47

 ACTIVITY? RSTR SSN1

 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 SNAPSHOT SSN1.SNP WAS SAVED ON TUE FEB 15, 1994  13:27

 NUMBER OF ELEMENTS RESTORED:
   CONS STATES   VARS  ICONS CHANNELS
    123     43     16     12      24
```

```
 ACTIVITY? LOFL

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? CASE SME2

 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 CASE SME2.SAV WAS SAVED ON MON FEB 14, 1994  17:05

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? FACT

     5 DIAGONAL AND      5 OFF-DIAGONAL ELEMENTS

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? RTRN
```

Get initial condition power flow case

```
 ACTIVITY? STRT
```

Activity STRT to initialize dynamics model

```
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS/E      TUE FEB 15, 1994  16:25
 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 INITIAL CONDITION LOAD FLOW USED  1 ITERATIONS
```

One (1) iteration indicates good match of setup to initial condition power flow

```
 -------------------------MACHINE INITIAL CONDITIONS--------------------------
 X------ BUS -----X ID  ETERM   EFD    POWER    VARS   P.F.  ANGLE   ID     IQ
   100 HYDRO   33.0  1 1.0353 1.7821   4.01    0.48 0.9928  41.36 0.5880 0.5247
   100 HYDRO   33.0  2 1.0353 1.7821   4.01    0.48 0.9928  41.36 0.5880 0.5247
   100 HYDRO   33.0  3 1.0353 1.7821   4.01    0.48 0.9928  41.36 0.5880 0.5247
   201 STEAM   3.30  1 1.0168 1.8556   8.00    2.38 0.9585  40.00 0.6560 0.4934
```

Summary of initial conditions in generators

```
 INITIAL CONDITIONS CHECK O.K.
```

Key message

```
 ENTER CHANNEL OUTPUT FILENAME: GOP1
```

Output if used will go in file GOP1

```
 ENTER SNAPSHOT FILENAME: SSN1

 NUMBER OF ELEMENTS IN USE ARE:
   CONS STATES   VARS  ICONS CHANNELS
    123     43     16     12      24
 ENTER NUMBER TO BE SAVED OR CARRIAGE RETURN FOR ABOVE VALUES
```

Bring snapshot up to date

```
 SNAPSHOT STORED IN FILE SSN1.SNP AT TIME = -0.017
```

*STRT always initializes at t = 0 conditions, with T = –2 * DELT*

a. Initialization of Dynamics Data

Figure 14.20. Checkout of Dynamics Simulation Setup (Sheet 1 of 5)

```
ACTIVITY? DOCU ALL

ENTER OUTPUT DEVICE CODE:
 0 FOR NO OUTPUT         1 FOR CRT TERMINAL
 2 FOR A FILE            3 FOR QMS PS2000
 4 FOR QMS PS800         5 FOR HARD COPY TERMINAL
 6 FOR ALTERNATE SPOOL DEVICE: 1
ENTER 0 FOR REPORTING MODE, 1 FOR DATA CHECKING MODE: 0

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS/E      TUE FEB 15, 1994  16:39
SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT

REPORT FOR ALL MODELS AT ALL BUSES        BUS   100 [HYDRO   33.0] PLANT MODELS

        ** GENSAL **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S
                      100 HYDRO   33.0   1     1-   12      1-    5

           MBASE      Z S O R C E          X T R A N        GENTAP
             5.0   0.00000+J 0.25000  0.00000+J 0.09000  1.02500

  T'DO    T''DO   T''QO     H     DAMP    XD      XQ      X'D    X''D     XL
 5.000    0.050   0.060   5.08    1.00  1.5000  1.2000  0.4000  0.2500  0.1200

                              S(1.0)  S(1.2)
                              0.0300  0.2500

     ** SCRX **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S     BUS
                 100 HYDRO   33.0   1     51-   58     22-   23    FED

     TA/TB     TB        K       TE      EMIN    EMAX  SWITCH  RC/RFD
     0.100  10.000    200.0    0.050     0.00    5.00    0.0    0.00

   ** HYGOV **  BUS   NAME  BSKV MACH  C O N ' S     STATE'S    V A R ' S
                100 HYDRO   33.0   1    81-   92     30-   33      1-   2

 R-PERM R-TEMP   TR    TF    TG    VELM  GMAX  GMIN   TW   AT DTURB  QNL
  0.050  0.750 8.00 0.050 0.500  0.200  1.00  0.00  1.30 1.10 0.00 0.080

        ** GENSAL **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S
                      100 HYDRO   33.0   2    13-   24      6-   10

           MBASE      Z S O R C E          X T R A N        GENTAP
             5.0   0.00000+J 0.25000  0.00000+J 0.09000  1.02500

  T'DO    T''DO   T''QO     H     DAMP    XD      XQ      X'D    X''D     XL
 5.000    0.050   0.060   5.08    1.00  1.5000  1.2000  0.4000  0.2500  0.1200

                              S(1.0)  S(1.2)
                              0.0300  0.2500

     ** SCRX **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S     BUS
                 100 HYDRO   33.0   2     59-   66     24-   25    FED

     TA/TB     TB        K       TE      EMIN    EMAX  SWITCH  RC/RFD
     0.100  10.000    200.0    0.050     0.00    5.00    0.0    0.00

   ** HYGOV **  BUS   NAME  BSKV MACH  C O N ' S     STATE'S    V A R ' S
                100 HYDRO   33.0   2    93-  104     34-   37      3-   4

 R-PERM R-TEMP   TR    TF    TG    VELM  GMAX  GMIN   TW   AT DTURB  QNL
  0.050  0.750 8.00 0.050 0.500  0.200  1.00  0.00  1.30 1.10 0.00 0.080

        ** GENSAL **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S
                      100 HYDRO   33.0   3    25-   36     11-   15

           MBASE      Z S O R C E          X T R A N        GENTAP
             5.0   0.00000+J 0.25000  0.00000+J 0.09000  1.02500

  T'DO    T''DO   T''QO     H     DAMP    XD      XQ      X'D    X''D     XL
 5.000    0.050   0.060   5.08    1.00  1.5000  1.2000  0.4000  0.2500  0.1200

                              S(1.0)  S(1.2)
                              0.0300  0.2500

     ** SCRX **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S     BUS
     [illegible]
```

Figure 14.21. Checkout of Dynamics Simulation Setup (Sheet 2 of 5)

b. Review of Dynamic Model Data via Activity DOCU

```
      TA/TB     TB       K       TE      EMIN    EMAX  SWITCH  RC/RFD
      0.100  10.000   200.0   0.050     0.00    5.00    0.0     0.00


  ** HYGOV **  BUS   NAME  BSKV MACH  C O N ' S     STATE'S   V A R ' S
               100 HYDRO   33.0   3   105-  116    38-   41     5-    6

 R-PERM R-TEMP   TR    TF    TG    VELM  GMAX  GMIN   TW    AT DTURB   QNL
  0.050  0.750  8.00 0.050 0.500  0.200  1.00  0.00  1.30  1.10 0.00 0.080
ENTER 0 TO END LIST, 1 FOR NEXT PAGE:

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      TUE FEB 15, 1994  16:39
SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT

REPORT FOR ALL MODELS AT ALL BUSES        BUS   201 [STEAM   3.30] PLANT MODELS


      ** GENROU **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S
                     201 STEAM   3.30   1     37-   50     16-   21

           MBASE     Z S O R C E          X T R A N        GENTAP
            10.0  0.00000+J 0.20000  0.00000+J 0.00000  1.00000

 T'D0 T''D0  T'Q0 T''Q0     H   DAMP   XD     XQ     X'D    X'Q   X''D    XL
 6.00 0.050  1.00 0.050   3.00  0.00 1.4000 1.3500 0.3000 0.6000 0.2000 0.1000

                               S(1.0)  S(1.2)
                               0.0300  0.4000


        ** SEXS **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S
                    201 STEAM  3.30   1     75-   80    28-   29

               TA/TB    TB      K      TE      EMIN   EMAX
               0.100   0.100  100.0   0.100    0.00   3.00


     ** TGOV1 **  BUS   NAME  BSKV MACH  C O N ' S     STATE'S   VAR
                  201 STEAM  3.30   1   117-  123    42-   43     7

       R         T1        VMAX       VMIN       T2         T3         DT
     0.050     0.500     1.000      0.300      1.000      1.000      0.000
ENTER 0 TO END LIST, 1 FOR NEXT PAGE:

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      TUE FEB 15, 1994  16:39
SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT

REPORT FOR ALL MODELS AT ALL BUSES                                 CHAN MODELS


                  *** CALL VOLMAG(     1,     8,     0) ***

             ICON   VOLTAGE VAR  ANGLE VAR   BUS    NAME   BSKV
                1            8           0   150   LOAD    33.0


                  *** CALL VOLMAG(     2,     9,     0) ***

             ICON   VOLTAGE VAR  ANGLE VAR   BUS    NAME   BSKV
                2            9           0   151   LOAD    3.30


                  *** CALL VOLMAG(     3,    10,     0) ***

             ICON   VOLTAGE VAR  ANGLE VAR   BUS    NAME   BSKV
                3           10           0   200   STEAM   33.0


                *** CALL FLOW1(    4,    11,    12,     0) ***
```

c. **Activity DOCU Output**

Figure 14.22. Checkout of Dynamics Simulation Setup (Sheet 3 of 5)

```
ACTIVITY? DLST

ENTER OUTPUT DEVICE CODE:
 0 FOR NO OUTPUT         1 FOR CRT TERMINAL
 2 FOR A FILE            3 FOR QMS PS2000
 4 FOR QMS_PS800         5 FOR HARD COPY TERMINAL
 6 FOR ALTERNATE SPOOL DEVICE: 1
ENTER CON RANGE: 1   123
ENTER VAR RANGE: 1   16
ENTER STATE RANGE: 1   43
ENTER ICON RANGE: 1  12
ENTER OUTPUT CHANNEL RANGE: 1   24

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      TUE FEB 15, 1994  16:55
SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT


CONS:

    1:  5.000           2: 0.5000E-01       3: 0.6000E-01       4:  5.084
    5:  1.000           6:  1.500           7:  1.200           8: 0.4000
    9: 0.2500          10: 0.1200          11: 0.3000E-01      12: 0.2500
   13:  5.000          14: 0.5000E-01      15: 0.6000E-01      16:  5.084
   17:  1.000          18:  1.500          19:  1.200          20: 0.4000
   21: 0.2500          22: 0.1200          23: 0.3000E-01      24: 0.2500
   25:  5.000          26: 0.5000E-01      27: 0.6000E-01      28:  5.084
   29:  1.000          30:  1.500          31:  1.200          32: 0.4000
   33: 0.2500          34: 0.1200          35: 0.3000E-01      36: 0.2500
   37:  6.000          38: 0.5000E-01      39:  1.000          40: 0.5000E-01
   41:  3.000          42: 0.0000          43:  1.400          44:  1.350
   45: 0.3000          46: 0.6000          47: 0.2000          48: 0.1000
   49: 0.3000E-01      50: 0.4000          51: 0.1000          52:  10.00
   53:  200.0          54: 0.5000E-01      55: 0.0000          56:  5.000
   57: 0.0000          58: 0.0000          59: 0.1000          60:  10.00
   61:  200.0          62: 0.5000E-01      63: 0.0000          64:  5.000
   65: 0.0000          66: 0.0000          67: 0.1000          68:  10.00
   69:  200.0          70: 0.5000E-01      71: 0.0000          72:  5.000
   73: 0.0000          74: 0.0000          75: 0.1000          76: 0.1000
   77:  100.0          78: 0.1000          79: 0.0000          80:  3.000
   81: 0.5000E-01      82: 0.7500          83:  8.000          84: 0.5000E-01
   85: 0.5000          86: 0.2000          87:  1.000          88: 0.0000
   89:  1.300          90:  1.100          91: 0.0000          92: 0.8000E-01
   93: 0.5000E-01      94: 0.7500          95:  8.000          96: 0.5000E-01
   97: 0.5000          98: 0.2000          99:  1.000         100: 0.0000
  101:  1.300         102:  1.100         103: 0.0000         104: 0.8000E-01
  105: 0.5000E-01     106: 0.7500         107:  8.000         108: 0.5000E-01
  109: 0.5000         110: 0.2000         111:  1.000         112: 0.0000
  113:  1.300         114:  1.100         115: 0.0000         116: 0.8000E-01
  117: 0.5000E-01     118: 0.5000         119:  1.000         120: 0.3000
  121:  1.000         122:  1.000         123: 0.0000
```

Call FLOW1 (7, 13, 14, 0)

```
VARS:

    1: 0.4043E-01       2:  1.000           3: 0.4043E-01       4:  1.000
    5: 0.4043E-01       6:  1.000           7: 0.4000E-01       8:  1.045
    9: 0.9947          10:  1.050          11:  1.008          12: -1.754
   13:  11.01          14:  3.207          15:  9.007          16:  3.391


STATES:

    1:  1.057           2: 0.8924           3: 0.4985           4: 0.0000
    5: 0.7219           6:  1.057           7: 0.8924           8: 0.4985
    9: 0.0000          10: 0.7219          11:  1.057          12: 0.8924
   13: 0.4985          14: 0.0000          15: 0.7219          16:  1.014
   17: 0.3086          18: 0.8830          19: 0.5554          20: 0.0000
   21: 0.6981          22: 0.7746E-02      23:  1.721          24: 0.7746E-02
   25:  1.721          26: 0.7746E-02      27:  1.721          28: 0.1670E-01
   29:  1.856          30: 0.0000          31: 0.8086          32: 0.8086
   33: 0.8086          34: 0.0000          35: 0.8086          36: 0.8086
   37: 0.8086          38: 0.0000          39: 0.8086          40: 0.8086
   41: 0.8086          42: 0.8000          43: 0.0000
```

d. Review of Data Values and Channels via Activity DLST

Figure 14.23. Checkout of Dynamic Simulation Setup (Sheet 4 of 5)

```
ICONS:

     1:   150          2:    151          3:   200          4:   100
     5:   200          6:   '1 '          7:   100          8:   150
     9:   '1 '        10:    200         11:   150         12:   '1 '

                                                   Call FLOW1 (7, 13, 14, 0)
OUTPUT CHANNELS:

#:ADDR     1:      1     2:      2     3:      4     4:  4001     5:  4002
       ROTOR ANGLE   ROTOR ANGLE   ROTOR ANGLE   P ELECTRICAL  P ELECTRICAL
      BUS  100 MC 1 BUS  100 MC 2 BUS  201 MC 1 BUS  100 MC 1 BUS  100 MC 2
IDENT  ANG1HYDRO     ANG2HYDRO     ANG1STEAM       P 1HYDRO      P 2HYDRO
VALUE     41.360        41.360        39.996      0.40074E-01   0.40074E-01

#:ADDR     6:  4004      7: 12001      8: 12002      9: 12004     10: 16001
       P ELECTRICAL   E TERMINAL    E TERMINAL    E TERMINAL   FIELD VLTAGE
      BUS  201 MC 1 BUS  100 MC 1 BUS  100 MC 2 BUS  201 MC 1 BUS  100 MC 1
IDENT   P 1STEAM     ET 1HYDRO     ET 2HYDRO     ET 1STEAM     EFD1HYDRO
VALUE   0.80000E-01     1.0353        1.0353        1.0168        1.7821

#:ADDR    11: 16002     12: 16004     13: 20001     14: 20002     15: 20004
       FIELD VLTAGE  FIELD VLTAGE  P MECHANICAL  P MECHANICAL  P MECHANICAL
      BUS  100 MC 2 BUS  201 MC 1 BUS  100 MC 1 BUS  100 MC 2 BUS  201 MC 1
IDENT  EFD2HYDRO     EFD1STEAM     PM 1HYDRO     PM 2HYDRO     PM 1STEAM
VALUE     1.7821        1.8556       0.80148       0.80148       0.80000

#:ADDR    16: 44008     17: 44009     18: 44010     19: 44011     20: 44012
       BUS VOLTAGE   BUS VOLTAGE   BUS VOLTAGE      MW FLOW      MVAR FLOW
           150           151           200       100-200CKT1   100-200CKT1
IDENT     V-LOAD        V-LOAD        V-STEAM     P  100-  200  Q  100-  200
VALUE     1.0450       0.99470        1.0500        1.0076       -1.7542

#:ADDR    21: 44013     22: 44014     23: 44015     24: 44016
          MW FLOW      MVAR FLOW       MW FLOW      MVAR FLOW
       100-150CKT1   100-150CKT1   200-150CKT1   200-150CKT1
IDENT  P  100-  150  Q  100-  150  P  200-  150  Q  200-  150
VALUE     11.015        3.2071        9.0075        3.3913

              Call FLOW1
            (7, 13, 14, 0)
```

e. Output of Activity DLST

Figure 14.24. Checkout of Dynamic Simulation Setup (Sheet 5 of 5)

The dynamics CON data is returned to the working memory of PSS®E by the command RSTR, SSN1. The file SSN1 is the Snapshot of working memory taken just before shutting down PSS®E to compile and load CONEC/CONET (see Figure 14.18, “Dialog of Basic PSS®E Dynamic Simulation Model Setup (Sheet 4 of 4)”, Sheet 4). With Snapshot SSN1 restored, the working memory contains the values of all CONs specified in the Dynamics Data File and of all ICONs established by activity CHAN. It contains no other valid data.

14.2.13. Retrieval of Network Data and Initial Conditions

The network data and initial condition power flow are retrieved from file SME2 where they were placed, in power flow converted saved case form, prior to the start of work on dynamics, (see Section 14.2.3, “Power Flow Model”). The network data is recovered and prepared for use by the activity sequence:

LOFL CASE, SME2 FACT RTRN

Following RTRN, the PSS®E working memory contains proper values of dynamics constant data, network parameters, and initial condition network and generator terminal voltages and loadings. All VAR and STATE array elements and all output channels (elements of array CHAN) are still invalid.

14.2.14. Entry of Additional Data

Additional data not provided by the prior power flow setup work or by activities DYRE and CHAN should be entered after the snapshot/saved case pair have been returned to the PSS®E working arrays. Additional data would be entered in an interactive dialog with activity ALTR. No such additional data entry is necessary in this example.

14.2.15. Updated Snapshot

The dynamics Snapshot should be updated any time that CON, ICON, VAR, or output channel data are changed. No such update is necessary in this example.

14.2.16. Initialization

The previous steps established all required constant (CON, ICON) data and output channel assignments in PSS®E working memory, together with generator terminal conditions as provided by the converted power flow. It is now possible to determine the initial condition ($t = t^-$) values of all algebraic variables (VAR, PMECH, EFD, etc.) and state variables representing conditions inside the generators, excitation systems, and other equipment modeled by the library subroutines called from CONEC and CONET. This process is handled by activity STRT; its dialog is shown in the first page,Figure 14.20, “Checkout of Dynamics Simulation Setup (Sheet 1 of 5)”. Activity STRT runs two functions simultaneously:

1. It sets state and algebraic variables to their initial condition values.

2. It makes a number of data consistency and operating limit checks.

STRT works backward through all dynamic simulation models to determine the initial condition values of all quantities in correspondence to the generator terminal loadings. For example:

- Generator current follows from terminal voltage, real power, and reactive power.
- Generator field voltage, electrical torque, and flux linkages follow from terminal voltages and current.
- Excitation system conditions follow from field voltage, etc.

The chain ends with the initialization of the excitation system voltage reference setpoints in array VREF and of the turbine-governor load reference setpoints in designated VARs. Consistency checking is handled in conjunction with this backward initialization process. Details of activity STRT’s error and diagnostic messages are covered in Section 14.3.2, “Initialization Errors”.

The STRT dialog in Figure 14.20, “Checkout of Dynamics Simulation Setup (Sheet 1 of 5)” shows a trouble-free initialization. The main output report, shown by the star in Figure 14.20, “Checkout of Dynamics Simulation Setup (Sheet 1 of 5)”, gives generator loading, field voltage, rotor angle, and power factor. The rotor angles shown here are angular spatial positions of the generator rotors. Their spread reflects both the angular spread between phase angles of the generator terminal voltages and the internal angle of each machine. The last two columns of the tabulation are the generator’s direct and quadrature axis components of terminal current, expressed relative to the rotor axis and illustrated by the machine phasor diagram in Figure 14.25, “Phasor Diagram Used in Initializing Synchronous Machines”.

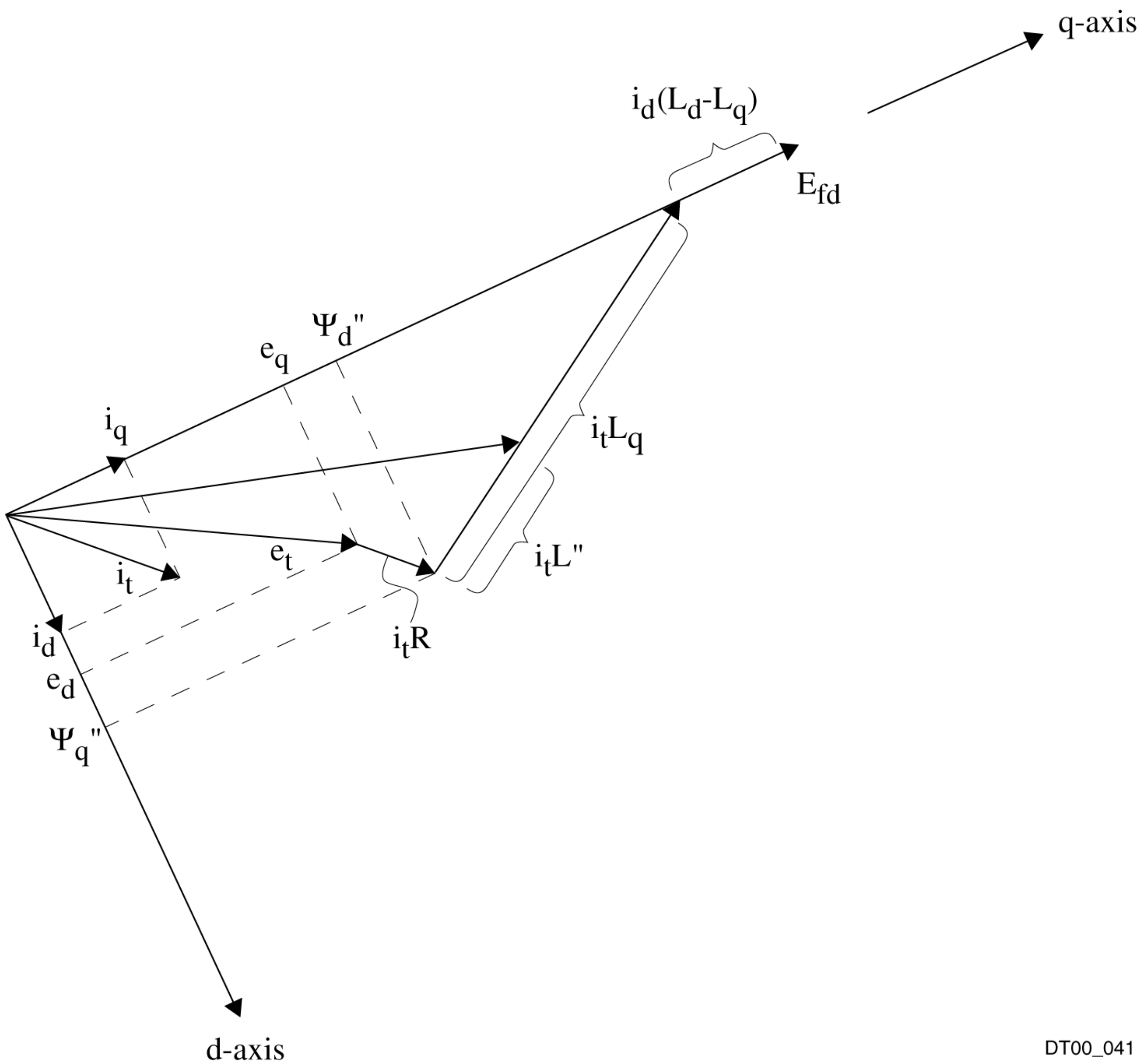


Figure 14.25. Phasor Diagram Used in Initializing Synchronous Machines

14.2.17. Initial Condition Error Checking

The message INITIAL CONDITIONS CHECK OK indicates that the initial values of the time derivatives of all state variables are zero, or adequately close to zero, and that the initial condition, therefore, represents steady-state operation. If any state variable has an initial time derivative of significant magnitude the INITIAL CONDITIONS CHECK OK message will be replaced by an INITIAL CONDITION ERROR listing of the values and time derivatives of all such state variables.

These error conditions should all be checked out before the system model setup is accepted as a valid starting point for dynamic simulation runs. Perseverance in tracking down the causes of these errors is essential if good quality simulation results are to be obtained, because they are very often symptoms of major errors or incompatibilities in the power flow and dynamic simulation data on which the setup is based. The question of initial condition errors is covered in detail in Section 14.3.2, “Initialization Errors”.

14.2.18. Initial Condition Snapshot

On exit from STRT, both the working memory and the Snapshot, if one was made or updated, contain a complete and initialized dynamic simulation setup. In the example, the complete record of the simulation model setup and its initial condition is now contained in the four system files:

CC1

CONEC, equipment structure and connection

CT1

CONET, system metering connections

SME2

Transmission system data

SSN1

Dynamic simulation data

The output file, GOP1, is selected to receive the output channels during the simulation run. The channel headings, as established by activity CHAN, are written into the output file.

Because error-free completion of STRT is the key point of the job setup process, STRT allows the user to update a Snapshot immediately, and before leaving the STRT activity itself. In this example, the Snapshot is placed in file SSN1 and updates (by overwriting) the partial setup Snapshot that was in the file prior to execution of STRT. All setup work done prior to this stage can be recovered quickly for a new simulation run by recompiling and loading CONEC and CONET from CC1 and CT1 if they are not the pair currently loaded with PSS®E and re-running the dialog shown in Figure 14.20, “Checkout of Dynamics Simulation Setup (Sheet 1 of 5)”.

14.2.19. Dynamic Simulation Documentation

Activity DOCU

The last four pages of Figure 14.20, “Checkout of Dynamics Simulation Setup (Sheet 1 of 5)” show the reports produced by activities DOCU and DLST and their documentation of the dynamic simulation setup. Pages 2 and 3 of Figure 14.20, “Checkout of Dynamics Simulation Setup (Sheet 1 of 5)” show the report of activity DOCU. These reports restate the information entered on the model data sheets in Sample Dynamics Data Sheet, and add the index values allocated by activity DYRE, in the places left open on the data sheets.

The DOCU reports list data and setup indices for each equipment model called from either the PSS®E tables or subroutines CONEC and CONET. The markings on the DOCU report show the correspondence of indices and data. The boxed line shows the beginning indices for the second unit at bus 100. The second line expands the indices of the call statement to show that the 12 constants required by model GENSAL (see Sample Dynamic Data Sheet) lie in CON array elements 13 through 24, and that the four state variables of this model are present in STATE array elements 6 through 10. The third line shows the data that has been taken from the power flow Saved Case and associated with this model. The fourth and subsequent lines for this model show the significance and value of the 12 CONs used by this model. Counting from the left shows that CON(21) is the value of X''_d, which must be identical to the imaginary part of ZSORCE.

Activity DOCU reports on all models called from the PSS®E model library.

The DOCU report is the most convenient way of documenting the majority of the dynamic simulation data used in a setup.

Activity DLST

The DLST report, shown on pages 4 and 5 of Figure 14.20, "Checkout of Dynamics Simulation Setup (Sheet 1 of 5)", may list any CON, VAR, STATE, ICON, or channel assignment used in a simulation setup. In this example, DLST has been used to display all data used in the setup. All CON data shown previously are listed by DLST; so are all VARs referred to by models.

The markings on the DLST output in Figure 14.20, "Checkout of Dynamics Simulation Setup (Sheet 1 of 5)" show the ICON values assigned and VAR/channel values that result. This call of subroutine FLOW1 was placed by CHAN when the user requested that the flow in branch 100-150, circuit 1, be placed in channels. Activity CHAN assigned ICONs 7 through 9 to FLOW1 and gave them values of 100, 150, and 1, respectively. Activity CHAN also assigned VARs 13 and 14 to this FLOW1 call so that it could set them to the P and Q flows in the branch. CHAN also sets the 21st and 22nd elements of the channel arrays (see Table 14.3, "Sequence of Activities to Recover Prefault System Data and Status") to pick up VARs 13 and 14 and display them in the two corresponding channels.

14.3. Error Checking

14.3.1. Gross Parameter Errors

The example shown in Figure 14.1, "Small Example System for Dynamic Simulation Setup Examples" through Figure 14.20, "Checkout of Dynamics Simulation Setup (Sheet 1 of 5)" culminates in an apparently correct initialization. The data used in the example, and summarized in the last four pages of Figure 14.20, "Checkout of Dynamics Simulation Setup (Sheet 1 of 5)", contain at least one major error, nevertheless. At least one erroneous data value is listed in both the DOCU and DLST reports. It is unlikely, though, that an engineer reading these reports would find it, and it is certain that reading DOCU and DLST reports for a large system is not a practical way of locating errors.

A preliminary check on the reasonableness of the CON values entered into the PSS®E database via the Dynamics Data File (Figure 14.14, "Basic Dynamics Data File for Setup of Simulation Model") or by alteration of CON values may be obtained by using activity DOCU in the checking mode. The checking selection instructs DOCU to make a reasonableness check of the values of every CON used by a dynamic simulation model. For example it checks CONs representing the generator parameter, X_d, to ensure that their values lie in the reasonable range for this parameter, $0.8 \le X_d \le 2.0$.

The checking mode of DOCU displays warning messages pertaining to each dynamic simulation model just ahead of the data report on that model. Figure 14.26, "Use of Activity DOCU to Review CON Values for Reasonableness (Sheet 1 of 2)" shows the recovery of the setup made in the previous example. This report shows warning messages for all the excitation system models used, and for the TGOV1 governor model at bus 201 used in the simulation. The warnings given for the governor model and the SCRX exciter models suggest that the flagged parameter values be checked for correctness. All are correct — though at one extreme or another of typical ranges. The warning message preceding the SEXS call does reveal a serious error, however. The value of T_b in the SEXS model certainly should not be 0.1 as detected by the checking mode of DOCU. A check of the SEXS data sheet in Sample Dynamic Data Sheet shows that the value should be 10, not 0.1; the value was mistyped in the Dynamics Data File (Figure 14.14, "Basic Dynamics Data File for Setup of Simulation Model", line 8).

```
ACTIVITY? RSTR SSN1
```

Recover Snapshot of dynamics data

```
 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 SNAPSHOT SSN1.SNP WAS SAVED ON TUE FEB 15, 1994  16:37

 NUMBER OF ELEMENTS RESTORED:
   CONS STATES   VARS  ICONS CHANNELS
    123     43     16     12      24

 ACTIVITY? LOFL

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? CASE SME2

 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 CASE SME2.SAV WAS SAVED ON MON FEB 14, 1994  17:05

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? FACT

     5 DIAGONAL AND      5 OFF-DIAGONAL ELEMENTS

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? RTRN
```

Retrieve initial condition power flow

```
 ACTIVITY? DOCU ALL

 ENTER OUTPUT DEVICE CODE:
  0 FOR NO OUTPUT         1 FOR CRT TERMINAL
  2 FOR A FILE            3 FOR QMS PS2000
  4 FOR QMS_PS800         5 FOR HARD COPY TERMINAL
  6 FOR ALTERNATE SPOOL DEVICE: 1
 ENTER 0 FOR REPORTING MODE, 1 FOR DATA CHECKING MODE: 1
```

Document to check parameter values

```
      PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED FEB 16, 1994  11:30
 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 DATA CHECK FOR ALL MODELS AT ALL BUSES    BUS   100 [HYDRO   33.0] PLANT MODELS


 BUS   100  MACHINE 1:
 TA/TB=     0.1000    K=       200.0000   TRANSIENT GAIN=    20.0000


      ** SCRX **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S    BUS
                  100 HYDRO   33.0   1     51-   58    22-   23    FED

        TA/TB     TB       K       TE      EMIN    EMAX  SWITCH  RC/RFD
        0.100  10.000   200.0   0.050    0.00    5.00    0.0     0.00


 BUS   100  MACHINE 2:
 TA/TB=     0.1000    K=       200.0000   TRANSIENT GAIN=    20.0000
```

Suspect values

```
      ** SCRX **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S    BUS
                  100 HYDRO   33.0   2     59-   66    24-   25    FED

        TA/TB     TB       K       TE      EMIN    EMAX  SWITCH  RC/RFD
        0.100  10.000   200.0   0.050    0.00    5.00    0.0     0.00


 BUS   100  MACHINE 3:
 TA/TB=     0.1000    K=       200.0000   TRANSIENT GAIN=    20.0000


      ** SCRX **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S    BUS
                  100 HYDRO   33.0   3     67-   74    26-   27    FED

        TA/TB     TB       K       TE      EMIN    EMAX  SWITCH  RC/RFD
        0.100  10.000   200.0   0.050    0.00    5.00    0.0     0.00
 ENTER 0 TO END LIST, 1 FOR NEXT PAGE:

      PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED FEB 16, 1994  11:30
 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT
```

Figure 14.26. Use of Activity DOCU to Review CON Values for Reasonableness (Sheet 1 of 2)

```
DATA CHECK FOR ALL MODELS AT ALL BUSES    BUS   201 [STEAM   3.30] PLANT MODELS

BUS    201  MACHINE 1:
TB=         0.1000

          ** SEXS **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S
                      201 STEAM   3.30   1     75-   80    28-   29

                TA/TB     TB       K       TE      EMIN    EMAX
                0.100    0.100   100.0   0.100    0.00    3.00

BUS    201  MACHINE 1:
T1=       0.5000
T2=       1.0000    T3=       1.0000

       ** TGOV1 **  BUS   NAME  BSKV MACH  C O N ' S     STATE'S   VAR
                    201 STEAM   3.30   1   117-  123    42-   43     7

        R          T1        VMAX       VMIN       T2         T3         DT
      0.050      0.500      1.000      0.300      1.000      1.000      0.000
ACTIVITY? STOP

BUS    201  MACHINE 1:
TB=         0.1000

          ** SEXS **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S
                      201 STEAM   3.30   1     75-   80    28-   29

                TA/TB     TB       K       TE      EMIN    EMAX
                0.100    0.100   100.0   0.100    0.00    3.00

BUS    201  MACHINE 1:
T1=       0.5000
T2=       1.0000    T3=       1.0000

       ** TGOV1 **  BUS   NAME  BSKV MACH  C O N ' S     STATE'S   VAR
                    201 STEAM   3.30   1   117-  123    42-   43     7

        R          T1        VMAX       VMIN       T2         T3         DT
      0.050      0.500      1.000      0.300      1.000      1.000      0.000

ACTIVITY? STOP
```

Suspect values

Figure 14.27. Use of Activity DOCU to Review CON Values for Reasonableness (Sheet 2 of 2)

The checking mode of activity DOCU is useful primarily for detecting gross errors like the typographical one pointed out above. *It is not a complete data check*, however, *and an execution of it with no warnings does not imply that all data is correct*. The checking mode of DOCU is useful both in initial model setup when data is being established for the first time, and when an extensive series of changes has been made and errors may have crept in.

14.3.2. Initialization Errors

A dynamic simulation model must be correct with respect to both equipment parameters and initial operating point. The previous check using DOCU gave some help in reviewing equipment parameter data, but contributed nothing to the checking of the initial condition operating point. The most important checking of the initial operating point must begin during the setup of the initial condition power flows. Generators must be checked for operation at an acceptable voltage and power factor. Their output must be above minimum load and below maximum turbine output. The mismatches of the initial condition power flow must be acceptably small. The power flow can only check operating point variables outward from the generator terminals. The checking of the initial condition with respect to variables within the equipment dynamic models is assisted by activity STRT.

Each equipment model checks all variables to which limits are applied to ensure that the initial variable value, as calculated, falls between the limits. An error message is printed if any initial variable value calculated during initialization falls outside of its operating limits. Calculated values are overridden by the appropriate limits.

Activity STRT attempts to calculate initial values of all variables to correspond to steady-state operation, and then makes a single test calculation of the time derivatives of all state variables. STRT executes the same three major steps that are used to determine the time derivatives during the dynamic simulation itself:

- Call CONEC with mode = 3.
- Solve the transmission network.
- Call CONEC with mode = 2.

The network solution should converge in one or two iterations and all time derivatives should be close to zero. Some small deviation of the time derivatives from zero is inevitable as a result of the small but nonzero mismatches of the initial condition converted power flow. STRT prints error messages stating the value of both time derivative and state variable for each state variable for which the calculated derivative exceeds a small tolerance from zero.

Figure 14.28, "Error Conditions Detected by STRT and Use of DOCU to Track Down Errors" shows the report from an execution of STRT made after considerable alterations had been made to the constant data in Snapshot SSN1, both to correct the error identified in Figure 14.26, "Use of Activity DOCU to Review CON Values for Reasonableness (Sheet 1 of 2)" and to refine other parameter values. Figure 14.28, "Error Conditions Detected by STRT and Use of DOCU to Track Down Errors" shows both OUT-OF-LIMIT messages and INITIAL CONDITIONS SUSPECT messages. The OUT-OF-LIMIT messages draw attention to the plant at bus 201. The INITIAL CONDITION SUSPECT messages draw attention to state variables 16 and 43 at bus 201. As the printout shows, the state variable 16 is used by model GENROU connected at bus 201, and that state variable 43 is used by model TGOV1, also connected at bus 21. The STRT report in Figure 14.28, "Error Conditions Detected by STRT and Use of DOCU to Track Down Errors" is followed immediately by a selective DOCU report for bus 201.

The first step in error checking is to check the limit parameters in the model data against the calculated initial conditions. Checking the E_{max} value for SEXS shows that the generator field voltage ceiling is 1.75 pu, while the initial value calculated from power flow conditions is 1.86. The conflict results in the 1.86 value being overridden by the limit of 1.75. The 1.75 value is wrong, it should be 2.75. A similar check on the V_{max} parameter in TGOV1 shows that the turbine output is limited to 0.75 pu of the rated value. Because the base MVA of the unit at bus 201 is 10.0, this corresponds to a maximum power of 7.5 MW, while the power flow value is 8.0 MW. The 0.75 value is wrong, it should be 0.95.

The next step is to check out the nonzero time derivative errors. The STRT message shows that STATE(16) is the first state variable used by GENROU. Reference to the GENROU data sheet in Sample Dynamic Data Sheet shows that this first state variable represents E'_q of the generator. E'_q is held in equilibrium by the applied field voltage. Its nonzero derivative is, therefore, due to the limitation of the excitation system output to 1.75 pu instead of 1.86 as needed for equilibrium. A similar check shows that the nonzero derivative of STATE(43) is due to the limitation of the value position in TGOV1. Both of the nonzero time derivatives, therefore, will be rectified when the errors in the values of CON(80) (E_{max}) and CON(119) (V_{max}) are corrected.

```
ACTIVITY? STRT
SEXS AT BUS    201 MACHINE 1 INITIALIZED OUT OF LIMITS
TGOV1 AT BUS    201 MACHINE 1 INITIALIZED OUT OF LIMITS

PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU, AUG 06 1987  12:00
SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT

INITIAL CONDITION LOAD FLOW USED  1 ITERATIONS

--------------------------MACHINE INITIAL CONDITIONS--------------------------
X------ BUS -----X ID  ETERM   EFD    POWER    VARS   P.F.  ANGLE    ID     IQ
100 HYDRO   33.0  1 1.0353 1.7822    4.01    0.48 0.9928  41.36 0.5880 0.5247
100 HYDRO   33.0  2 1.0353 1.7822    4.01    0.48 0.9928  41.36 0.5880 0.5247
100 HYDRO   33.0  3 1.0353 1.7822    4.01    0.48 0.9928  41.36 0.5880 0.5247
201 STEAM   3.30  1 1.0167 1.8555    8.00    2.38 0.9585  40.00 0.6560 0.4934


INITIAL CONDITIONS SUSPECT:
I   DSTATE(I)     STATE(I)      MODEL   STATE    BUS  X-- NAME --X  MACH
16  -0.17591E-01   1.0142        GENROU   K       201  STEAM   3.30   1
43  -0.50007E-01  0.80001        TGOV1    K+1     201  STEAM   3.30   1

ENTER CHANNEL OUTPUT FILENAME:
ENTER SNAPSHOT FILENAME:

ACTIVITY? DOCU

ENTER OUTPUT DEVICE CODE:
0 FOR NO OUTPUT   1 FOR CRT TERMINAL
2 FOR A FILE      3 FOR VERSATEC
4 FOR PRINTER     5 FOR HARD COPY TERMINAL
6 FOR ALTERNATE SPOOL DEVICE: 1
ENTER 0 FOR REPORTING MODE, 1 FOR DATA CHECKING MODE: 0
ENTER UP TO 20 BUS NUMBERS
201
PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU, AUG 06 1987  12:00
SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT

                 *** CALL GENROU(  201,'1',    4,    37,    16) ***

        BUS   NAME BASKV MACH KOUNT   C O N ' S      STATE'S  SLOT
        201 STEAM   3.30   1      4    37-   50     16-   21     4

        MBASE      Z S O R C E         X T R A N       GENTAP
        10.0    0.00000+J 0.20000  0.00000+J 0.00000  1.00000

T'D0 T''D0   T'Q0 T''Q0     H    DAMP   XD     XQ     X'D    X'Q   X''D    XL
6.00 0.050   1.00 0.050   3.00   0.00 1.4000 1.3500 0.3000 0.6000 0.2000 0.1000

                         S(1.0)   S(1.2)
                         0.0300   0.4000


                 *** CALL SEXS(  201,'1',    4,    75,    28) ***

        BUS   NAME BSVLT MACH KOUNT   C O N ' S      STATE'S  SLOT
        201 STEAM   3.30   1      4    75-   80     28-   29     4

        TA/TB    TB      K      TE     EMIN   EMAX
        0.100   0.100  100.0   0.100   0.00   1.75


                 *** CALL TGOV1(  201,'1',    4,  117,    42,     7) ***

        BUS   NAME BSVLT MACH KOUNT   C O N ' S      STATE'S   VAR  SLOT
        201 STEAM   3.30   1      4   117-  123     42-   43     7     4

        R         T1        VMAX       VMIN       T2         T3         DT
        0.050     0.500     0.750      0.300      1.000      1.000      0.000
ENTER UP TO 20 BUS NUMBERS
0
```

Variables in SEXS and TGOV1 not valid

State variables cannot be initialized for zero time derivative

EFD upper limit is 1.75, power flow requests 1.855

Figure 14.28. Error Conditions Detected by STRT and Use of DOCU to Track Down Errors

The error-free completion of activity STRT does not imply a correct system model setup or valid initial condition. It remains entirely possible for the setup to contain errors with regard to both parameter values and operating point. Equipment parameters can fall entirely within reasonable ranges, satisfying both DOCU and STRT, and yet be incorrect. Additional checking of equipment parameters is covered in Chapter 24, *Elementary Blocks for Handling Transfer Functions in Dynamic Models* . Operating conditions can be completely within equipment limits and in perfect steady state, satisfying STRT, and yet still contain errors that will invalidate a study.

14.4. Running Simulations

14.4.1. Basic Steps

A dynamic simulation setup of the type covered in Section 14.2, “Basic Setup Example” provides the basis for a wide range of simulation runs, both from the original initial condition and from new initial conditions in which loadings and equipment statuses may have changed. Figure 14.29, “Dialog for Dynamic Simulation Run (Sheet 1 of 4)” shows a simple simulation run based on the setup as built up in Section 14.2, “Basic Setup Example”. The principal steps are:

- Recovery of the setup data by picking up converted power flow saved case SME2 and Snapshot SSN1.
- Reinitialization with activity STRT.
- Numerical integration of the differential equations with activity RUN to advance the time trajectory of the state variables.
- Application and removal of perturbations, such as faults and line switchings, with activity ALTR.

Note that data items were changed from those originally entered, based on data checking. The run shown in Figure 14.29, “Dialog for Dynamic Simulation Run (Sheet 1 of 4)”, in summary, employs the following activities:

RSTR

Recovers the Snapshot

LOFL, CASE, FACT, RTRN

Recovers the initial condition converted power flow

STRT

Initializes the dynamic simulation run at t = –2.*DELT (standard procedure of STRT)

RUN

Advances the system, unperturbed to $t = 0^{-}$

ALTR

Perturbs the system by application of a three-phase short circuit at bus 200. (The fault is represented by a large shunt admittance.)

RUN

Advances the system to $t = 0.1^{-}$

ALTR

Removes the fault, by removing the large shunt, and open branch 100-200

RUN

Advances time to $t = 3.0^{-}$

SNAP

Records the conditions at $t = 3.0^{-}$ in file SSN2 in case the simulation needs to be continued later

LOFL SAVE

Records the network data at $t = 3.0^{-}$ in file SLF2 in case the run needs to be continued later

Annotations on Figure 14.29, "Dialog for Dynamic Simulation Run (Sheet 1 of 4)" point out details of the dialog with each activity used in the run. The results of the simulation run are deposited in file GOP, and may be plotted or listed by utility program PSSPLT. Figure 14.33, "Dialog for Plotting Program PSSPLT to Plot Results From GOP as Made During Run Shown in Figure 14.29, "Dialog for Dynamic Simulation Run (Sheet 1 of 4)" " shows a typical dialog with PSSPLT to produce plots of output channels versus time, and Figure 14.34, "Representative Plot of the Simulation Results (Sheet 1 of 5)" shows a series of representative plots of the simulation results.

```
$ pssds4
Starting your PSSDS...

                POWER TECHNOLOGIES INCORPORATED

         12000 BUS POWER SYSTEM SIMULATOR--PSS®E-22.0

 INITIATED AT DYNAMICS ENTRY POINT ON WED FEB 16, 1994  17:17

 ACTIVITY? RSTR SSN1 <------------------------------- Recover initial condition Snapshot

 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 SNAPSHOT SSN1.SNP WAS SAVED ON WED FEB 16, 1994  12:15

 NUMBER OF ELEMENTS RESTORED:
   CONS STATES   VARS  ICONS CHANNELS
    123     43     16     12      24

 ACTIVITY? LOFL

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? CASE SME2

 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 CASE SME2.SAV WAS SAVED ON MON FEB 14, 1994  17:05        Recover initial condition
                                                            converted power flow case
 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? FACT

     5 DIAGONAL AND      5 OFF-DIAGONAL ELEMENTS

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? RTRN

 ACTIVITY? STRT <------------------------------------------ Initialize

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED FEB 16, 1994  17:20
 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 INITIAL CONDITION LOAD FLOW USED  1 ITERATIONS

 --------------------------MACHINE INITIAL CONDITIONS--------------------------
 X------ BUS -----X ID  ETERM   EFD    POWER    VARS   P.F.   ANGLE   ID     IQ
   100 HYDRO   33.0  1 1.0353 1.7821   4.01    0.48 0.9928  41.36 0.5880 0.5247
   100 HYDRO   33.0  2 1.0353 1.7821   4.01    0.48 0.9928  41.36 0.5880 0.5247
   100 HYDRO   33.0  3 1.0353 1.7821   4.01    0.48 0.9928  41.36 0.5880 0.5247
   201 STEAM   3.30  1 1.0168 1.8556   8.00    2.38 0.9585  40.00 0.6560 0.4934

 INITIAL CONDITIONS CHECK O.K.              Put results in file GOP for
                                            subsequent plotting
 ENTER CHANNEL OUTPUT FILENAME: GOP <
 ENTER SNAPSHOT FILENAME: <---------------- No need for updating Snapshot

 ACTIVITY? RUN                                             Run to t = 0-; print
                                                           channels every 2 steps;
                                                           plot channels (to GOP)
                                                           every 2 steps
 AT TIME = -0.017 ENTER TPAUSE, NPRT, NPLT, CRTPLT: 0 2 2
 CHANNEL OUTPUT FILE IS GOP
    TIME   ANG1HYDRO      ANG2HYDRO      ANG1STEAM       P 1HYDRO       P 2HYDRO
  -0.017     41.360         41.360         39.996       0.40074E-01    0.40074E-01
            P 1STEAM       ET 1HYDRO      ET 2HYDRO      ET 1STEAM      EFD1HYDRO
     6     0.80000E-01     1.0353         1.0353         1.0168         1.7821
           EFD2HYDRO      EFD1STEAM      PM 1HYDRO      PM 2HYDRO      PM 1STEAM
    11      1.7821         1.8556        0.80148        0.80148        0.80000
             V-LOAD         V-LOAD        V-STEAM      P  100-  200   Q  100-  200
    16      1.0450        0.99470         1.0500         1.0076        -1.7542
           P  100-  150   Q  100-  150   P  200-  150   Q  200-  150
    21      11.015         3.2071         9.0075         3.3913

   0.000    41.360         41.360         39.996       0.40074E-01    0.40074E-01
     6     0.80000E-01     1.0353         1.0353         1.0168         1.7821
    11      1.7821         1.8556        0.80148        0.80148        0.80000
    16      1.0450        0.99470         1.0500         1.0076        -1.7542
    21      11.015         3.2071         9.0075         3.3913
```

a. Start-Up (Prefault)

Figure 14.29. Dialog for Dynamic Simulation Run (Sheet 1 of 4)

```
ACTIVITY? ALTR                          Use ALTR to apply 3-phase fault at bus 200

SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT

TIME =   0.0000

ENTER CHANGE CODE:
 0 = NO MORE CHANGES        1 = OUTPUT CHANNEL DATA
 2 = CONS                   3 = VARS
 4 = CRT PLOT CHANNELS      5 = ICONS
 6 = SOLUTION PARAMETERS    7 = STATES
 8 = CASE HEADING: 0                    No change to CONs, etc.

NETWORK DATA CHANGES (1=YES, 0=NO)? 1   Yes, fault is a network change
PICK UP NEW SAVED CASE (1=YES, 0=NO)? 0 No need

ENTER CHANGE CODE:
 0 = EXIT ACTIVITY                  1 = BUS DATA
 2 = GENERATOR DATA                 3 = BRANCH DATA
 4 = TRANSFORMER DATA               5 = AREA INTERCHANGE DATA
 6 = TWO-TERMINAL DC LINE DATA      7 = SOLUTION PARAMETERS
 8 = CASE HEADING                   9 = SWITCHED SHUNT DATA
10 = IMPEDANCE CORRECTION TABLES   11 = MULTI-TERMINAL DC DATA
12 = ZONE DATA                     13 = AREA TRANSACTIONS DATA: Fault is bus data change

ENTER BUS NUMBER (0 FOR NEW CHANGE CODE, -1 TO EXIT): 200    Bus 200

BUS DATA FOR BUS   200 [STEAM    33.0]:
  CODE    PLOAD    QLOAD      S H U N T      I L O A D      Y L O A D
OLD  1     0.00     0.00     0.00    0.0     0.0    0.0     0.0    0.0 CHANGE IT? 1
ENTER CODE, PLOAD, QLOAD, G, B, IP, IQ, YP, YQ
,,,,-2E11                                                    Represent fault by
NEW  1     0.00     0.00     0.00 -0.2E+12   0.0    0.0     0.0    0.0   large admittance
                                                             to ground
    AREA     VOLT    ANGLE    NAME      BASVLT LOSZON
OLD     1  1.0500   -0.11 STEAM        33.000      1 CHANGE IT? 0

ENTER BUS NUMBER (0 FOR NEW CHANGE CODE, -1 TO EXIT): -1

    5 DIAGONAL AND     5 OFF-DIAGONAL ELEMENTS
                                                    Run to t = 0.1-; Print
ACTIVITY? RUN                                       and plot every step

AT TIME =   0.000 ENTER TPAUSE, NPRT, NPLT, CRTPLT: .1 1
CHANNEL OUTPUT FILE IS GOP
  TIME   ANG1HYDRO      ANG2HYDRO      ANG1STEAM      P 1HYDRO       P 2HYDRO
  0.000    41.360         41.360         39.996       0.82596E-03    0.82596E-03
          P 1STEAM       ET 1HYDRO      ET 2HYDRO      ET 1STEAM      EFD1HYDRO
    6     0.00000        0.32043        0.32043        0.30718        1.7821
         EFD2HYDRO      EFD1STEAM      PM 1HYDRO      PM 2HYDRO      PM 1STEAM
   11      1.7821         1.8556         0.80148        0.80148        0.80000     Conditions
           V-LOAD         V-LOAD         V-STEAM       P  100-  200   Q  100-  200  at t = 0+
   16     0.22053E-01    0.20413E-01    0.40423E-09    0.99867E-01    0.99564
         P  100-  150   Q  100-  150   P  200-  150   Q  200-  150
   21     0.14792        1.0113         0.22254E-09   -0.88674E-08


  0.100    49.627         49.627         54.119       0.37375E-03    0.37375E-03
    6     0.18626E-08    0.21516        0.21516        0.21663        1.0845       Conditions
   11      1.0845        2.7500         0.80207        0.80207        0.77546      at t = 0.1-
   16     0.14797E-01    0.13680E-01    0.27751E-09    0.45006E-01    0.44870
   21     0.67119E-01    0.45596        0.59865E-10   -0.40855E-08
```

b. Fault Application (During Fault)

Figure 14.30. Dialog for Dynamic Simulation Run (Sheet 2 of 4)

```
ACTIVITY? ALTR

SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT

TIME =  0.1000

ENTER CHANGE CODE:
 0 = NO MORE CHANGES       1 = OUTPUT CHANNEL DATA
 2 = CONS                  3 = VARS
 4 = CRT PLOT CHANNELS     5 = ICONS
 6 = SOLUTION PARAMETERS   7 = STATES
 8 = CASE HEADING: 0

NETWORK DATA CHANGES (1=YES, 0=NO)? 1
PICK UP NEW SAVED CASE (1=YES, 0=NO)? 0

ENTER CHANGE CODE:
 0 = EXIT ACTIVITY                 1 = BUS DATA
 2 = GENERATOR DATA                3 = BRANCH DATA
 4 = TRANSFORMER DATA              5 = AREA INTERCHANGE DATA
 6 = TWO-TERMINAL DC LINE DATA     7 = SOLUTION PARAMETERS
 8 = CASE HEADING                  9 = SWITCHED SHUNT DATA
10 = IMPEDANCE CORRECTION TABLES  11 = MULTI-TERMINAL DC DATA
12 = ZONE DATA                    13 = AREA TRANSACTIONS DATA: 1

ENTER BUS NUMBER (0 FOR NEW CHANGE CODE, -1 TO EXIT): 200

BUS DATA FOR BUS   200 [STEAM   33.0]:
  CODE    PLOAD   QLOAD     S H U N T     I L O A D     Y L O A D
OLD  1     0.00    0.00    0.00-0.2E+12    0.0     0.0     0.0     0.0 CHANGE IT? 1
ENTER CODE, PLOAD, QLOAD, G, B, IP, IQ, YP, YQ
,,,,0
NEW  1     0.00    0.00    0.00    0.00    0.0     0.0     0.0     0.0

    AREA    VOLT   ANGLE   NAME     BASVLT LOSZON
OLD    1  0.0000   46.30 STEAM      33.000      1 CHANGE IT? 0

ENTER BUS NUMBER (0 FOR NEW CHANGE CODE, -1 TO EXIT): 0

ENTER CHANGE CODE:
 0 = EXIT ACTIVITY                 1 = BUS DATA
 2 = GENERATOR DATA                3 = BRANCH DATA
 4 = TRANSFORMER DATA              5 = AREA INTERCHANGE DATA
 6 = TWO-TERMINAL DC LINE DATA     7 = SOLUTION PARAMETERS
 8 = CASE HEADING                  9 = SWITCHED SHUNT DATA
10 = IMPEDANCE CORRECTION TABLES  11 = MULTI-TERMINAL DC DATA
12 = ZONE DATA                    13 = AREA TRANSACTIONS DATA: 3

ENTER FROM BUS, TO BUS, CIRCUIT IDENTIFIER
 (FROM BUS = 0 FOR NEW CHANGE CODE, -1 TO EXIT): 100 200 1

BRANCH DATA FOR CIRCUIT 1  FROM   100 [HYDRO   33.0] TO   200 [STEAM   33.0]:
 STATUS    LINE R    LINE X  CHARGING  RATE-A  RATE-B  RATE-C
OLD   1   0.02000   0.20000   0.03000    15.0    17.5    20.0 CHANGE IT? 1
ENTER STATUS, R, X, CHARGING, RATE-A, RATE-B, RATE-C, # OF CIRCUITS
0
NEW   0   0.02000   0.20000   0.03000    15.0    17.5    20.0

LINE SHUNTS: BUS   100 [HYDRO   33.0]  BUS   200 [STEAM   33.0]
OLD                 0.00000   0.00000          0.00000   0.00000 CHANGE IT? 0

METERED END IS BUS   100 [HYDRO   33.0]. ENTER 1 TO REVERSE: 0

ENTER FROM BUS, TO BUS, CIRCUIT IDENTIFIER
 (FROM BUS = 0 FOR NEW CHANGE CODE, -1 TO EXIT): -1

    5 DIAGONAL AND     4 OFF-DIAGONAL ELEMENTS
```

c. Fault Clearance

Figure 14.31. Dialog for Dynamic Simulation Run (Sheet 3 of 4)

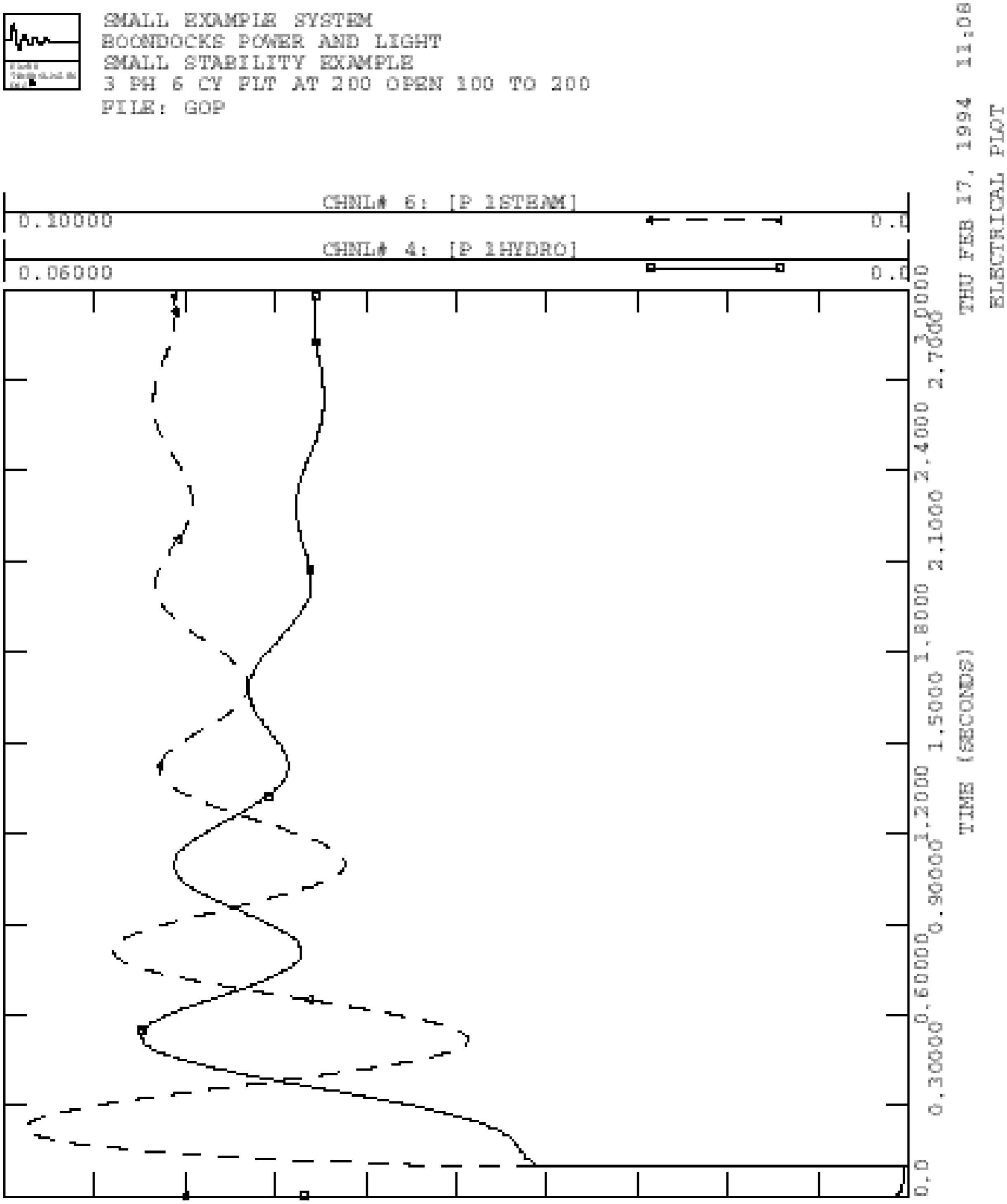
```
ACTIVITY? RUN

AT TIME =  0.100 ENTER TPAUSE, NPRT, NPLT, CRTPLT: 3 35 3
CHANNEL OUTPUT FILE IS GOP
   TIME  ANG1HYDRO     ANG2HYDRO     ANG1STEAM      P 1HYDRO      P 2HYDRO
  0.100    49.627        49.627        54.119       0.24792E-01   0.24792E-01
          P 1STEAM     ET 1HYDRO     ET 2HYDRO     ET 1STEAM     EFD1HYDRO
   6      0.51703E-01   0.65921       0.65921       0.66068        1.0758
         EFD2HYDRO     EFD1STEAM     PM 1HYDRO     PM 2HYDRO     PM 1STEAM
  11       1.0758        2.7500       0.80207       0.80207       0.77546
           V-LOAD        V-LOAD        V-STEAM     P  100-  200  Q  100-  200
  16      0.65843       0.62578       0.66287       0.00000       0.00000
         P  100-  150  Q  100-  150  P  200-  150  Q  200-  150
  21       7.4376        1.0787        5.1703        2.0607

  0.392    119.35        119.35        117.78       0.42846E-01   0.42846E-01
   6      0.67378E-01    1.0311        1.0311       0.99718        4.2097
  11       4.2097        2.7500       0.80883       0.80883       0.70099
  16       1.0225       0.97320        1.0262       0.00000       0.00000
  21       12.854        4.1344        6.7378        2.2363

  2.725    212.93        212.93        211.68       0.38933E-01   0.38933E-01
   6      0.82793E-01    1.0428        1.0428        1.0253        1.9074
  11       1.9074        2.0502       0.79535       0.79535       0.82726
  16       1.0417       0.99156        1.0466       0.00000       0.00000
  21       11.680        3.2766        8.2793        3.2893

   TIME  ANG1HYDRO     ANG2HYDRO     ANG1STEAM      P 1HYDRO      P 2HYDRO
  3.000    203.25        203.25        201.25       0.39259E-01   0.39259E-01
          P 1STEAM     ET 1HYDRO     ET 2HYDRO     ET 1STEAM     EFD1HYDRO
   6      0.81273E-01    1.0399        1.0399        1.0227        1.9243
         EFD2HYDRO     EFD1STEAM     PM 1HYDRO     PM 2HYDRO     PM 1STEAM
  11       1.9243        2.0501       0.79783       0.79783       0.83028
           V-LOAD        V-LOAD        V-STEAM     P  100-  200  Q  100-  200
  16       1.0389       0.98885        1.0437       0.00000       0.00000
         P  100-  150  Q  100-  150  P  200-  150  Q  200-  150
  21       11.778        3.2330        8.1273        3.3026

ACTIVITY? SNAP SSN2

NUMBER OF ELEMENTS IN USE ARE:
    CONS STATES   VARS  ICONS CHANNELS
     123      43     16     12      24
ENTER NUMBER TO BE SAVED OR CARRIAGE RETURN FOR ABOVE VALUES


SNAPSHOT STORED IN FILE SSN2.SNP AT TIME =   3.000

ACTIVITY? LOLF
INVALID ACTIVITY--PLEASE TRY AGAIN

ACTIVITY? LOFL

ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? SAVE SLF2

CASE SAVED IN FILE SLF2.SAV ON WED FEB 16, 1994  17:26

ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? STOP
```

d. Saving Progress Conditions

Figure 14.32. Dialog for Dynamic Simulation Run (Sheet 4 of 4)

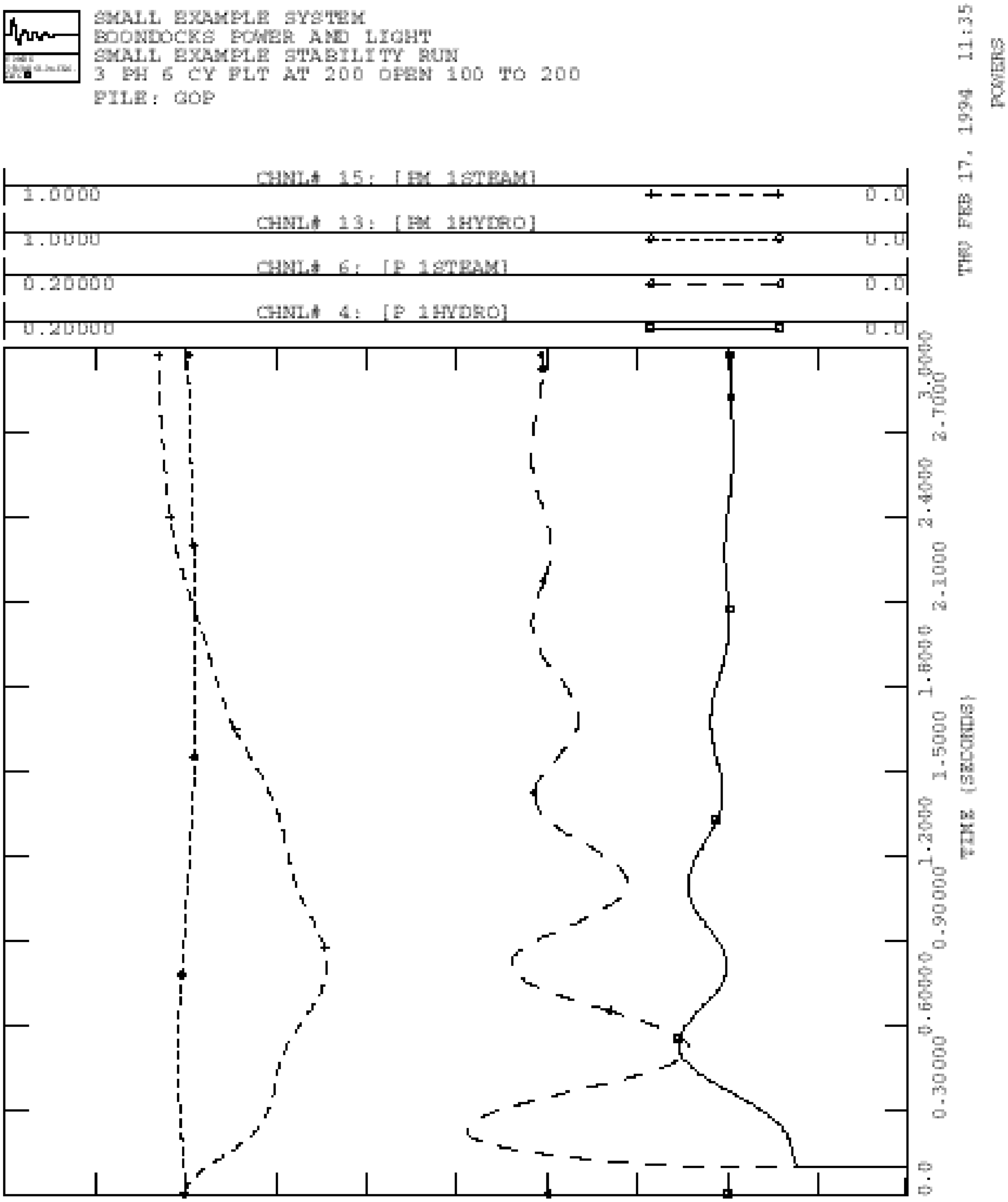
```
$ PSSPLT                                                   Start plot program

POWER TECHNOLOGIES INCORPORATED

CHANNEL OUTPUT FILE PLOTTING PROGRAM -- PSSPLT-15.0

 INITIATED ON WED, JAN 07 1987  11:06

ACTIVITY? CHNF GOP                                         Results were put in GOP by PSS®E

SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT

ACTIVITY? SUBT

SUBTITLE LINE 1 IS
ENTER NEW SUBTITLE LINE OR <CR> TO LEAVE UNCHANGED
SMALL EXAMPLE STABILITY RUN
                                                           Title for plots
SUBTITLE LINE 2 IS
ENTER NEW SUBTITLE LINE OR <CR> TO LEAVE UNCHANGED
3 PH 6 CY FLT AT 200 OPEN 100 TO 200

ACTIVITY? TINT

URRENT VALUE FOR TSTART =  -999.0000, TSTOP =   999.0000
ENTER TSTART, TSTOP: 0 3                                   Horizontal scale 0 to 3 sec

ACTIVITY? SLCT

ENTER CHANNEL NUMBER (0 FOR NO MORE): 4                    Pick channel 4 and set scale
CHANNEL     4 [ P 1HYDRO    ]   MIN = 0.0, MAX = 0.0
ENTER CMIN, CMAX (OR 'R' TO RE-SELECT CHANNEL): 0 .05

ENTER CHANNEL NUMBER (0 FOR NO MORE): 6                    Pick channel 6 and set scale
CHANNEL     6 [ P 1STEAM    ]   MIN = 0.0, MAX = 0.0
ENTER CMIN, CMAX (OR 'R' TO RE-SELECT CHANNEL): 0 .1

ENTER CHANNEL NUMBER (0 FOR NO MORE): 0                    No more curves this plot

ACTIVITY? PLOT

ENTER 25 CHARACTER LABEL :
*************************
: ELECTRICAL POWERS                                        Specify label
SUPPORTED PLOTTING DEVICES ARE:
 0 = NONE                          1 = VERSATEC
 2 = HP 7221A                      3 = TEKTRONIX 4010
 4 = TEKTRONIX 4014                5 = TEKTRONIX 4014 W/EGM
 6 = TEKTRONIX 4662                7 = TEKTRONIX 4663
10 = CALCOMP                      12 = KMW V.P.
17 = TEKTRONIX 4105/04/06         18 = TEKTRONIX 4107/09
20 = TEKTRONIX 4112               21 = TEKTRONIX 4113
22 = TEKTRONIX 4114               23 = TEKTRONIX 4115/4125
27 = HP 7470A                     28 = HP 7475A
31 = QMS LASERGRAFIX              33 = TEKTRONIX 4111
36 = IMAGEN                       37 = TEKTRONIX FILE
38 = HP-GL FILE                   99 = INDE. PLOT FILE
ENTER DESIRED PLOTTING DEVICE: 31                          Choose QMS

ACTIVITY? STOP

ENTER NUMBER OF COPIES (0 TO 5), DEVICE NAME FOR QMS LASERGRAFIX: 1    Request one copy
Job 01011 entered on queue QMSPLOT.                                    of plot
```

Figure 14.33. Dialog for Plotting Program PSSPLT to Plot Results From GOP as Made During Run Shown in Figure 14.29, "Dialog for Dynamic Simulation Run (Sheet 1 of 4)"



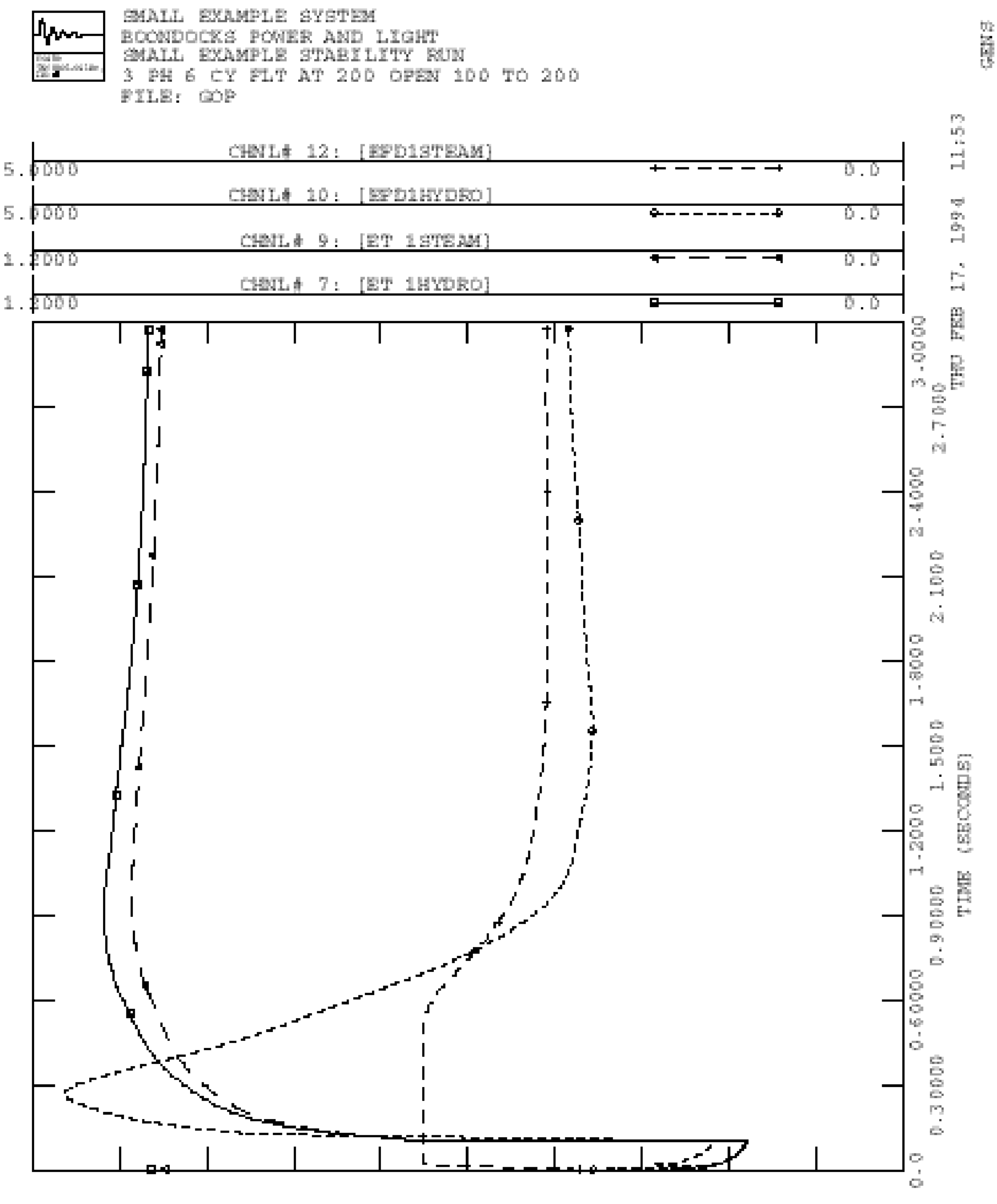
a. Electrical Powers

Figure 14.34. Representative Plot of the Simulation Results (Sheet 1 of 5)



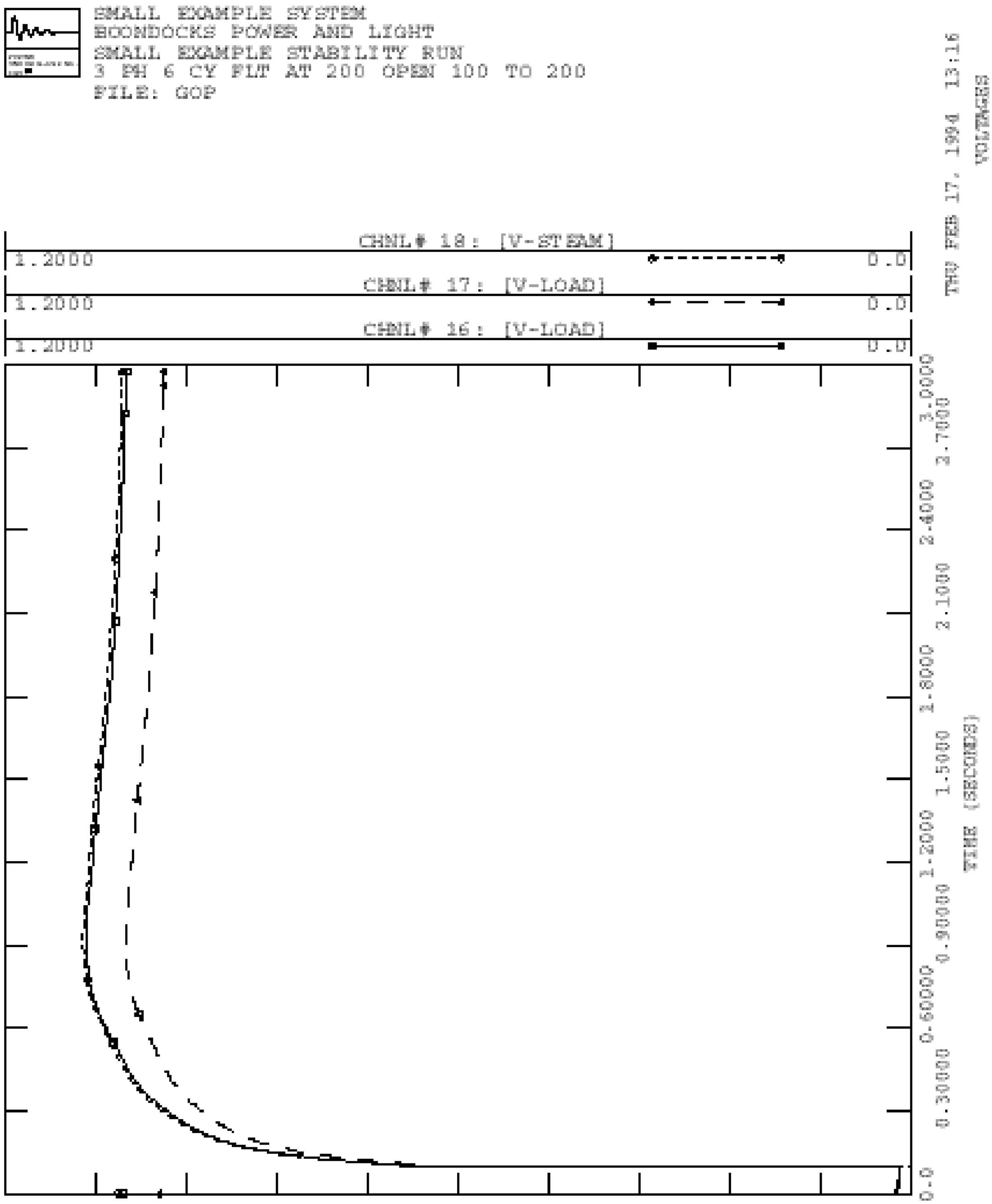
b. Powers

Figure 14.35. Representative Plot of the Simulation Results (Sheet 2 of 5)



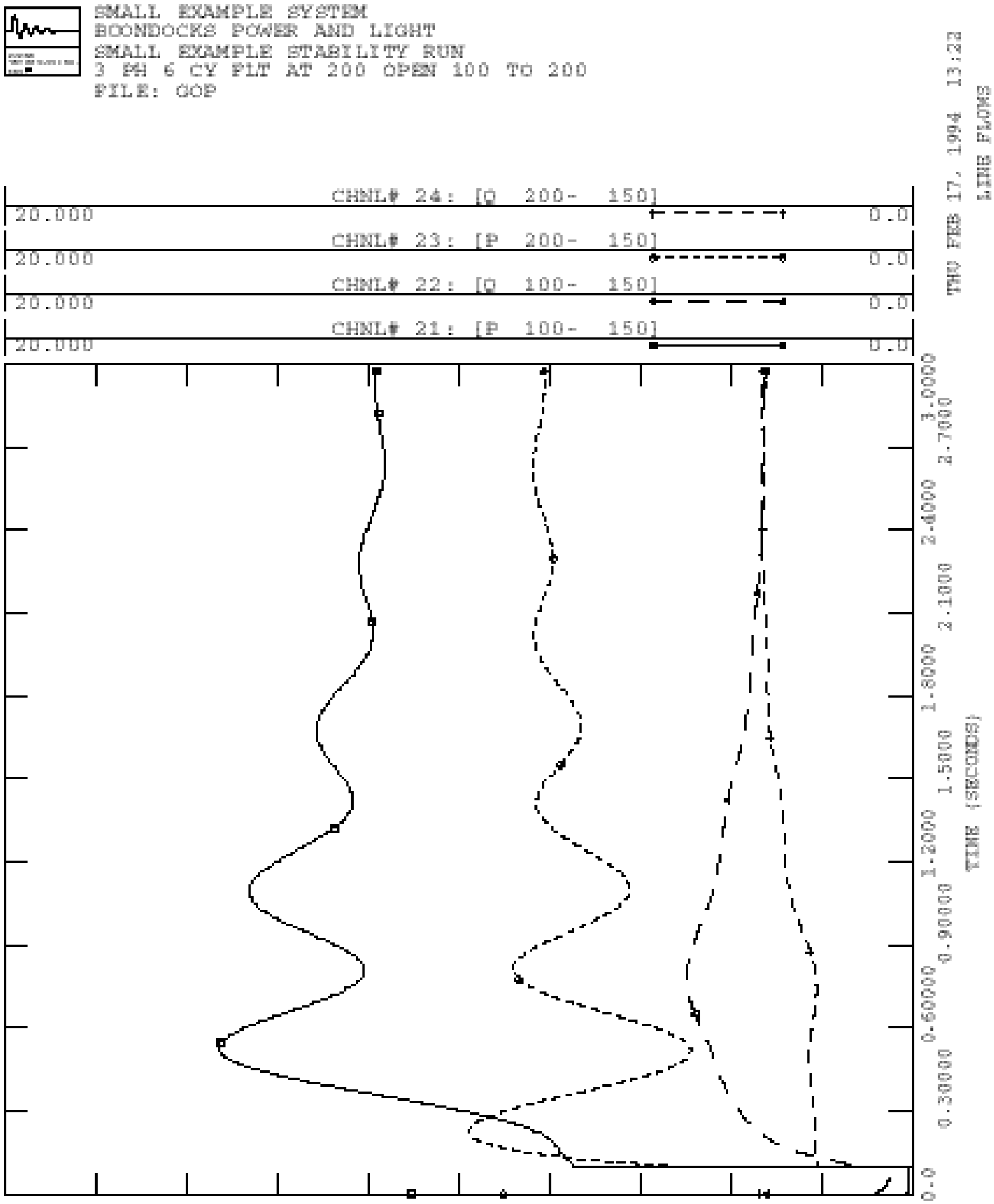
c. Generators

Figure 14.36. Representative Plot of the Simulation Results (Sheet 3 of 5)



d. Voltages

Figure 14.37. Representative Plot of the Simulation Results (Sheet 4 of 5)



e. Line Flows

Figure 14.38. Representative Plot of the Simulation Results (Sheet 5 of 5)

14.4.2. Simulation Procedure

Plotting Interval

The variable NPLT specified to activity RUN informs PSS®E that the output channels should be transferred to the output file every NPLT time steps. Except for the initial brief unperturbed run from initialization to the time at which the first perturbation is to be applied (usually t = 0), NPLT should be an odd number.

Figure 14.39, "Distortion of Simulation Display by Adjustment of Plotting"a shows the effect of changing the plotting interval on the display of simulation results. Plotting results every time step is the best that can be achieved; it reveals the high-frequency oscillation superimposed on the slower variation. Plotting every time step is expensive in terms of disk file space, however; it makes the PSS®E dynamics output files so large that it is not practical to retain more than one or two at a time on the disk. Economical use of disk storage requires that output channels be recorded in the output file as infrequently as is consistent with a reasonable quality of display.

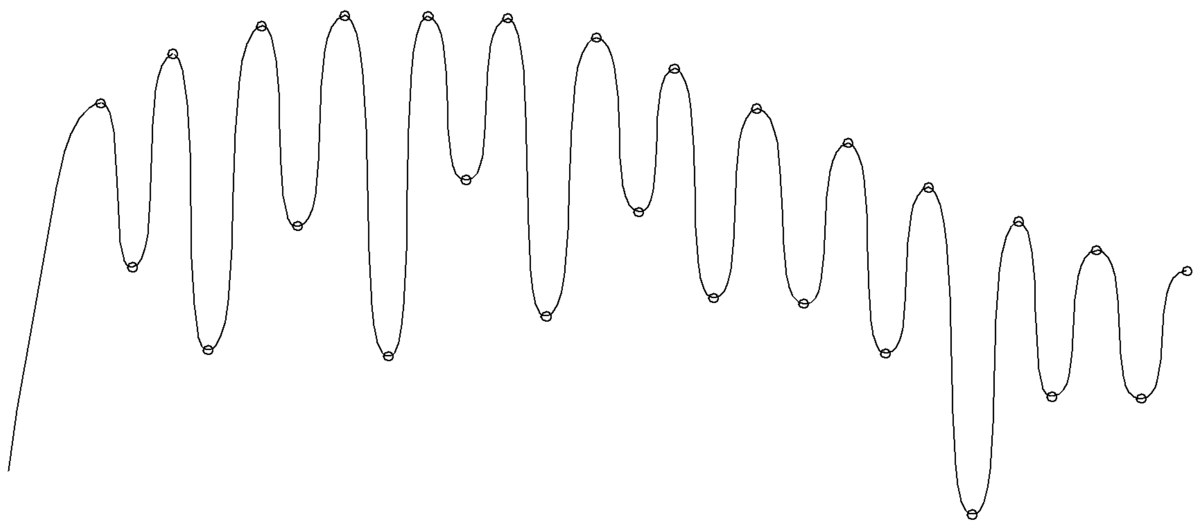
Figure 14.39, "Distortion of Simulation Display by Adjustment of Plotting"b shows that plotting every second time step would completely mask the presence of the high-frequency component. It also shows that, while it would not reveal the details of the high-frequency component, plotting every third time step would at least indicate that some such component is present in the result. Of course, a high-frequency ripple with a true period close to three time steps, instead of two time steps, as in Figure 14.39, "Distortion of Simulation Display by Adjustment of Plotting", would be masked by plotting every third step and indicated by plotting every second step.

A plotting interval of an odd number of steps is recommended because the most troublesome high-frequency ripples found in digital dynamic simulation results have a period of two steps. The most common ripple causing problems is not a true high-frequency component of the system's response, but an alternating positive and negative deviation of calculated values from true values due to marginal numerical stability, or numerical instability of the digital integration process. Such an alternating deviation has an effective period of two time steps and hence is most readily revealed if output is plotted at intervals of an odd number of steps.

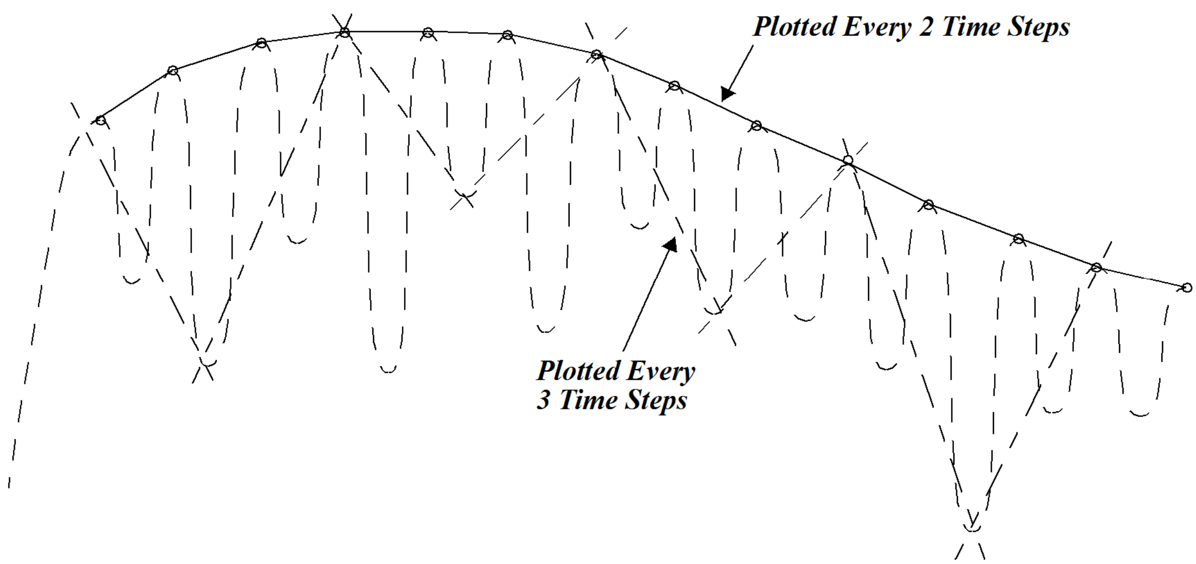
While plotting every three, five, or seven time steps is usually a reasonable compromise between plot quality and economy of disk space, it is not uncommon for numerical instabilities to go unnoticed even when the above precautions are observed. In such troublesome situations, the only reliable alternative is to plot the output channels every time step (NPLT = 1). Even plotting every step can sometimes leave doubt as to whether a jagged plot is due to a true high-frequency component or to numerical instability. In these cases, the only way to obtain an authoritative answer is to reduce the time step and rerun the simulation, again plotting every time step.

Unperturbed Simulation

Discrimination between a true oscillatory or unstable simulation result and a numerical instability is often assisted by making a simulation run with no perturbation. Such a run should, in a perfect computer, remain completely steady with no deviation from the initial condition, regardless of the number of integration steps taken. In practice, the finite word length and associated rounding errors in the computer will give rise to small deviations from the initial condition. If both the system being simulated and the numerical integration process are stable, these errors will not build up beyond a small level corresponding to the machine's precision limitation, regardless of the number of time steps taken. If either the system being simulated or the numerical integration is unstable, the unperturbed simulation will eventually exhibit a growing deviation from the initial condition. Hence, if a simulation that is behaving suspiciously in a perturbed simulation run but does not deviate in a long unperturbed simulation, it is at least reasonable to suppose that the numerical process is stable.



a. True Result



b. Calculated and Plotted Results

Figure 14.39. Distortion of Simulation Display by Adjustment of Plotting

If, on the other hand, the unperturbed simulation fails to remain steady, the question of numerical instability versus true instability remains. In this case, the diagnosis should be based on:

1. Numerical instabilities are almost always overcome by reduction of the integration step width.

2. The majority of numerical instabilities experienced with the algorithms used in PSS®E and in power system applications develop in unperturbed runs as a deviation of one or more state variables with growing amplitude and alternating sign.

Applying and Removing Disturbances

The majority of disturbances are applied and removed by using the NETWORK DATA CHANGES option of activity ALTR. This option causes ALTR to initiate an automatic linkage to activities CHNG and FACT to modify the network data. The specific actions to be used for some more common disturbances are summarized in Figure 14.40, "Implied Linkage via Activities CHNG and FACT from Activity ALTR" and Table 14.2, "Application of Some Common Perturbations ".

Network switching changes such as fault application, fault clearance, and branch tripping may be applied either to the network data that is currently in working memory, or to a new set of network data that is picked up from a converted power flow saved case. New network data is picked up by the PICK UP NEW SAVE CASE option of activity ALTR. A reply of yes to the question PICK UP NEW SAVE CASE? causes PSS®E to pick up new network data, but not a new voltage solution, from a designated power flow saved case. This option often avoids complications in undoing the application of a fault or other disturbance by returning directly to the predisturbance network data.

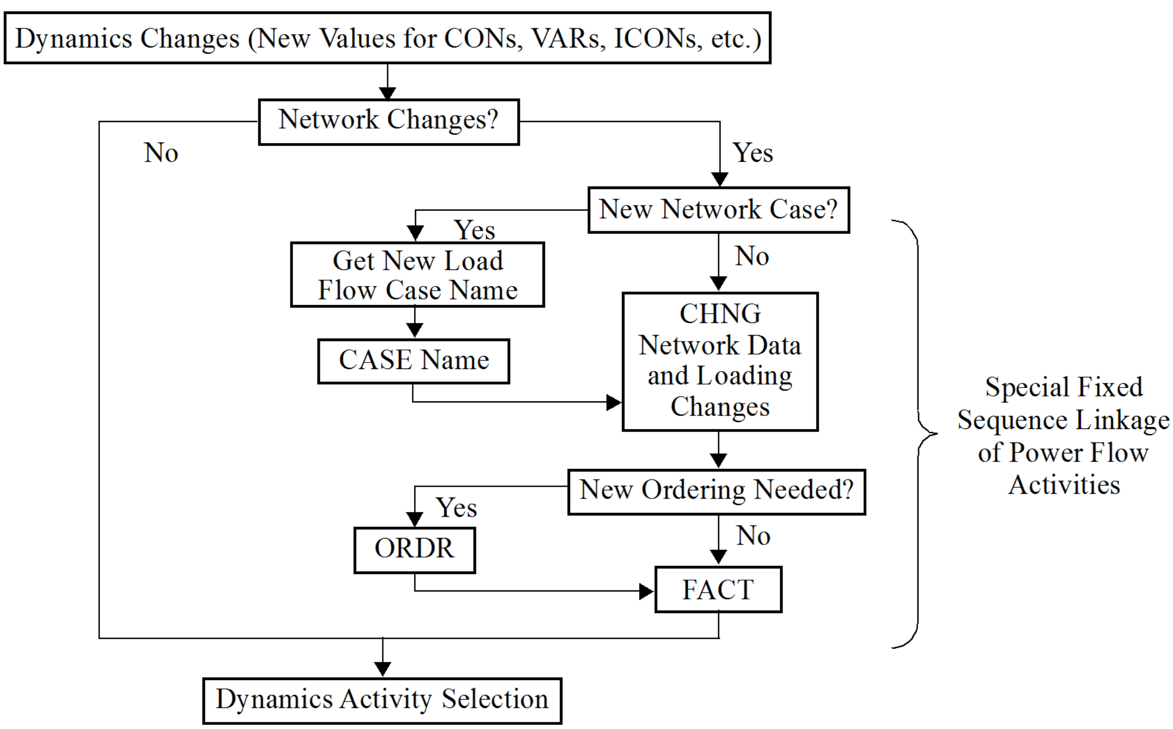


Figure 14.40. Implied Linkage via Activities CHNG and FACT from Activity ALTR

Table 14.2. Application of Some Common Perturbations

Operation or Disturbance	Implementation in PSS®E
Apply 3-phase short circuit at bus *i*.	Add large shunt admittance *B* = –2E10 at bus *i* with ALTR.
Clear fault at bus *i*.	Either pick up prefault power flow case with PICK UP NEW SAVE CASE option of ALTR, or return shunt admittance at bus i to prefault value with ALTR.
Open circuit.	Set circuit status to 0* [a] with ALTR.
Reclose circuit.	Set circuit status to 1** with ALTR.
Clear a bus by tripping all circuits connected to it.	Branch to power flow activities with LOFL and use activity DSCN.
Trip all generators at a bus.	Change bus type code to 1 with activity ALTR.
Trip one or more of a group of identical units at a bus that are represented by a single generator in PSS®E.	Change MBASE for the bus from m × UBASE to n × UBASE with ALTR; where UBASE = unit base MVA and number of units is changed from *m* to *n*.
Trip a single generator, leaving other generators connected.	Change status, ISG, of generator to 0, leaving status of other generators at the bus as 1.

[a]*If line reactors are represented by bus data, instead of as direct line connected reactors, adjust shunt susceptance on bus at each end. ** If outage isolates any bus, change its type code to 4.

For example, short circuit faults involve the addition of a shunt admittance to the shunt that is already present at a bus. This initial shunt represents the effect of a shunt connected device. Clearance of such faults requires restoration of the shunt admittance at the bus to its prefault value. This can be done without the need to take note of the prefault shunt value by using the PICK UP NEW SAVE CASE option of activity ALTR to pick up the same saved case that was used in initialization. Consider a simulation involving a three-phase short circuit at the bus shown in Figure 14.41, “Use of NEW SAVE CASE Option to Recover Prefault System Data and Status”.

The sequence of activities are shown in Table 14.3, “Sequence of Activities to Recover Prefault System Data and Status”.

The alternative procedure for fault clearance would be to use ALTR, without the PICK UP NEW SAVE CASE option, to change the reactive shunt at the faulted bus from –2E10 back to –7.109 before opening the branch. This has the same effect as recovering the prefault Saved Case but is more susceptible to error, particularly when several prefault data values must be re-entered to accomplish removal of a disturbance.

Take care in using the PICK UP NEW SAVE CASE option when the simulation includes relay models or dynamic load models. For details refer to the *PSS®E Program Operation Manual* Applying Disturbances.

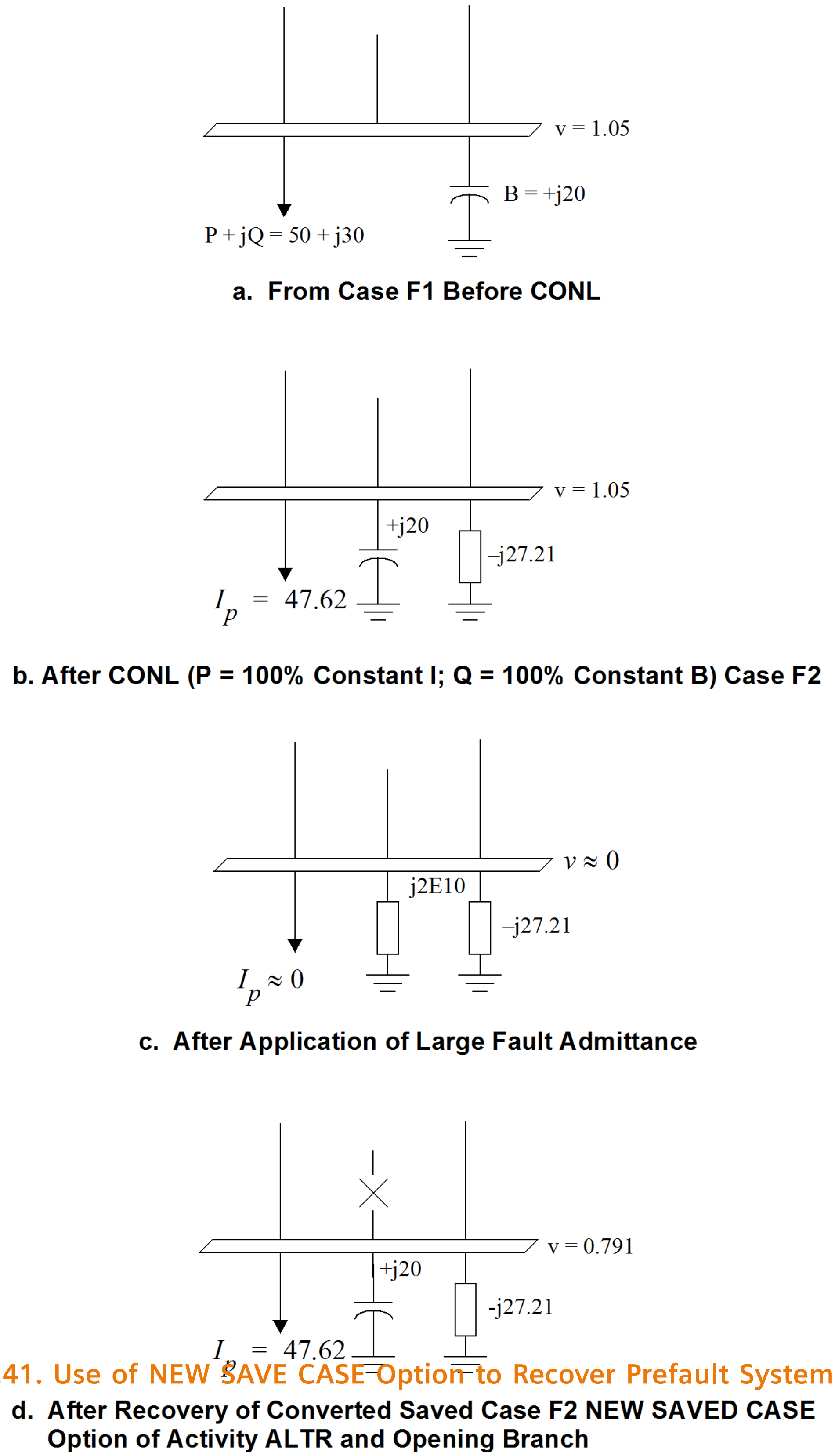


Figure 14.41. Use of NEW SAVE CASE Option to Recover Prefault System Data and Status

Table 14.3. Sequence of Activities to Recover Prefault System Data and Status

RSTR	Pick up Snapshot	
LOFL, CASE,F2, FACT, RTRN	Pick up initial condition power flow	Bus as in Figure 14.41, "Use of NEW SAVE CASE Option to Recover Prefault System Data and Status"b
STRT	Initialize	
RUN	Run to $t = 0^{-}$	
ALTR (no new Saved Case); change shunt to (0,–2E10)	Apply fault; add to present data	Bus as in Figure 14.41, "Use of NEW SAVE CASE Option to Recover Prefault System Data and Status"c
RUN	Run through fault	
ALTR (new Saved Case, F2); open branch	Clear fault; recover data from before fault; make changes from prefault conditions rather than faulted	Bus as in Figure 14.41, "Use of NEW SAVE CASE Option to Recover Prefault System Data and Status"b; bus as in Figure 14.41, "Use of NEW SAVE CASE Option to Recover Prefault System Data and Status"d
RUN	Postfault simulation	

Saved Case - Snapshot Pairs

The complete condition of a dynamic simulation at any instant may be recorded by making a comparison Snapshot and power flow Saved Case. This comparison was done, for example, at the end of the run shown in Figure 14.29, "Dialog for Dynamic Simulation Run (Sheet 1 of 4)" using file SSN2 for the snapshot and file SLF2 for the power flow case.

The creation of the power flow case, while not essential in this example, is still advisable. The run could be restarted by picking up the Snapshot, SSN2; picking up the prefault power flow, SME2; and then using ALTR to open branch 100-200 to reconstitute the conditions at $t = 3.0^{-}$. This practice is susceptible to error, though, and the use of companion Snapshot/Saved Case pairs is preferable.

A Snapshot and/or Saved Case may be made at any point in a simulation. It is recommended that these files be made immediately before any major switching or other change is applied in a simulation run.

1. An error in setting up the switched system condition can be corrected by exiting from activity ALTR, re-entering ALTR, picking up the Saved Case just made with the PICK UP NEW SAVE CASE option, and redoing the sequence of changes.

2. A disturbed network condition can be undone by recovering the predisturbance network condition with the PICK UP NEW SAVE CASE option of activity ALTR, rather than by a reverse sequence of changes.

3. A new run can take place with an alternative switching or disturbance if it is discovered after a run has been advanced beyond the switching before an error is discovered. A new run is made by recovering both the power flow case, with LOFL-CASE-FACT, and the Snapshot as made before the erroneous switching, and then re-executing activities ALTR, RUN, and so on.

Restarting a Simulation Run

The most basic restarting procedure follows this order:

RSTR (Snapshot at time, t) LOFL CASE (power flow Saved Case for time, t) FACT RTRN RUN—to continue simulation

For example, the small example run of Figure 14.29, “Dialog for Dynamic Simulation Run (Sheet 1 of 4)” and Figure 14.33, “Dialog for Plotting Program PSSPLT to Plot Results From GOP as Made During Run Shown in Figure 14.29, “Dialog for Dynamic Simulation Run (Sheet 1 of 4)” ” can be restarted and extended to a longer time span by picking up files SSN2 and SLF2. Figure 14.42, “Simple Continuation of Dynamic Simulation Run” shows the dialog for this restart and extension of the run from t = 3 to t = 4 sec with no new perturbation. At t = 4, the conditions are preserved in a new Snapshot File, SSN3, and a new power flow Saved Case File, SLF3. These files will allow the run to be continued still longer, if desired.

A simulation need not be carried on as a simple extension after a restart. Figure 14.43, “Restarting Simulation Run with Immediate Application of New Perturbation Trip All Generation at Bus 201 (Sheet 1 of 2)” shows the dialog and resulting plot for a restart from the end point, t = 3.0, of the run shown in Figure 14.29, “Dialog for Dynamic Simulation Run (Sheet 1 of 4)” and continuation with the steam turbine generator at bus 201 being tripped at t = 3.0^+ sec. The basic restart procedure in this case may omit the FACT step, because the recovery of the Snapshot and Saved Case is to be followed immediately by activity ALTR, which will refactorize the network after the imposition of network changes. The ALTR dialog in Figure 14.43, “Restarting Simulation Run with Immediate Application of New Perturbation Trip All Generation at Bus 201 (Sheet 1 of 2)”a shows:

1. Change of bus 201 type code from 2 to 1 to remove all of its generation from service.
2. A yes reply to the question DO YOU NEED TO RE-ORDER? because a bus type code has been changed.

Activity ALTR is followed by activity RUN and from this point onward, the dialog is no different in this restart case than it would be in an uninterrupted run.

Multiple - Alternative Runs

A PSS®E dynamics simulation Snapshot contains both the name of the dynamics output file, if any, currently in use, and the position of the writing pointer within that file. Restarting a dynamic simulation run from a Snapshot automatically causes the output channel results for the continuation of the simulation to be placed immediately behind the results recorded up to the point where the Snapshot was made. If the restart point is before the end of the run in which the snapshot was made, the continuation results will overwrite the corresponding results from the original run. If the restart point is the end of the original run, the file will be extended to accommodate the continuation results.

Figure 14.45, “Use of Snapshot, Saved Case, and Dynamics Output Files for Three Runs Examining Switching Alternatives” and Figure 14.46, “Management of Dynamics Output Files in Switching Operation Runs” illustrate the management of output files when making three simulation runs to evaluate alternative control actions:

Run 1: 5-sec simulation, no load shedding.

Run 2: 5-sec simulation, load shedding option A applied at t = 3.

Run 3: 5-sec simulation, load shedding option B applied at t = 4.

Figure 14.45, “Use of Snapshot, Saved Case, and Dynamics Output Files for Three Runs Examining Switching Alternatives” shows the form of results expected. Run 1 will be done first with Snapshots being made at t = 3 and t = 4 so that run 2 and run 3 can be restarts; this will allow the 15 sec of simulation results to be produced with 5 + 2 + 1 = 8 sec of simulation calculations. The results of the three runs must be stored in separate files so that comparison plots can be made later. The dynamics output files to be used are OREF (Run 1), OSWA (Run 2), and OSWB (Run 3).

```
$ pssds4
Starting your PSSDS...

                POWER TECHNOLOGIES INCORPORATED

         12000 BUS POWER SYSTEM SIMULATOR--PSS®E-22.0

 INITIATED AT DYNAMICS ENTRY POINT ON THU FEB 17, 1994  14:28

 ACTIVITY? RSTR SSN2

 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 SNAPSHOT SSN2.SNP WAS SAVED ON WED FEB 16, 1994  17:25

 NUMBER OF ELEMENTS RESTORED:
   CONS STATES   VARS  ICONS CHANNELS
    123     43     16     12      24

 ACTIVITY? LOFL

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? CASE SLF2

 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 CASE SLF2.SAV WAS SAVED ON WED FEB 16, 1994  17:26

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? FACT

     5 DIAGONAL AND      4 OFF-DIAGONAL ELEMENTS

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? RTRN

 ACTIVITY? RUN

 AT TIME =   3.000 ENTER TPAUSE, NPRT, NPLT, CRTPLT: 4 15 3
 CHANNEL OUTPUT FILE IS GOP
    TIME   ANG1HYDRO      ANG2HYDRO      ANG1STEAM      P 1HYDRO       P 2HYDRO
   3.000     203.25         203.25         201.25       0.39259E-01    0.39259E-01
            P 1STEAM      ET 1HYDRO      ET 2HYDRO      ET 1STEAM      EFD1HYDRO
    6      0.81273E 01     1.0399         1.0399         1.0227         1.9241
           EFD2HYDRO      EFD1STEAM      PM 1HYDRO      PM 2HYDRO      PM 1STEAM
   11       1.9241         2.0501        0.79783        0.79783        0.83028
             V-LOAD         V-LOAD        V-STEAM     P  100-  200   Q  100-  200
   16       1.0389        0.98885         1.0437        0.00000        0.00000
           P  100-  150  Q  100-  150  P  200-  150  Q  200-  150
   21       11.778         3.2330         8.1273         3.3026

   3.125     199.64         199.64         198.10       0.38909E-01    0.38909E-01
    6      0.82105E-01     1.0388         1.0388         1.0216         1.9337
   11       1.9337         2.0514        0.79877        0.79877        0.82872
   16       1.0378        0.98778         1.0426        0.00000        0.00000
   21       11.673         3.2323         8.2106         3.2904

   3.875     192.69         192.69         190.74       0.39218E-01    0.39218E-01
    6      0.80482E-01     1.0353         1.0353         1.0180         1.9673
   11       1.9673         2.0533        0.80214        0.80214        0.81080
   16       1.0341        0.98430         1.0389        0.00000        0.00000
   21       11.765         3.2178         8.0482         3.2662

   4.000     193.61         193.61         191.44       0.39385E-01    0.39385E-01
    6      0.79922E-01     1.0350         1.0350         1.0176         1.9709
   11       1.9709         2.0530        0.80231        0.80231        0.80726
   16       1.0338        0.98401         1.0386        0.00000        0.00000
   21       11.816         3.2162         7.9922         3.2648


 ACTIVITY? SNAP SSN3

 NUMBER OF ELEMENTS IN USE ARE:
   CONS STATES   VARS  ICONS CHANNELS
    123     43     16     12      24
 ENTER NUMBER TO BE SAVED OR CARRIAGE RETURN FOR ABOVE VALUES

 SNAPSHOT STORED IN FILE SSN3.SNP AT TIME =   4.000

 ACTIVITY? LOFL

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? SAVE SLF3

 CASE SAVED IN FILE SLF3.SAV ON THU FEB 17, 1994   14:31

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? STOP
```

Recover dynamics data from SSN2

Recover network data from Saved Case SLF2

Run to t = 4.0; print every 15 steps; plot every 3 steps

Continue simulation run

New output is appended to existing output in file GOP

Make new Snapshot and Saved Case of conditions at t = 4.0 to prepare for further continuation

Figure 14.42. Simple Continuation of Dynamic Simulation Run

```
$ pssds4
Starting your PSSDS...

                POWER TECHNOLOGIES INCORPORATED

         12000 BUS POWER SYSTEM SIMULATOR--PSS™E-22.0

 INITIATED AT DYNAMICS ENTRY POINT ON THU FEB 17, 1994  15:11

 ACTIVITY? RSTR SSN2                              Recover Snapshot (preswitch)

 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 SNAPSHOT SSN2.SNP WAS SAVED ON WED FEB 16, 1994  17:25

 NUMBER OF ELEMENTS RESTORED:
   CONS STATES   VARS  ICONS CHANNELS
    123     43     16     12      24

 ACTIVITY? LOFL

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? CASE SLF2

 SMALL EXAMPLE SYSTEM                             Recover preswitch load flow case.
 BOONDOCKS POWER AND LIGHT                        Don't need to factorize because
                                                  changes will be made - doesn't hurt!
 CASE SLF2.SAV WAS SAVED ON WED FEB 16, 1994  17:26

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? FACT

     5 DIAGONAL AND      4 OFF-DIAGONAL ELEMENTS

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? RTRN

 ACTIVITY? ALTR                                   ALTR to trip generation at bus 201
                                                  by changing type code to 1
 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 TIME =  3.0000

 ENTER CHANGE CODE:
  0 = NO MORE CHANGES        1 = OUTPUT CHANNEL DATA
  2 = CONS                   3 = VARS
  4 = CRT PLOT CHANNELS      5 = ICONS
  6 = SOLUTION PARAMETERS    7 = STATES
  8 = CASE HEADING: 0

 NETWORK DATA CHANGES (1=YES, 0=NO)? 1            It's a network change
 PICK UP NEW SAVED CASE (1=YES, 0=NO)? 0          We'll work on present network data

 ENTER CHANGE CODE:
  0 = EXIT ACTIVITY                      1 = BUS DATA
  2 = GENERATOR DATA                     3 = BRANCH DATA
  4 = TRANSFORMER DATA                   5 = AREA INTERCHANGE DATA
  6 = TWO-TERMINAL DC LINE DATA          7 = SOLUTION PARAMETERS
  8 = CASE HEADING                       9 = SWITCHED SHUNT DATA
 10 = IMPEDANCE CORRECTION TABLES       11 = MULTI-TERMINAL DC DATA
 12 = ZONE DATA                         13 = AREA TRANSACTIONS DATA: 1   It's a bus data change

 ENTER BUS NUMBER (0 FOR NEW CHANGE CODE, -1 TO EXIT): 201   Bus 201

 BUS DATA FOR BUS    201 [STEAM   3.30]:
   CODE    PLOAD    QLOAD        S H U N T      I L O A D     Y L O A D
 OLD  2     0.00     0.00     0.00     0.00     0.0     0.0     0.0     0.0 CHANGE IT? 1
 ENTER CODE, PLOAD, QLOAD, G, B, IP, IQ, YP, YQ                Set type
 NEW  1     0.00     0.00     0.00     0.00     0.0     0.0     0.0     0.0   code to 1

     AREA     VOLT    ANGLE    NAME      BASVLT LOSZON
 OLD    1   1.0227  169.11 STEAM        3.300      1 CHANGE IT? 0

 ENTER BUS NUMBER (0 FOR NEW CHANGE CODE, -1 TO EXIT): -1

     5 DIAGONAL AND      4 OFF-DIAGONAL ELEMENTS

 ACTIVITY? RUN                                    Continue simulation

 AT TIME =   3.000 ENTER TPAUSE, NPRT, NPLT, CRTPLT: 6 49 5
 CHANNEL OUTPUT FILE IS GOP
    TIME   ANG1HYDRO      ANG2HYDRO      ANG1STEAM      P 1HYDRO       P 2HYDRO
   3.000    203.25         203.25         0.00000       0.58069E-01    0.58069E-01
            P 1STEAM       ET 1HYDRO      ET 2HYDRO      ET 1STEAM      EFD1HYDRO
       6    0.00000        0.93785        0.93785        0.00000        1.9241
          t = 3+ results
```

a. ALTR Dialog

Figure 14.43. Restarting Simulation Run with Immediate Application of New Perturbation Trip All Generation at Bus 201 (Sheet 1 of 2)

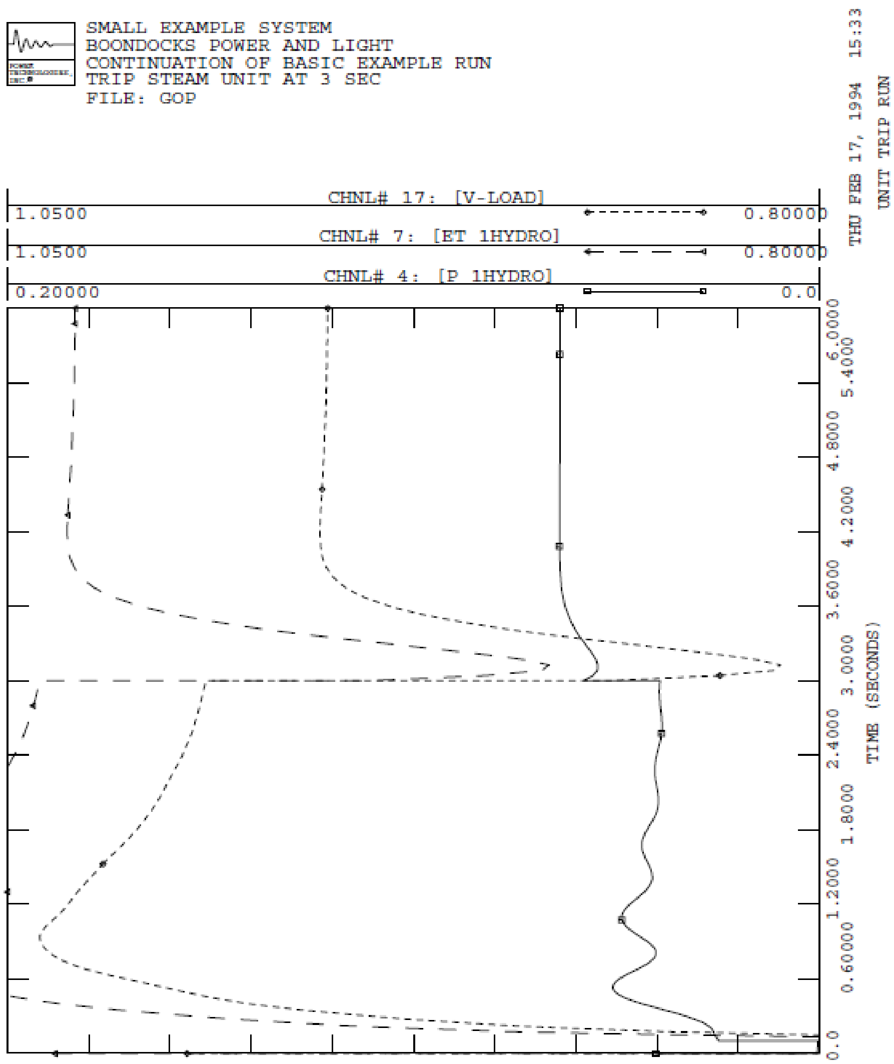


Figure 14.44. b. Result of Continuation Run Restarting Simulation Run with Immediate Application of New Perturbation: Trip All Generation at Bus 201 (Sheet 2 of 2)

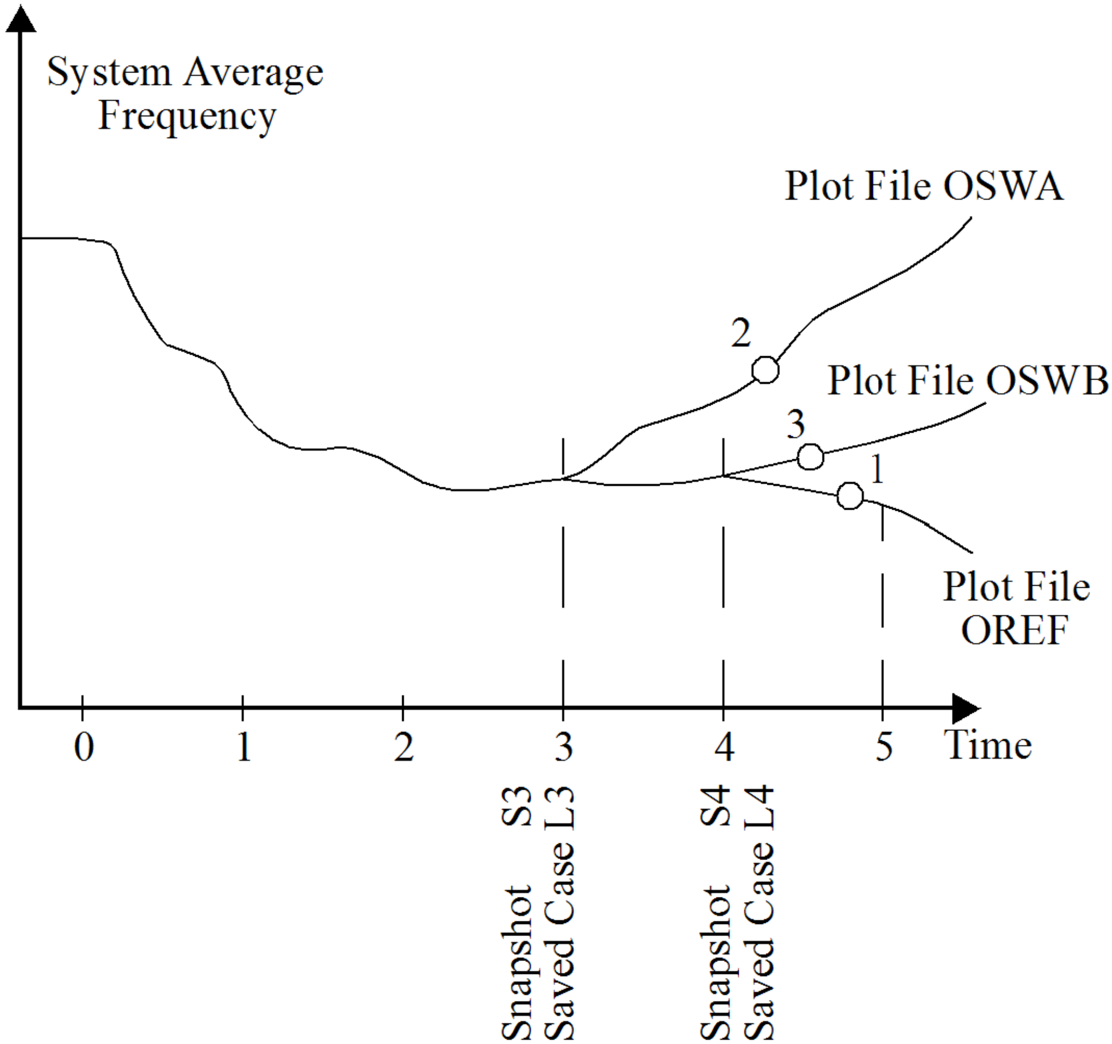


Figure 14.45. Use of Snapshot, Saved Case, and Dynamics Output Files for Three Runs Examining Switching Alternatives

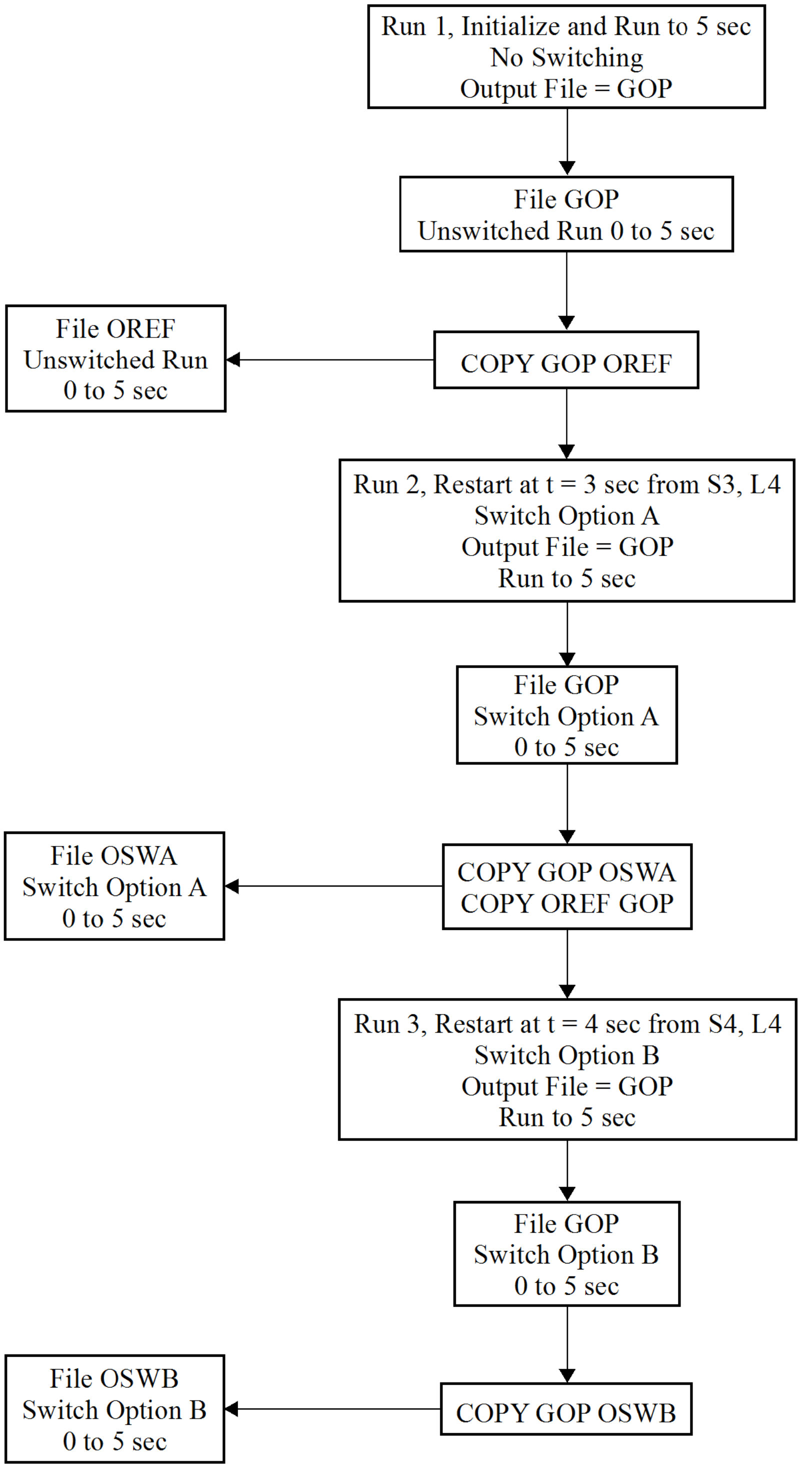


Figure 14.46. Management of Dynamics Output Files in Switching Operation Runs

All simulation runs should be made with a single working plot file, which can be copied into three storage files as the runs are completed. Figure 14.46, "Management of Dynamics Output Files in Switching Operation Runs" shows the sequence of PSS®E runs and file manipulations needed to accomplish the three runs.

The first run places the entire 5-sec unswitched result into file GOP, which is immediately duplicated for reference in file OREF. The second run reuses file GOP, leaving the results of the first 3 sec untouched and overwriting the channel values of the last 2 sec with the results for switch option A. File GOP is then duplicated again into file OSWA. Because file GOP no longer contains the required result for Run 3 in the interval from 3 to 4 sec, its original unswitched form is recovered by duplicating file OREF in place of GOP. The restart procedure is then used again to make Run 3.

14.5. Use of CONET in System Modeling

The following example uses obsolete load type models that are called from subroutine CONET. At present, load type models are called from the internal PSS®E tables, similar to plant-related models, and *are not* called from subroutine CONET. The following is included only as an example of using CONET. There are still some categories of models that exist in CONET and, in future PSS®E releases, will also be executed from the PSS®E internal tables. As this happens, the following example will no longer be relevant.

14.5.1. Calling Models via CONET

The basic example covered in Section 14.2, "Basic Setup Example" involved only equipment associated with generating plants. None of the equipment modeled involved a direct algebraic voltage-current relationship. The CONET subroutine used in Section 14.2, "Basic Setup Example" was produced automatically by activity DYRE and required no refinement prior to its use in the simulation.

Models not part of the PSS®E tables involving algebraic relationship between current and voltage at a load (Type 1) bus must be called from subroutine CONET so that they are executed at each iteration of the network solution process (Figure Figure 14.20, "Checkout of Dynamics Simulation Setup (Sheet 1 of 5)"). Because activity DYRE automatically includes equipment models and the program keeps track of storage locations, it is recommended that new equipment models be added automatically. Manual addition by allocating storage is prone to mistakes.

The following subsections illustrate the use of equipment modeling by showing an example case in which the simulation setup from Section 14.2, "Basic Setup Example" is augmented by additional detail in its representation of loads.

14.5.2. Example Using CONET Models

Added Modeling Requirements

Consider the following augmentations of the basic simulation setup from Section 14.2, "Basic Setup Example":

1. Recognize the sensitivity of all network impedances and admittances to local frequency.

2. Model the real power constant current component of load at buses 150 and 151 as varying according to:

$$I_p = I_{po}\left(\frac{\omega^*}{\omega_o}\right)^{1.6}$$

3. Model three-stage load shedding at bus 151 by a solid-state type underfrequency relay.

The augmented setup is to be constructed on the basis of the same converted power flow case, SME2, used in Section 14.2, "Basic Setup Example", and is not to disturb the original setup. Accordingly, the new setup will be recorded in three new files, SNU1, CC2, and CT2, for a new CONEC subroutine and a new CONET subroutine, respectively.

When building upon a previous setup automatically, it is necessary to set up temporary CONEC and CONET files, which have been named TEMCOC and TEMCOT. Table 14.4, "Files to be Used in First Dynamic Simulation Setup Example" shows the original file allocation table (Table 14.1, "Files to be Used in First Dynamic Simulation Setup Example") as augmented.

Table 14.4. Files to be Used in First Dynamic Simulation Setup Example

Power Flow Raw Data	SMALL
Solved Initial Condition Power Flow	SME1
Solved Converted IC Power Flow	SME2
Dynamics Raw Data	SMEDD
Initial Condition Snapshot	SSN1
First Plotting Output File	GOP1
Subroutine CONEC Source	CC1
Subroutine CONET Source	CT1
Progress Snapshot	SSN2
Progress Power Flow Case	SLF2
Additional Power Flow Raw Data	NEWMOD
Initial Condition Snapshot	SNU1
Temporary CONEC Source	TEMCOC
Temporary CONET Source	TEMCOT
Subroutine CONEC Source	CC2
Subroutine CONET Source	CT2

Model Data Sheets

The first step in adding equipment to an existing setup of the modeling subroutines is to complete the data sheets for each model to be used, with respect to both parameter values (Network Frequency Dependence Model (NETFRQ) Model Data Sheet through Underfrequency Load Shedding Relay Model (LDSHD) Model Data Sheet). The data is transferred to a new raw data dynamics file, NEWMOD, Figure 14.48, "Additional Dynamics Data File for Adding to Basic Model" shows a listing of the new raw data file.

Construction of Base CONEC/CONET Subroutines

The base CONEC subroutine is already available from the previous work (Section 14.2, "Basic Setup Example"); it is recorded in file CC1 and will have no changes to it because the new equipment needed is all CONET models.

Figure 14.49, "Dialog for Adding More Raw Data (Sheet 1 of 2)" shows the dialog that creates the new model calls starting from the original Snapshot, this is recorded in file TEMCOT. Figure 14.51, "Files Created by DYRE and CHAN in Making New Setup" shows the new temporary subroutine CONET that DYRE created and placed in file TEMCOT.

NETFRQ

Network Frequency Dependence Model

CALL NETFRQ from CONET			
This model makes network parameters dependent upon local bus frequency			

0, 'NETFRQ'/

Network Frequency Dependence Model (NETFRQ) Model Data Sheet

LOADF

Frequency Sensitive Load Model

CALL LOADF (I,J) from CONET		
The bus number where this model is called is in ICON	#______	I,
This model uses CONs starting with	#______	J.

ICON	#	Value	Description
I		151	Bus number

CONs	#	Description
J	1.6	Current load exponent, k
J+1	0	Real power load exponent, m
J+2	0	Reactive power load exponent, n

The constant current and constant power load components are made sensitive to bus frequency according to:

$$I_p + j\,I_q = (I_{po} + j\,I_{qo})\left(\frac{\omega^*}{\omega_o}\right)^k$$

$$P = P_o\left(\frac{\omega^*}{\omega_o}\right)^m$$

$$Q = Q_o\left(\frac{\omega^*}{\omega_o}\right)^n$$

Figure 14.47. IBUS, 'LOADF', k, m, n/ Frequency Sensitive Load Model (LOADF) Model Data Sheet for Bus 151

LODSHD

Underfrequency Load Shedding Relay Model

CALL LODSHD (I,J,L,M) from CONET		
The bus number where this model is called is in ICON	#______	I,
It uses CONs starting with	#______	J,
and VARs starting with	#______	L,
and ICONs starting with	#______	M.

ICON	#	Value	Description
I		151	Bus number

CONs	#	Value	Description
J		59.7	First load shedding point (Hz)
J+1		0.05	First point pickup time (sec)

CONs	#	Value	Description
J+2		0.5	First fraction of load to be shed
J+3		59.5	Second load shedding point (Hz)
J+4		0.05	Second fraction pickup time (sec)
J+5		0.3	Second fraction of load to be shed
J+6		59.0	Third load shedding point (Hz)
J+7		0.05	Third point pickup time (sec)
J+8		0.2	Third fraction of load to be shed
J+9		0.085	Breaker time (sec)
J+10		0	Nominal shunt Mvar not subject to load shedding

ICONs	#	Description
M		First point delay flag
M+1		First point time-out flag
M+2		First timer status
M+3		Second point delay flag
M+4		Second point time-out flag
M+5		Second timer status
M+6		Third point delay flag
M+7		Third point time-out flag
M+8		Third timer status

VARs	#	Description
L		First timer memory
L+1		Second timer memory
L+2		Third timer memory

IBUS, 'LODSHD', CON list/

Underfrequency Load Shedding Relay Model (LDSHD) Model Data Sheet

FILE NEWMOD

```
0 'NETFRQ' /
150 'LOADF' 1.6 0 0/
151 'LOADF' 1.6 0 0/
151 'LOADSHD' 59.7 .05 .5 59.5 .05 .3 59.0 .05 .2 .085 0/
```

Figure 14.48. Additional Dynamics Data File for Adding to Basic Model

```
$ pssds4
Starting your PSSDS...

                POWER TECHNOLOGIES INCORPORATED

         12000 BUS POWER SYSTEM SIMULATOR--PSS®E-22.0

 INITIATED AT DYNAMICS ENTRY POINT ON FRI FEB 18, 1994  09:38

 ACTIVITY? RSTR SSN1
```

Recover previous initial condition snapshot

```
 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 SNAPSHOT SSN1.SNP WAS SAVED ON WED FEB 16, 1994  12:15

 NUMBER OF ELEMENTS RESTORED:
   CONS STATES   VARS  ICONS CHANNELS
    123     43     16     12      24

 ACTIVITY? LOFL

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? CASE SME2

 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 CASE SME2.SAV WAS SAVED ON MON FEB 14, 1994  17:05

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? FACT

     5 DIAGONAL AND      5 OFF-DIAGONAL ELEMENTS

 ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? RTRN
```

Recover initial condition converted power flow case

```
 ACTIVITY? DYRE,ADD
```

DYRE to read new data and build new subroutines CONEC and CONET

```
 ENTER DYNAMICS DATA SOURCE FILENAME: NEWMOD
 ENTER FILENAME FOR CONEC ADDITIONS: TEMCOC
 ENTER FILENAME FOR CONET ADDITIONS: TEMCOT
```

Place sources in files TEMCOC and TECCOT

```
 ENTER FILENAME FOR PSSPLT RELAY CHARACTERISTIC DATA: TEMCOR

 NEXT AVAILABLE ADDRESSES ARE:
    CON  STATE     VAR   ICON
    124     44      17     13
 ENTER STARTING CON, STATE, VAR, ICON OR CARRIAGE RETURN
```

Start allocating arrays after those already in use

```
 OUT OF FILE DATA--SWITCH TO TERMINAL INPUT MODE

 OTHER MODELS USE:
  CONS      124-  140
  VARS       17-   19
  ICONS      13-   24


 SUMMARY OF MODELS READ:

 MISC:  LOADF  LODSHD NETFRQ
            2      1      1

 NEXT AVAILABLE ADDRESSES ARE:
    CON  STATE     VAR   ICON
    141     44      20     25
```

Summary of locations in use

```
 EDIT NEW CALLS INTO CONEC AND CONET--THEN COMPILE AND CLOAD4
```

Figure 14.49. Dialog for Adding More Raw Data (Sheet 1 of 2)

```
ACTIVITY? CHAN

NEXT AVAILABLE ADDRESSES ARE:
  CHANNEL    VAR    ICON
      25      20      25
ENTER STARTING CHANNEL, VAR, ICON INDICES OR CARRIAGE RETURN

ENTER OUTPUT CATEGORY:
 0 = EXIT            1 = ANGLE           2 = PELEC
 3 = QELEC           4 = ETERM           5 = EFD
 6 = PMECH           7 = SPEED           8 = XADIFD
 9 = ECOMP          10 = VOTHSG         11 = VREF
12 = BSFREQ         13 = VOLTAGE        14 = VOLT & ANG
15 = FLOW (P)       16 = FLOW (P&Q)     17 = FLOW (MVA)
18 = RELAY2 (R&X)   19 = VAR            20 = STATE
21 = MACH ITERM     22 = MACH APP IMP: 7
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 100 1
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 100 2
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 201
ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 0

ENTER OUTPUT CATEGORY:
 0 = EXIT            1 = ANGLE           2 = PELEC
 3 = QELEC           4 = ETERM           5 = EFD
 6 = PMECH           7 = SPEED           8 = XADIFD
 9 = ECOMP          10 = VOTHSG         11 = VREF
12 = BSFREQ         13 = VOLTAGE        14 = VOLT & ANG
15 = FLOW (P)       16 = FLOW (P&Q)     17 = FLOW (MVA)
18 = RELAY2 (R&X)   19 = VAR            20 = STATE
21 = MACH ITERM     22 = MACH APP IMP: 12
ENTER BUS NUMBER, 'IDENTIFIER': 150
ENTER BUS NUMBER, 'IDENTIFIER': 151
ENTER BUS NUMBER, 'IDENTIFIER': 200
ENTER BUS NUMBER, 'IDENTIFIER': 0

ENTER OUTPUT CATEGORY:
 0 = EXIT            1 = ANGLE           2 = PELEC
 3 = QELEC           4 = ETERM           5 = EFD
 6 = PMECH           7 = SPEED           8 = XADIFD
 9 = ECOMP          10 = VOTHSG         11 = VREF
12 = BSFREQ         13 = VOLTAGE        14 = VOLT & ANG
15 = FLOW (P)       16 = FLOW (P&Q)     17 = FLOW (MVA)
18 = RELAY2 (R&X)   19 = VAR            20 = STATE
21 = MACH ITERM     22 = MACH APP IMP: 0

NEXT AVAILABLE ADDRESSES ARE:
  CHANNEL    VAR    ICON
      31      20      25

ACTIVITY? SNAP SNU1

NUMBER OF ELEMENTS IN USE ARE:
  CONS STATES    VARS   ICONS CHANNELS
   140      43     19      24      30
ENTER NUMBER TO BE SAVED OR CARRIAGE RETURN FOR ABOVE VALUES

SNAPSHOT STORED IN FILE SNU1.SNP AT TIME = -0.017

ACTIVITY? STOP
```

Use activity CHAN to add more output channels

Channels 26-28 will be machine rotor speeds

Save new data

Must stop PSS®E to recompile and relink

Figure 14.50. Dialog for Adding More Raw Data (Sheet 2 of 2)

```
C--REPLACE IF (.NOT. IFLAG) STATEMENT IN ORIGINAL CONET FILE WITH THE FOLLOWING
C
      CALL NETFRQ
      CALL LOADF (    13,   124)
      CALL LOADF (    14,   127)
C
      IF (.NOT. IFLAG) GO TO 9000
C
C   NETWORK MONITORING MODELS
C
      CALL LODSHD(    15,   130,    17,    16)
```

Figure 14.51. Files Created by DYRE and CHAN in Making New Setup

Combining Automatic and Manual CONEC/CONET Sections

The combining of the old and new generated sections of CONET requires the use of the editor program. PSS®E must be stopped, and a Snapshot taken to preserve work done to date.

Because no user models or models being handled by subroutine CONEC are being used in this example, file TEMCOC can be ignored.

Figure 14.52, "Editing CONETs to Combine Old and New Setups" shows the completed CONET subroutine after TEMCOT has been inserted with the editor. The new CONEC and CONET subroutines must be incorporated into the executable code of PSS®E, in place of the previous versions, before any additional work is done on the new setup by relinking and reloading (see Section 14.2.11, "Compilation and Linking of CONEC/CONET").

```
      SUBROUTINE CONET
C
$INSERT COMON4.INS
C
      CALL NETFRQ
      CALL LOADF (    13,   124)
      CALL LOADF (    14,   127)
C
C   PLACE ABOVE CALLS BEFORE IFLAG TEST IN CONET
C
      IF (.NOT. IFLAG) GO TO 9000
C
C   NETWORK MONITORING MODELS
C   ADD FOLLOWING CALLS AFTER IT
C
      CALL LODSHD(    15,   130,    17,    16)
C
      IF (.NOT. IFLAG) GO TO 9000
C
C
 9000 CONTINUE
C
      RETURN
      END
```

Figure 14.52. Editing CONETs to Combine Old and New Setups

Recording of Simulation Setup Details

Both the executable code and the dynamics data arrays of PSS®E are now completely set up in accordance with the new requirements outlined in the section called "Added Modeling Requirements" and simulations may now be run with the new system representation. Before doing simulation runs, however, it is advisable to record full details of the simulation setup for future reference. A complete record of the setup is given by the following data:

1. The name of the initial condition power flow Saved Case File, SME1.

2. The name of the converted power flow Saved Case File, SME2.

3. The name of the initial condition or preinitial condition Snapshot File, SNU1.

4. The names of the CONEC and CONET subroutine source files, CC2 and CT2.

5. The number of the last CON, VAR, ICON, STATE, and channel used in the setup; 140, 19, 25, 43 and 30, respectively, in this example.

6. Complete printed reports from activities DOCU and DLST, as shown in Figure 14.53, “DOCU of New Models Only Rest Like Before (Figure 14.27, “Use of Activity DOCU to Review CON Values for Reasonableness (Sheet 2 of 2)”)” and Figure 14.54, “Listing of New Data by Activity DLST”, together with printed listings of the CONEC and CONET source files.

```
ACTIVITY? RSTR SNU1

SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT

SNAPSHOT SNU1.SNP WAS SAVED ON FRI FEB 18, 1994  11:09

NUMBER OF ELEMENTS RESTORED:
  CONS STATES   VARS  ICONS CHANNELS
   140     43     19     24     30

ACTIVITY? LOFL

ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? CASE SME2

SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT

CASE SME2.SAV WAS SAVED ON MON FEB 14, 1994  17:05

ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? FACT

    5 DIAGONAL AND     5 OFF-DIAGONAL ELEMENTS

ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? RTRN

ACTIVITY? DOCU CN  <---------------------------- Document CONEC models

ENTER OUTPUT DEVICE CODE:
 0 FOR NO OUTPUT        1 FOR CRT TERMINAL
 2 FOR A FILE           3 FOR QMS PS2000
 4 FOR QMS_PS800        5 FOR HARD COPY TERMINAL
 6 FOR ALTERNATE SPOOL DEVICE: 1
ENTER 0 FOR REPORTING MODE, 1 FOR DATA CHECKING MODE: 0

ACTIVITY? DOCU CT  <---------------------------- Document CONET models

ENTER OUTPUT DEVICE CODE:
 0 FOR NO OUTPUT        1 FOR CRT TERMINAL
 2 FOR A FILE           3 FOR QMS PS2000
 4 FOR QMS_PS800        5 FOR HARD COPY TERMINAL
 6 FOR ALTERNATE SPOOL DEVICE: 1
ENTER 0 FOR REPORTING MODE, 1 FOR DATA CHECKING MODE: 0

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI FEB 18, 1994  11:10
SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT

                     REPORT FOR CONET MODELS AT ALL BUSES

                             *** CALL NETFRQ ***


                    *** CALL LOADF(   13,   124) ***

                   BUS   NAME  BSKV  ICON   C O N ' S
                   150 LOAD    33.0    13   124-  126

                       I EXP     P EXP     Q EXP
                      1.6000    0.0000    0.0000


                    *** CALL LOADF(   14,   127) ***

                   BUS   NAME  BSKV  ICON   C O N ' S
                   151 LOAD    3.30    14   127-  129

                       I EXP     P EXP     Q EXP
                      1.6000    0.0000    0.0000


               *** CALL LODSHD(   15,  130,    17,    16) ***

        BUS   NAME  BSKV  ICON    C O N ' S   V A R ' S     ICON'S
        151 LOAD    3.30    15   130-  140     17-   19    16-   24

          HZ-1        T1      FRAC-1      HZ-2        T2     FRAC-2
         59.700     0.050     0.500    59.500     0.050     0.300

               HZ-3       T3      FRAC-3       TB    EXCL MVAR
              59.000     0.050     0.200     0.085      0.0
```

Figure 14.53. DOCU of New Models Only Rest Like Before (Figure 14.27, “Use of Activity DOCU to Review CON Values for Reasonableness (Sheet 2 of 2)”)

```
ACTIVITY? DLST

ENTER OUTPUT DEVICE CODE:
 0 FOR NO OUTPUT        1 FOR CRT TERMINAL
 2 FOR A FILE           3 FOR QMS PS2000
 4 FOR QMS_PS800        5 FOR HARD COPY TERMINAL
 6 FOR ALTERNATE SPOOL DEVICE: 1
ENTER CON RANGE: 124 140
ENTER VAR RANGE: 17 19
ENTER STATE RANGE: 0
ENTER ICON RANGE: 13 25
ENTER OUTPUT CHANNEL RANGE: 25 30

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI FEB 18, 1994  11:11
SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT


CONS:

  124:  1.600         125: 0.0000         126: 0.0000         127:  1.600
  128: 0.0000         129: 0.0000         130:  59.70         131: 0.5000E-01
  132: 0.5000         133:  59.50         134: 0.5000E-01     135: 0.3000
  136:  59.00         137: 0.5000E-01     138: 0.2000         139: 0.8500E-01
  140: 0.0000


VARS:

   17: 0.0000          18: 0.0000          19: 0.0000


ICONS:

   13:   150           14:   151           15:   151           16:     0
   17:     0           18:     0           19:     0           20:     0
   21:     0           22:     0           23:     0           24:     0
   25:     0


OUTPUT CHANNELS:

#:ADDR    25: 24001       26: 24002      27: 24004      28:116002      29:116003
       SPD DEVIAT'N    SPD DEVIAT'N   SPD DEVIAT'N   BUS FREQ DEV   BUS FREQ DEV
      BUS  100 MC 1   BUS  100 MC 2  BUS  201 MC 1        150            151
IDENT  SPD1HYDRO       SPD2HYDRO      SPD1STEAM      FRQ-LOAD       FRQ-LOAD
VALUE   0.00000         0.00000        0.00000        0.00000        0.00000

#:ADDR    30:116004
       BUS FREQ DEV
            200
IDENT  FRQ-STEAM
VALUE   0.00000
```

Figure 14.54. Listing of New Data by Activity DLST

Items 1 through 4 are recorded for this example in Table 14.4, “Files to be Used in First Dynamic Simulation Setup Example”. Item 5 is stored in the Snapshot. It is strongly recommended that similar tabulations, together with the printed reports of item 6 be stored together in a notebook for *every* dynamic simulation setup involved in an engineering study. *All* data in items 1 through 6 are needed for a complete reconstruction of a simulation setup, and all are needed for troubleshooting work.

Simulation Run With New Setup

The new setup may now be used to make new simulation runs. Figure 14.55, “Simulation Run with New Setup () to Observe Action of Load Shedding Relay at Bus 151 (Sheet 1 of 2)” shows the dialog for a simulation run, based on the new setup, in which the 10-MVA generator (carrying 8 MW) is tripped off the line at bus 201, leaving the small Boondocks Power and Light system with 20 MW of load (see Figure 14.5, “Data for

Small Example System as Established in Power Flow Cases SME1 and SME2"), and 12.02 MW of generation from the three remaining hydro units at bus 100. The purpose of the simulation run is to check that the load shedding relay settings specified in Underfrequency Load Shedding Relay Model (LDSHD) Model Data Sheet will enable the system to recover with the essential load still energized and without catastrophic voltage and frequency excursions. Figure 14.55, "Simulation Run with New Setup () to Observe Action of Load Shedding Relay at Bus 151 (Sheet 1 of 2)" shows by messages that the first and second stages of load shedding pick up, and that the corresponding feeder circuit breakers open at $t = 0.333$ and $t = 0.442$, respectively. This removes (0.5 + 0.3) per unit of the 15-MW load (that is 12 MW) at bus 151, leaving the system with a nominal 8 MW of load (3 MW remaining at bus 151 and 5 MW at bus 150); the shaft speed and bus frequency channels then indicate rapid recovery of frequency.

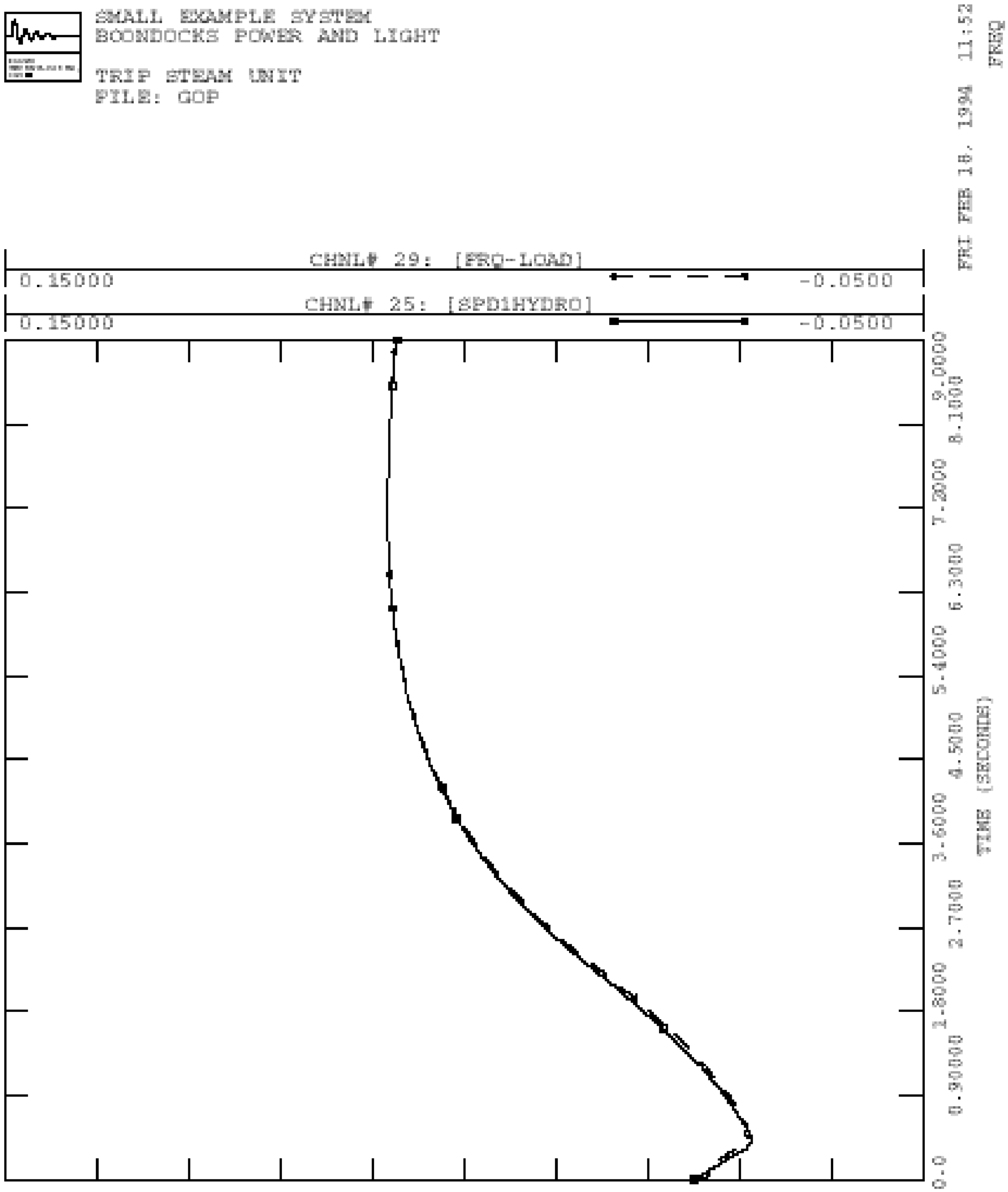
The results of this simulation are plotted in Figure 14.57, "Simulation Run with New Setup (Sheet 1 of 4)" through Figure 14.60, "Simulation Run with New Setup (Sheet 4 of 4)". Figure 14.57, "Simulation Run with New Setup (Sheet 1 of 4)" shows the shaft speed of one of the hydro units and frequency at bus 150. The slight difference is due to the five time step filter time constant of the bus frequency detector model, BUSFRQ. The load shedding certainly reverses the decline of frequency and, because it leaves a 12-MW hydro turbine output available for 8 MW (nominal) of load, it produces a major overfrequency as the hydro governors run their power back from their initial power output of 0.8 per unit of rating to 0.6 per unit. The hydro turbine power response is shown in Figure 14.59, "Simulation Run with New Setup (Sheet 3 of 4)". Figure 14.58, "Simulation Run with New Setup (Sheet 2 of 4)" shows hydro unit terminal voltage jumps from below unity to over 1.25 per unit when load is shed. This rapid rise of voltage, in conjunction with the load real power characteristic (60% constant current and 40% constant admittance, as shown in Figure 14.3, "Preparation of Power Flow Case for Use in Dynamic Simulation (Sheet 1 of 2)") produces a rapid increase in load on remaining feeders when the first stage of load is shed. Figure 14.60, "Simulation Run with New Setup (Sheet 4 of 4)" shows how the output of the hydro plant is split between lines 100-150 and 200-150 after tripping of the steam unit.

```
ACTIVITY? STRT              Pick up Snapshot SNU1 and Saved Case SME2 before this

    PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI FEB 18, 1994  11:12
 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 INITIAL CONDITION LOAD FLOW USED  1 ITERATIONS

 --------------------------MACHINE INITIAL CONDITIONS--------------------------
 X------ BUS -----X ID  ETERM   EFD    POWER    VARS   P.F.  ANGLE   ID     IQ
   100 HYDRO   33.0  1 1.0353 1.7821    4.01     0.48 0.9928  41.36 0.5880 0.5247
   100 HYDRO   33.0  2 1.0353 1.7821    4.01     0.48 0.9928  41.36 0.5880 0.5247
   100 HYDRO   33.0  3 1.0353 1.7821    4.01     0.48 0.9928  41.36 0.5880 0.5247
   201 STEAM   3.30  1 1.0168 1.8556    8.00     2.38 0.9585  40.00 0.6560 0.4934

 INITIAL CONDITIONS CHECK O.K.

 ENTER CHANNEL OUTPUT FILENAME: GOP
 ENTER SNAPSHOT FILENAME: SNU1        Save initialized setup in SNU1,
                                      replacing previous uninitialized setup
 NUMBER OF ELEMENTS IN USE ARE:
   CONS STATES   VARS  ICONS CHANNELS
    140     43     19     24     30
 ENTER NUMBER TO BE SAVED OR CARRIAGE RETURN FOR ABOVE VALUES


 SNAPSHOT STORED IN FILE SNU1.SNP AT TIME = -0.017

 ACTIVITY? RUN                        Predisturbance run

 AT TIME = -0.017 ENTER TPAUSE, NPRT, NPLT, CRTPLT: 0 2 2
 CHANNEL OUTPUT FILE IS GOP
    TIME  ANG1HYDRO     ANG2HYDRO     ANG1STEAM     P 1HYDRO      P 2HYDRO

 ACTIVITY? ALTR

 SMALL EXAMPLE SYSTEM
 BOONDOCKS POWER AND LIGHT

 TIME =   0.0000                      Activity ALTR to trip all
                                      generation at bus 201
 ENTER CHANGE CODE:
  0 = NO MORE CHANGES         1 = OUTPUT CHANNEL DATA
  2 = CONS                    3 = VARS
  4 = CRT PLOT CHANNELS       5 = ICONS
  6 = SOLUTION PARAMETERS     7 = STATES
  8 = CASE HEADING: 0                     No dynamics array changes

 NETWORK DATA CHANGES (1=YES, 0=NO)? 1
 PICK UP NEW SAVED CASE (1=YES, 0=NO)? 0

 ENTER CHANGE CODE:
  0 = EXIT ACTIVITY                    1 = BUS DATA
  2 = GENERATOR DATA                   3 = BRANCH DATA
  4 = TRANSFORMER DATA                 5 = AREA INTERCHANGE DATA
  6 = TWO-TERMINAL DC LINE DATA        7 = SOLUTION PARAMETERS
  8 = CASE HEADING                     9 = SWITCHED SHUNT DATA
 10 = IMPEDANCE CORRECTION TABLES     11 = MULTI-TERMINAL DC DATA
 12 = ZONE DATA                       13 = AREA TRANSACTIONS DATA: 1    Select bus 201

 ENTER BUS NUMBER (0 FOR NEW CHANGE CODE, -1 TO EXIT): 201

 BUS DATA FOR BUS   201 [STEAM   3.30]:
   CODE   PLOAD   QLOAD      S H U N T      I L O A D     Y L O A D
 OLD  2    0.00    0.00    0.00    0.00     0.0    0.0     0.0    0.0 CHANGE IT? 1
 ENTER CODE, PLOAD, QLOAD, G, B, IP, IQ, YP, YQ
1
 NEW  1    0.00    0.00    0.00    0.00     0.0    0.0     0.0    0.0
                                                                Status to 1 to ignore
     AREA    VOLT    ANGLE   NAME      BASVLT LOSZON            all generation
 OLD    1  1.0168     3.50 STEAM        3.300      1 CHANGE IT? 0
```

Figure 14.55. Simulation Run with New Setup (Section 14.5, "Use of CONET in System Modeling") to Observe Action of Load Shedding Relay at Bus 151 (Sheet 1 of 2)

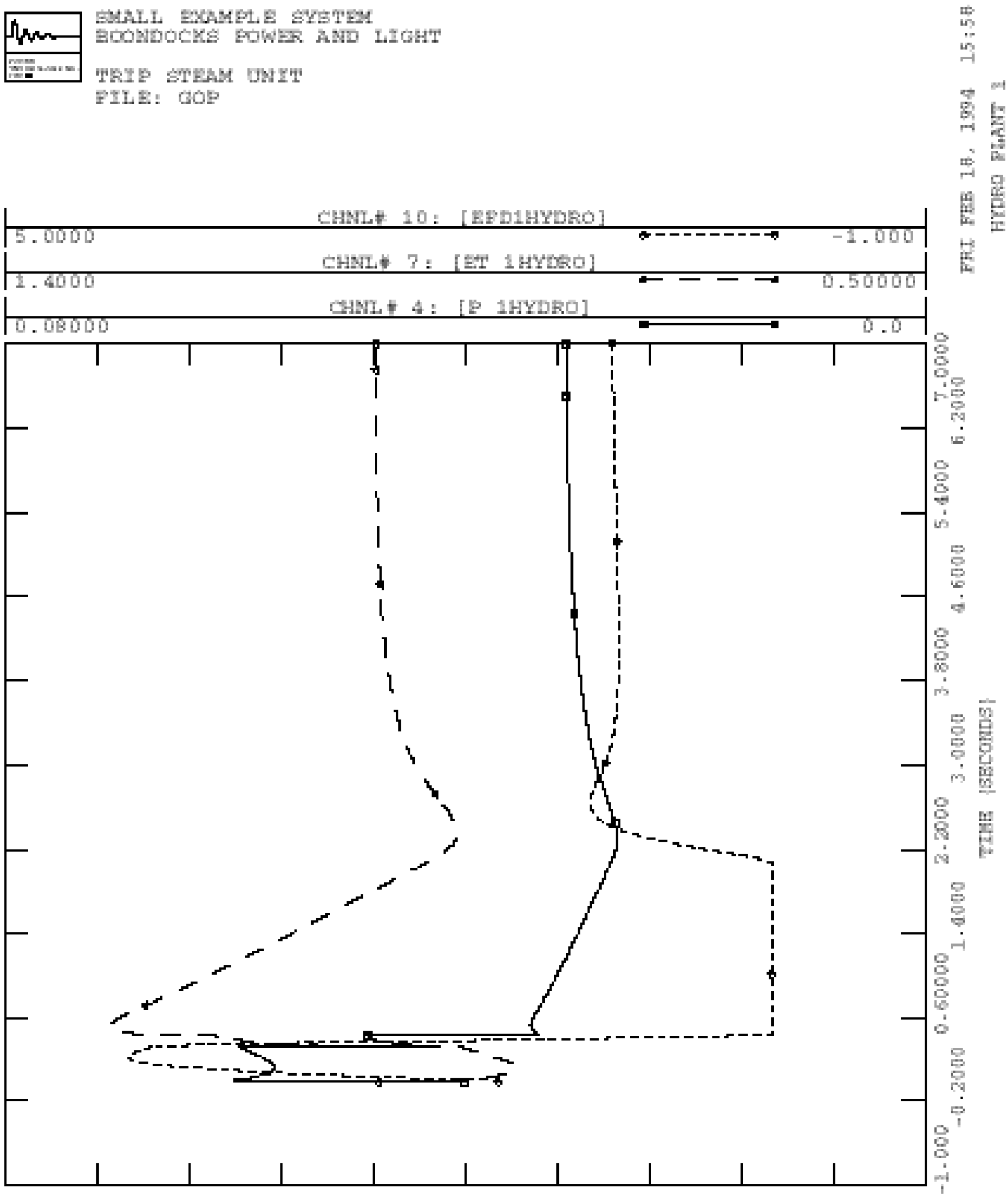
```
ENTER BUS NUMBER (0 FOR NEW CHANGE CODE, -1 TO EXIT): <---- Reorder because a bus type
                                                            code was changed
    5 DIAGONAL AND      5 OFF-DIAGONAL ELEMENTS

ACTIVITY? RUN <------------------------------------------- Run for 5 sec

AT TIME =   0.000 ENTER TPAUSE, NPRT, NPLT, CRTPLT: 5 30 3
CHANNEL OUTPUT FILE IS GOP
   TIME  ANG1HYDRO     ANG2HYDRO     ANG1STEAM      P 1HYDRO      P 2HYDRO
  0.000    41.360        41.360       0.00000       0.60132E-01   0.60132E-01
          P 1STEAM     ET 1HYDRO     ET 2HYDRO      ET 1STEAM     EFD1HYDRO
   6      0.00000       0.95017       0.95017       0.00000        1.7821
         EFD2HYDRO     EFD1STEAM     PM 1HYDRO      PM 2HYDRO     PM 1STEAM
  11       1.7821       0.00000       0.80148       0.80148       0.00000
           V-LOAD        V-LOAD        V-STEAM      P  100-  200  Q  100-  200
  16      0.94114       0.89562       0.94460        4.5152       -0.61377
         P  100-  150  Q  100-  150  P  200-  150  Q  200-  150  SPD1HYDRO
  21       13.524        3.5345        4.5106        2.0234       0.45186E-09
         SPD2HYDRO     SPD1STEAM     FRQ-LOAD      FRQ-LOAD      FRQ-STEAM
  26      0.45186E-09   0.00000       0.50281E-08   0.43926E-08   0.49347E-08

LODSHD AT BUS   151 STAGE 1 PICKUP TIMER STARTED AT TIME =  0.200 FREQ = 59.696   Messages from
                                                                                  LODSHD model
LODSHD AT BUS   151 STAGE 1 BREAKER TIMER STARTED AT TIME =  0.250                indicating
  0.250    18.270        18.270       0.00000       0.58129E-01   0.58129E-01     disconnection
   6      0.00000       0.92897       0.92897       0.00000        4.1877         of load
  11       4.1877       0.00000       0.79909       0.79909       0.00000
  16      0.91945       0.87496       0.92283        4.3647       -0.55138
  21       13.074        3.4432        4.3602        1.9479       -0.84376E-02
  26     -0.84376E-02   0.00000      -0.66198E-02  -0.65662E-02  -0.66253E-02

LODSHD AT BUS   151 STAGE 2 PICKUP TIMER STARTED AT TIME =  0.308 FREQ = 59.486

LODSHD AT BUS   151 STAGE 1 BREAKER TIMER TIMED OUT AT TIME =  0.333
    50.00 PERCENT OF INITIAL LOAD SHED
       7.5 MW AND    4.0 MVAR (NOMINAL) SHED. VOLT = 0.9020 FREQUENCY = 59.430

    5 DIAGONAL AND      5 OFF-DIAGONAL ELEMENTS

LODSHD AT BUS   151 STAGE 2 BREAKER TIMER STARTED AT TIME =  0.358

LODSHD AT BUS   151 STAGE 2 BREAKER TIMER TIMED OUT AT TIME =  0.442
    30.00 PERCENT OF INITIAL LOAD SHED
       4.5 MW AND    2.4 MVAR (NOMINAL) SHED. VOLT = 1.1855 FREQUENCY = 59.272

    5 DIAGONAL AND      5 OFF-DIAGONAL ELEMENTS
  0.483   -39.425       -39.425       0.00000       0.34178E-01   0.34178E-01
   6      0.00000        1.2923        1.2923       0.00000       0.00000
  11      0.00000       0.00000       0.79444       0.79444       0.00000
  16       1.3532        1.3139        1.3554        2.5666        -4.3283
  21       7.6868       -2.1124        2.5655        1.1030       -0.12384E-01
  26     -0.12384E-01   0.00000      -0.11382E-01  -0.11369E-01  -0.11384E-01

  5.000    2789.7        2789.7       0.00000       0.30796E-01   0.30796E-01
   6      0.00000        1.0343        1.0343       0.00000        1.0074
  11       1.0074       0.00000       0.74026       0.74026       0.00000
  16       1.0890        1.0573        1.0909        2.3130        -3.1204
  21       6.9259       -1.8077        2.3119       0.64822       0.61197E-01
  26      0.61197E-01   0.00000       0.60943E-01   0.60942E-01   0.60943E-01

ACTIVITY? RUN <---------------------------------- Go on another 4 sec to see hydro governor action

AT TIME =   5.000 ENTER TPAUSE, NPRT, NPLT, CRTPLT: 9 60 15
CHANNEL OUTPUT FILE IS GOP
   TIME  ANG1HYDRO     ANG2HYDRO     ANG1STEAM      P 1HYDRO      P 2HYDRO
  5.000    2789.7        2789.7       0.00000       0.30796E-01   0.30796E-01
          P 1STEAM     ET 1HYDRO     ET 2HYDRO      ET 1STEAM     EFD1HYDRO
   6      0.00000        1.0343        1.0343       0.00000        1.0074
         EFD2HYDRO     EFD1STEAM     PM 1HYDRO      PM 2HYDRO     PM 1STEAM
  11       1.0074       0.00000       0.74026       0.74026       0.00000
           V-LOAD        V-LOAD        V-STEAM      P  100-  200  Q  100-  200
  16       1.0890        1.0573        1.0909        2.3130        -3.1205
         P  100-  150  Q  100-  150  P  200-  150  Q  200-  150  SPD1HYDRO
  21       6.9259       -1.8079        2.3118       0.64824       0.61197E-01
         SPD2HYDRO     SPD1STEAM     FRQ-LOAD      FRQ-LOAD      FRQ-STEAM
  26      0.61197E-01   0.00000       0.60943E-01   0.60942E-01   0.60943E-01

ACTIVITY? STOP
```

Figure 14.56. Simulation Run with New Setup (Section 14.5, “Use of CONET in System Modeling”) to Observe Action of Load Shedding Relay at Bus 151 (Sheet 2 of 2)



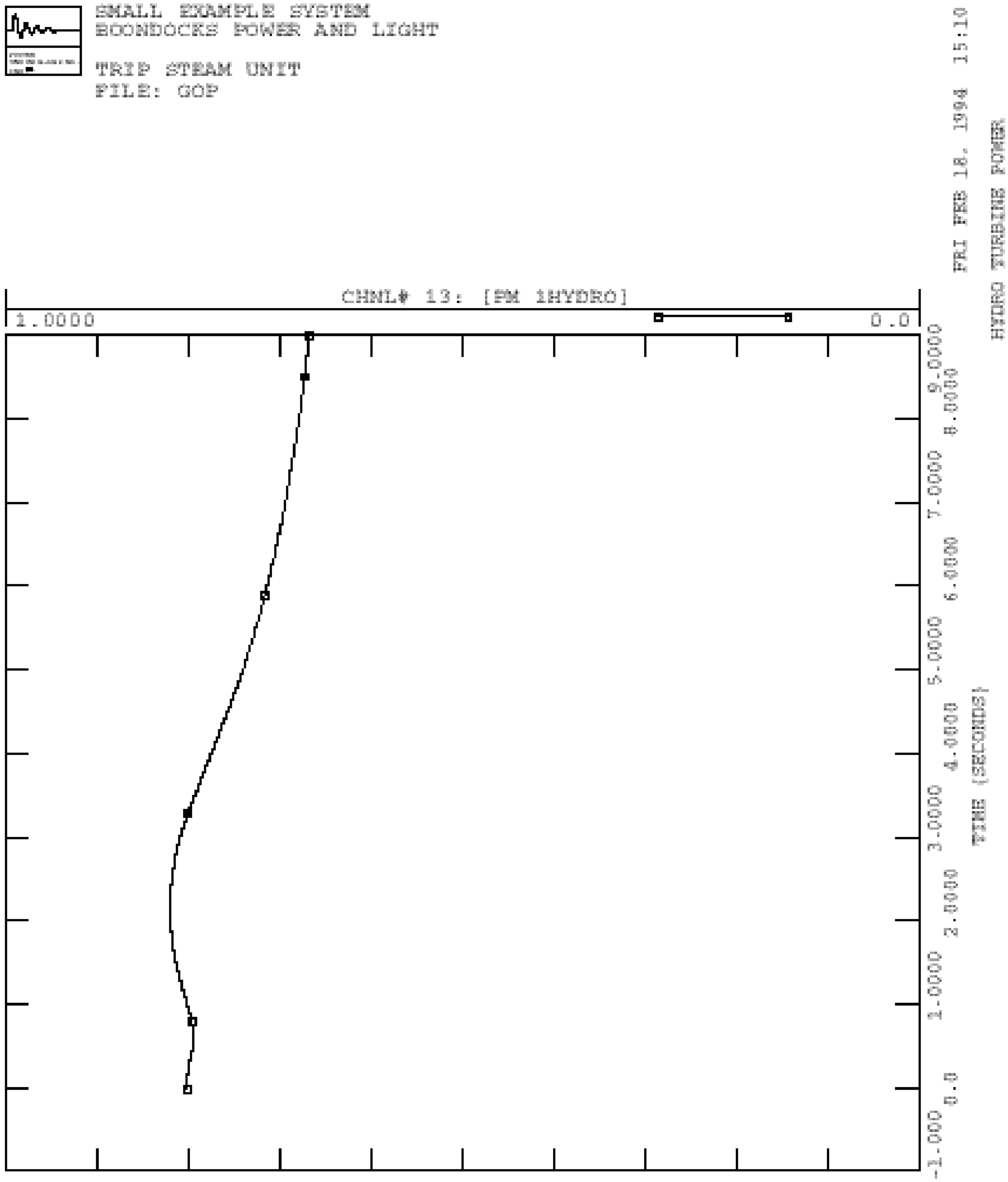
a. Frequency

Figure 14.57. Simulation Run with New Setup (Sheet 1 of 4)



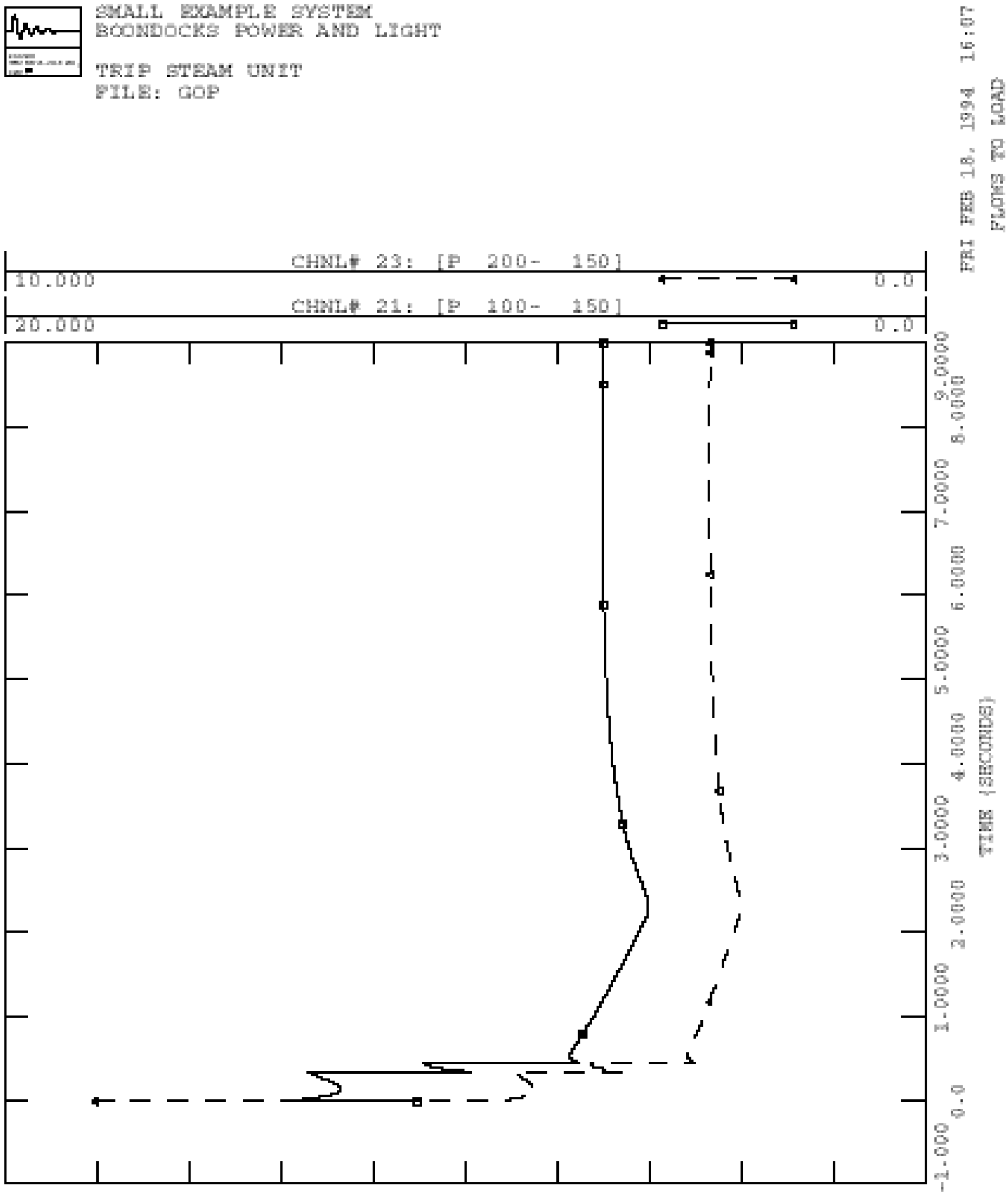
b. Hydro Plant 1

Figure 14.58. Simulation Run with New Setup (Sheet 2 of 4)



c. Hydro Turbine Power

Figure 14.59. Simulation Run with New Setup (Sheet 3 of 4)



d. Flows to Load

Figure 14.60. Simulation Run with New Setup (Sheet 4 of 4)

Chapter 15
Generator Modeling

15.1. Introduction

The dynamic simulation model library of PSS®E represents a wide, and constantly growing, variety of electromechanical equipment. New models are added to the library constantly as new types of equipment are developed by the manufacturers, as research work provides improved information on existing equipment, and as PSS®E user needs evolve. In addition to calling on the PSS®E library models, users may create their own models to handle the simulation of special items of equipment. The coding of model subroutines is discussed in the *PSS®E Program Operation Manual*.

15.2. Standards on Equipment Modeling and Data Exchange

While there are no nationally or internationally sanctioned standards on the modeling of power system equipment or on the exchange of data between simulation programs, there are several data file formats that have become quite widely used and recognized as convenient vehicles for mechanizing the burdensome task of building up databases for simulations of interconnected systems. The PSS®E Dynamics Data File format may reasonably be regarded as one of these widely recognized formats.

The PSS®E package includes its own data file formats, and provides interface programs for several other data formats (see *PSS®E Program Operation Manual*). PTI endorses the recommendations of the IEEE regarding the exchange of power flow and dynamic simulation data. The IEEE recommendations reflect the views of many of the electric utility companies, equipment manufacturers, and software suppliers presently active in North America. These recommendations are published in the following sources:

1. "Computer Representation of Excitation Systems," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-87, No. 6, pp. 1460-1468, 1968 (Committee Report).

2. "Dynamic Models for Steam and Hydro Turbines in Power System Studies," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-92, pp. 1904-1915, 1973 (Committee Report).

3. "Procedures for the Exchange of Power Plant and Load Data for Synchronous Stability Studies," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 7, pp. 3229-3245, 1981 (Committee Report).

4. "Excitation System Models for Power System Stability Studies," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 2, pp. 494-509, 1981 (Committee Report).

The recommendations given in these reports represent stages in the constant evolution of power system equipment modeling. They are not, and cannot be, a final statement of practice because the designs of new equipment will continue to change, and the modeling needs will change accordingly, as the equipment technology advances. These references provide a base for the establishment of system dynamic simulation setups, but leave a constant requirement for the introduction of new models to handle new equipment and study situations where the common viewpoint taken by the IEEE Committees is not applicable. The PSS®E library includes models corresponding to most of those included in references 1, 2, and 3, but also includes many models that are not covered in these references.

The selection of the best model for a given study must be made by the user of PSS®E. The models corresponding to IEEE recommendations have the advantage, in some situations, in that data is already available for them in existing computer data files. However, in other situations the models may be insufficiently detailed or unable to represent an effect of specific interest, regardless of the availability of data.

15.3. Rules for Using PSS®E Equipment Models

15.3.1. Memory Reference

Each model is a Fortran subroutine for which the function is to pick up equipment parameter values from the CON array, terminal conditions from the system condition arrays, state variables from the STATE array, and to place time derivative values into the DSTATE array. The arguments of each model's subroutine call direct the model to specific areas of the CON, system condition, and STATE and DSTATE arrays.

The model CALL for each individual unit of equipment must refer to a unique area of the STATE, VAR and system condition arrays, but CALLs for identical units may refer to the same areas in the CON and ICON arrays.

15.3.2. Model Calling Sequence

In order to properly coordinate the outputs and inputs of the library models, they should be called from CONEC in the following order:

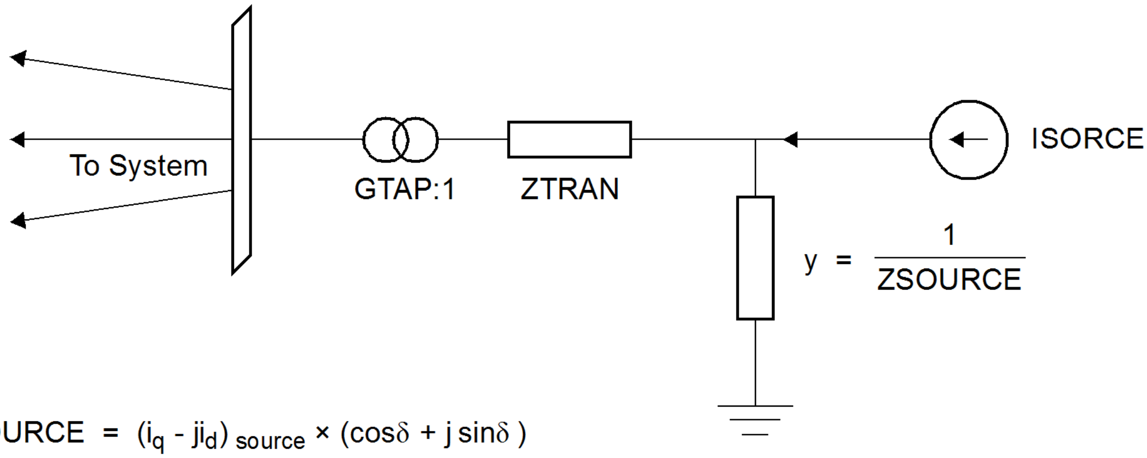
1. Generator models.
2. Current compensating models.
3. Excitation stabilizer models.
4. Excitation system models.
5. Turbine-governor models.
6. Miscellaneous models.

15.4. Generator Models

15.4.1. Source Impedance

The PSS®E generator models range from the simplest to highly elaborate representations of the synchronous machine. All models share certain common features, however. All generator models ultimately present the electric transmission network with a positive sequence source voltage where instantaneous amplitude and phase are known and where current is to be determined. The equivalent circuit used to represent the generator as a boundary condition in the network solution is described in Dynamic Boundary Conditions and Figure Time Regimes Considered in Power System Simulations. Although, physically, a generator is best thought of as a voltage source behind the step-up transformer and a dynamic impedance, it is represented in PSS®E by a Norton equivalent in which the voltage source is replaced by an equivalent current source, ISORCE. The determination of the Norton source current in the principal generator models is illustrated in Figure 15.1, "Generator Model Equivalent Current Source and Norton Equivalent Circuit".

Rotor flux linkage transients and magnetic saturation are the principal factors affecting the dynamic behavior of synchronous machines in the perturbation frequency bandwidth, 0 to about 10 Hz, covered by PSS®E dynamic simulation. The magnitude and phase of the source current are determined at any instant as a function of the instantaneous values of generator state variables (i.e., rotor circuit flux linkages, shaft speed, and rotor angle). The value of the generator's effective dynamic impedance, ZSORCE, may be either its transient or subtransient impedance, depending on which dynamic model is chosen to represent the behavior of rotor circuit flux linkages.



$$ISOURCE = (i_q - j i_d)_{source} \times (\cos\delta + j\sin\delta)$$

For GENROU, GENSAL, GENDCO, GENROE, GENSAE:

$$(i_q - j i_d)_{source} = \frac{(\Psi d'' + j\Psi q'')\frac{\omega}{\omega_o}}{ZSOURCE}$$

For GENCLS:

$$(i_q - j i_d)_{source} = \frac{0 + jEFD}{ZSOURCE}$$

Figure 15.1. Generator Model Equivalent Current Source and Norton Equivalent Circuit

The theoretical background on the modeling of synchronous machines in conjunction with the interconnecting electrical network is outlined in these references:

1. "Structure in the Computation of Power System Nonlinear Dynamical Response," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-88, pp. 1-6, 1969, (J.M. Undrill).

2. "FACE Multimachine Power System Simulator Program, IEEE PICA Conference Record, 1969, (D.N. Ewart, R.P. Schulz).

3. "Equipment and Load Modeling in Power System Dynamic Simulation," U.S. Energy Research & Development Agency Publication CONF 750867, pp. 394-418, (J.M. Undrill).

The generator parameters ZSORCE, GENTAP, and ZTRAN must be included in the corresponding arrays of the power flow case used as the base for the dynamic simulation. If the generator step-up transformer is represented as part of the transmission network, the values of GENTAP and ZTRAN should be left with default values of unity and zero, respectively.

15.4.2. Generator Rotor Modeling

The PSS®E library includes a family of generator models, as summarized in Table 15.1, "Summary of Generator Models in Terms of Data Used ", that allows generator rotor effects to be modeled in different levels of detail depending upon study requirements, availability of data, and users' preferences. Table 15.1, "Summary of

Generator Models in Terms of Data Used ” summarizes the standard generator models in terms of effects modeled and data requirements.

Table 15.1. Summary of Generator Models in Terms of Data Used

Reactance and Time Constants Used	Model				
	GENSAL and GENSAE	GENROU and GENROE	GENDCO	GENTRA	GENCLS
X_d	✔	✔	✔	✔	✔
X_q	✔	✔	✔	✔	
X'_d	✔	✔	✔	✔	✔
X'_q		✔	✔		
X''_d	✔	✔	✔		
X''_q	* [a]	*	*		
X_l	✔	✔	✔	✔	
T'_{do}	✔	✔	✔	✔	
T'_{qo}		✔	✔		
T''_{do}	✔	✔	✔	✔	
T''_{qo}	✔	✔	✔	✔	
Saturation Factors	✔	✔	✔	✔	
T_a			✔		

[a] * X''_q is assumed to be equal to X''_d.

Table 15.2, “Generator Rotor Transfer Functions” summarizes the operational impedances used to represent the rotor flux dynamics, and Figure 15.2, “Electromagnetic Model of Salient Pole Generator” through Figure 15.5, “Electromagnetic Model of Salient Pole Generator Considering Field Winding Transients Only (Model GENTRA)” show the corresponding transfer function block diagrams. All synchronous machine models use the generator open-circuit magnetization curve as their source of data for representing saturation.

Figure 15.6, “Typical Generator Open-Circuit Saturation Curves” shows typical magnetization curves in per-unit form and Figure 15.7, “Definition of Saturation Factor, *S*, for Entry as Generator Data” defines two *S* parameters used to codify the magnetization curves for computer modeling.

The generator rotor electromagnetic models, except GENCLS, inherently represent both steady-state and dynamic machine properties. The steady-state properties of greatest importance are the initial condition (t^-) values of flux linkages and of the per-unit field voltage, E_{fd}, needed to maintain a given real and reactive power loading. These are determined by the machine reactances and the modeling of saturation. The dynamic effects of greatest importance are the development of synchronizing and damping torques where instantaneous magnitudes during nonsteady conditions are different from those existing in the steady state. These effects are determined by the relative values of the synchronous, transient, and subtransient reactances, and by the rotor circuit time constants. If they are used with valid values for all of their data models, GENSAL, GENROU, GENSAE, GENROE, and GENDCO are an inherently correct representation of electromagnetic synchronizing and damping effects over the entire 0 to 10 Hz bandwidth to which PSS®E is applicable. No limit exists on the elapsed time period that these three models can simulate.

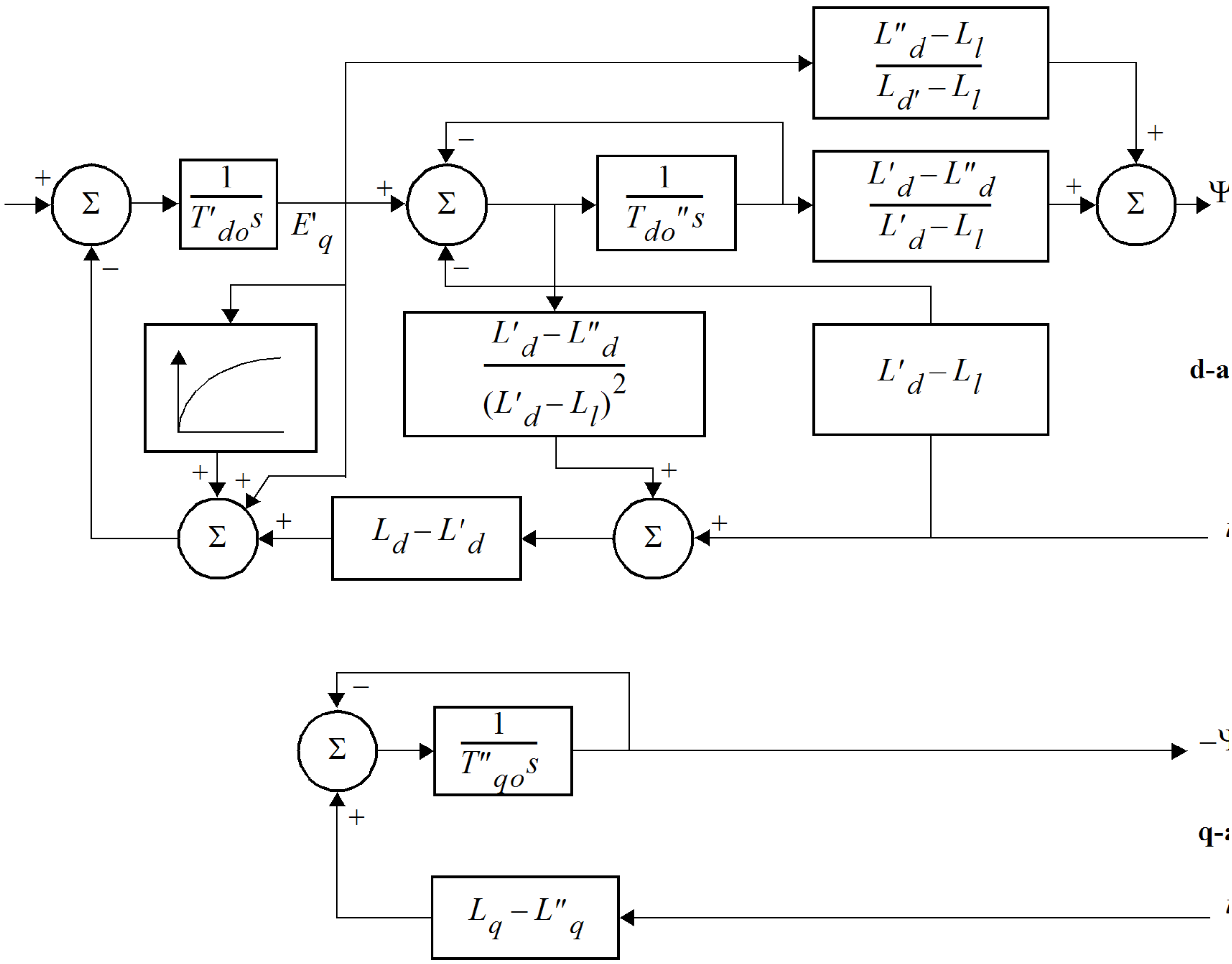
Models GENTRA and GENCLS represent synchronous machines at a more empirical and less accurate level than the three more complete models. GENTRA is included in PSS®E solely for compatibility with older stability analysis programs that used its level of representation; its use is not recommended by PTI. GENTRA will usually represent transient synchronizing torque effects reasonably accurately during the first swing of rotor angle after a simple short circuit fault, but it does not give adequate representation of damping effects.

The GENCLS model is intended to be used primarily as an effective short circuit current source in setting up approximate equivalents of segments of large interconnected power systems that are far removed from the area of specific interest.

Table 15.2. Generator Rotor Transfer Functions

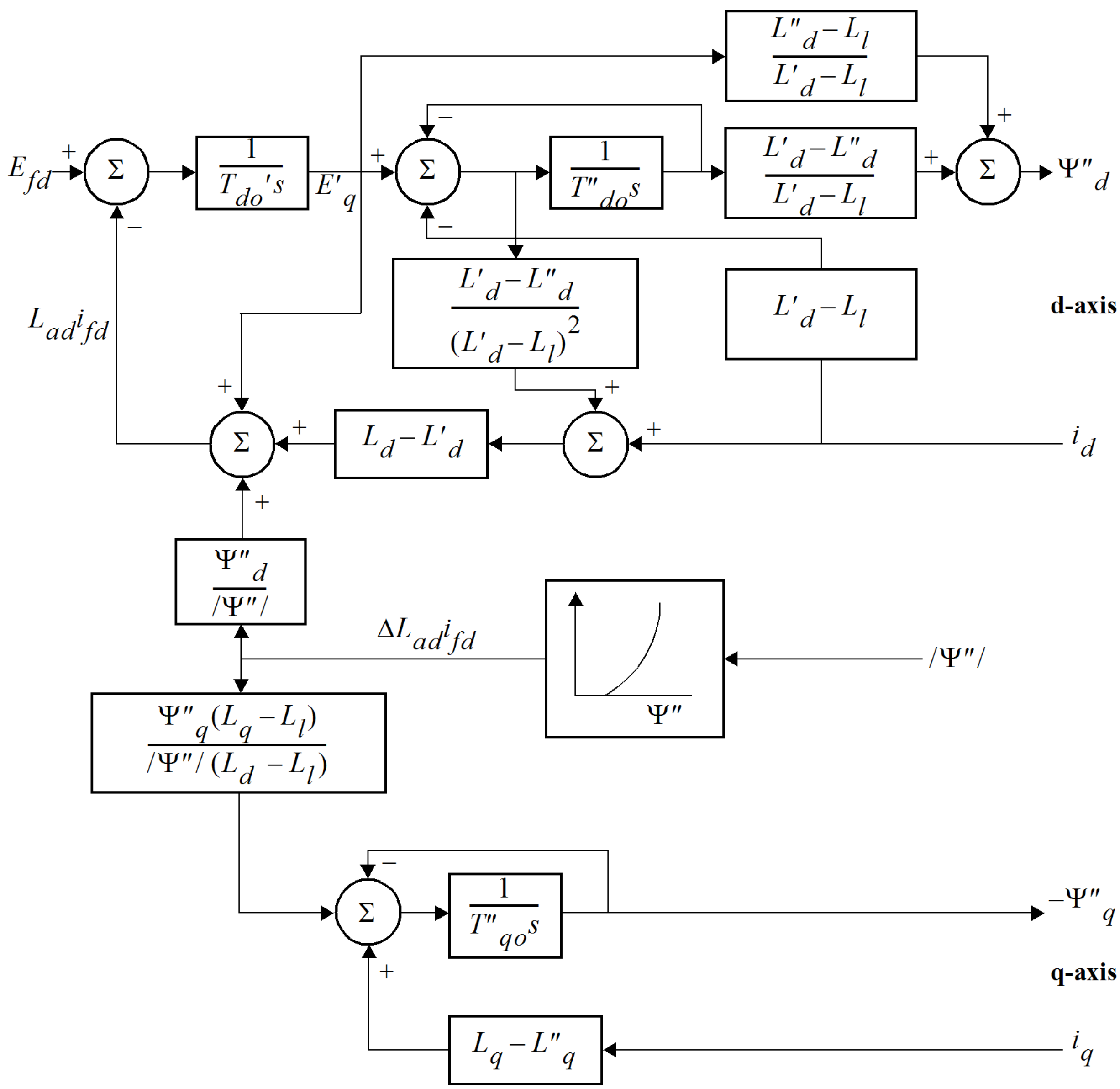
Model	GENSAL* [a]	GENROU**, GENDCO	GENTRA	GENCLS
Machine type	Salient pole	Solid rotor	Laminated rotor	Classical
d-axis rotor circuits	Field plus one amortisseur	Field plus one iron circuit	Field winding only	None
q-axis rotor circuits	One amortisseur	Two iron circuits	None	None
$L_d(s)$	$\frac{L_d\left(1 + T'_{do}\frac{L'_d}{L_d}s\right)\left(1 + T''_{do}\frac{L''_d}{L'_d}s\right)}{(1 + T'_{do}s)\,(1 + T''_{do}s)}$	As for GENSAL	$\frac{L_d\left(1 + \frac{L'_d}{L_d}T'_{do}s\right)}{(1 + T'_{do}s)}$	N/A
$L_q(s)$	$\frac{L_q\left(1 + \frac{L''}{L_q}T''_{qo}s\right)}{(1 + T''_{qo}s)}$	$\frac{L_q\left(1 + \frac{L'_q}{L_q}T'_{qo}s\right)\left(1 + \frac{L''}{L'_q}T''_{qo}s\right)}{(1 + T'_{qo}s)\,(1 + T''_{qo}s)}$	L_q	N/A
Saturation	*d*-axis mutual inductance as a function of E'_q	*d*- and *q*-axis mutual inductances as a function of ψ''	As for GENSAL	None

[a]GENSAE – same as GENSAL except saturation of *d*- and *q*-axis mutual inductances as an exponential function of ψ'' .
** GENROE – same as GENROU except saturation of *d*- and *q*-axis mutual inductances as an exponential function of ψ'' .



a. Model

Figure 15.2. Electromagnetic Model of Salient Pole Generator



b. Model

Figure 15.3. Electromagnetic Model of Salient Pole Generator

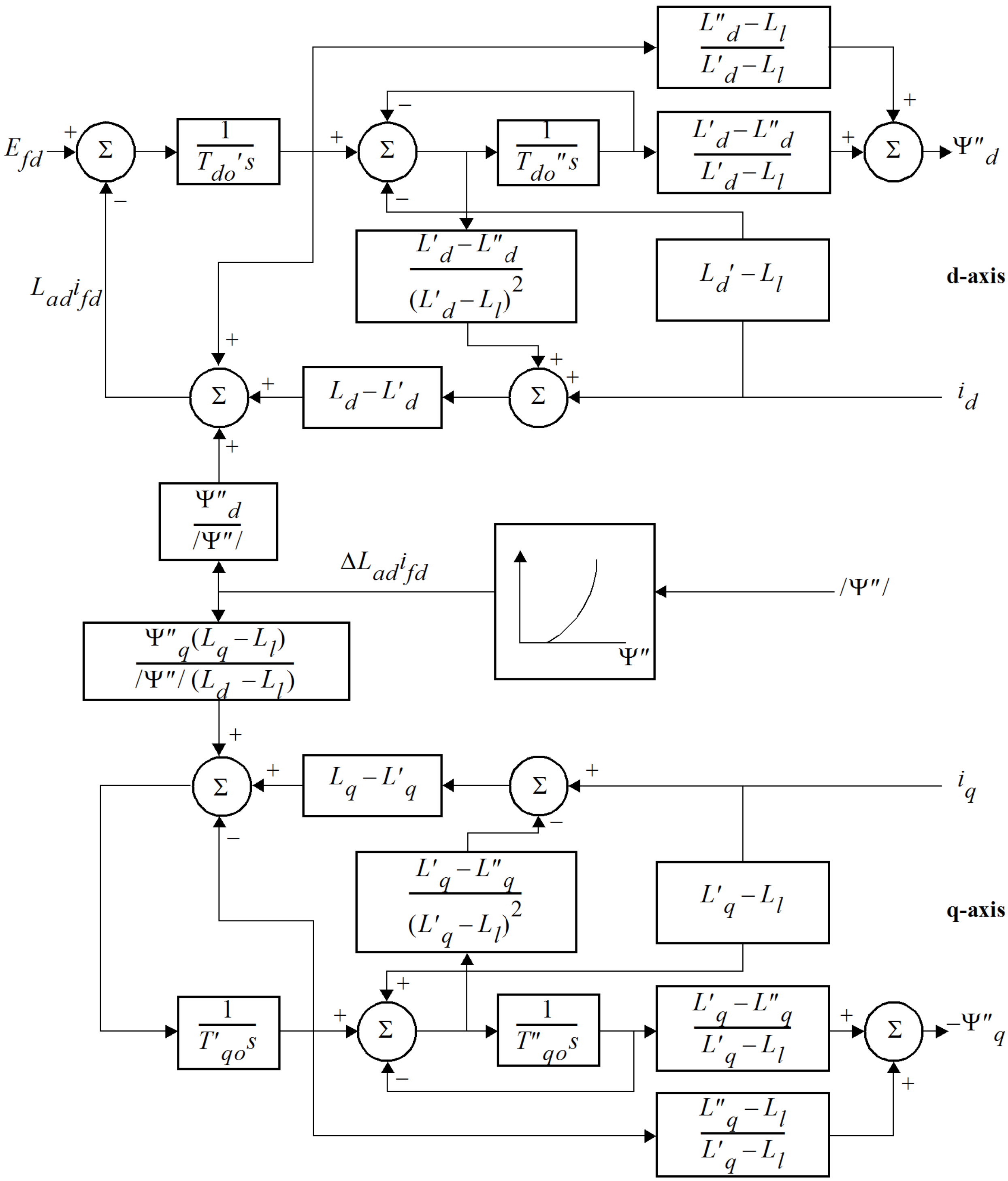


Figure 15.4. Electromagnetic Model of Round Rotor Generator (Models GENROU, GENROE, and GENDCO)

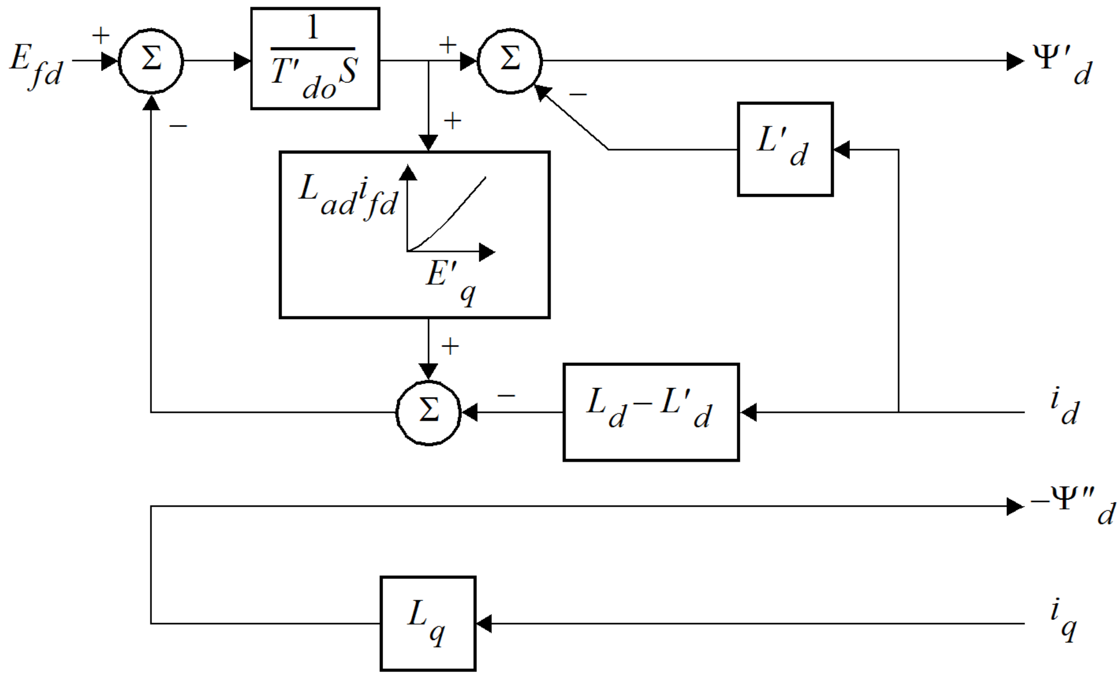


Figure 15.5. Electromagnetic Model of Salient Pole Generator Considering Field Winding Transients Only (Model GENTRA)

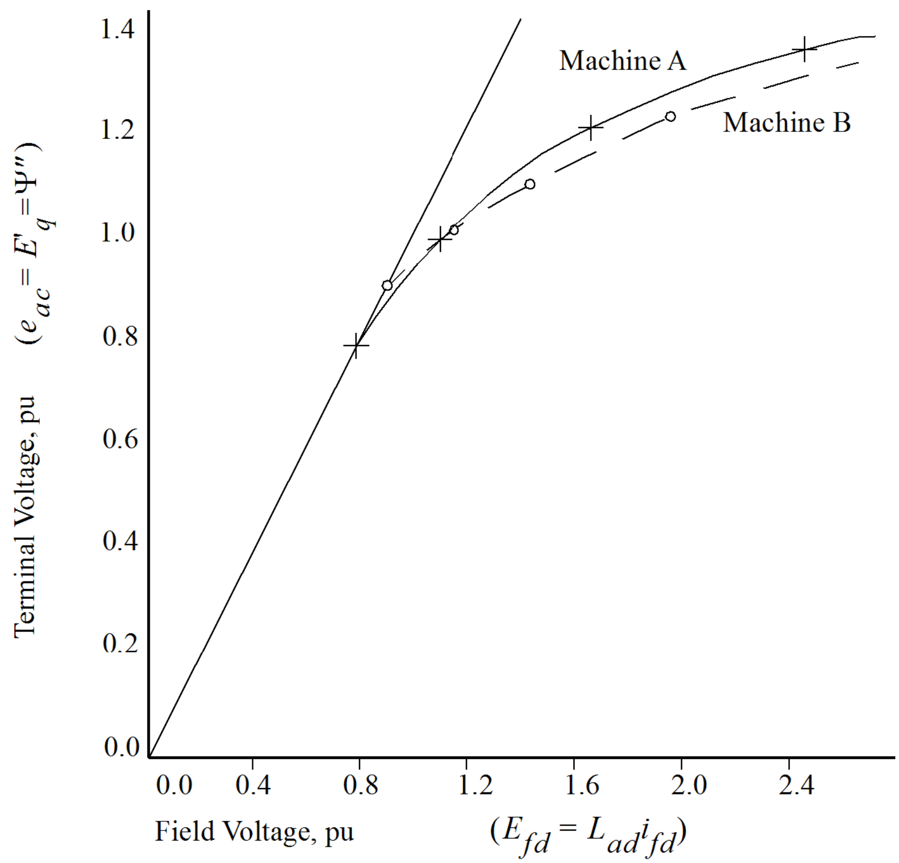


Figure 15.6. Typical Generator Open-Circuit Saturation Curves

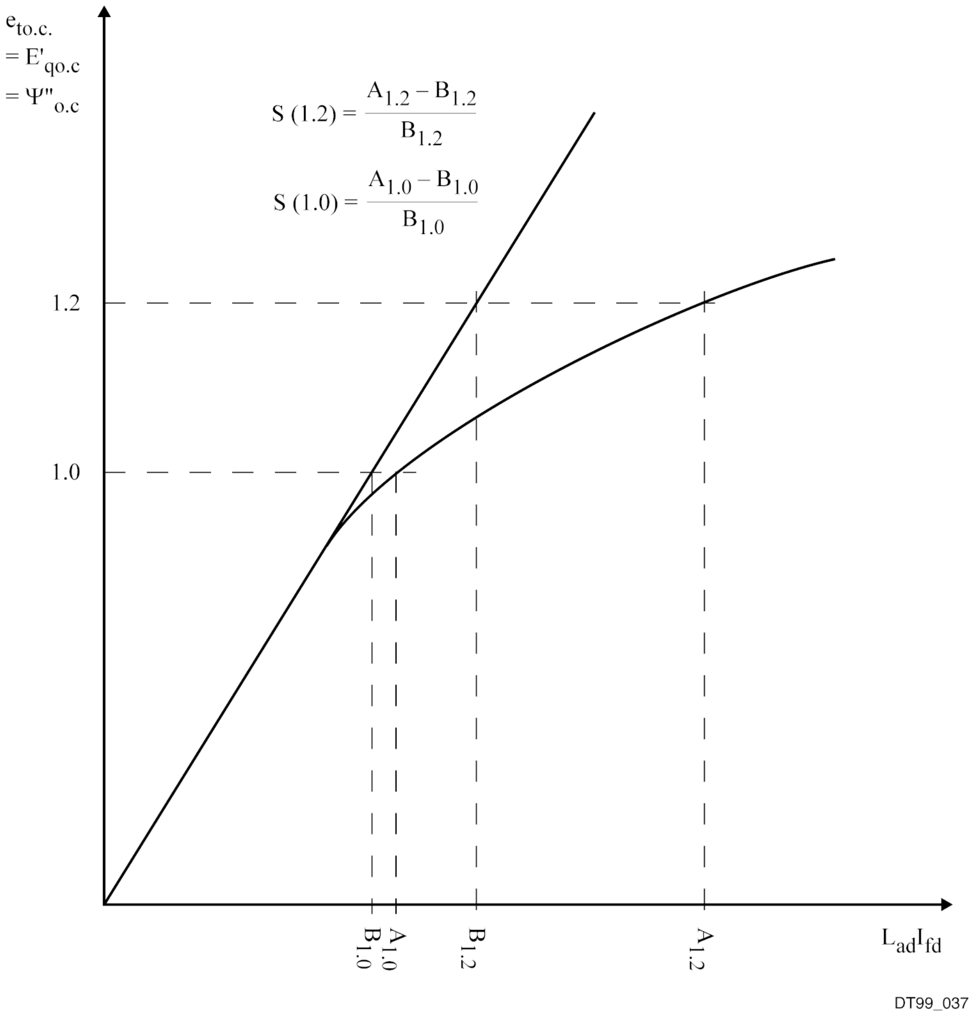


Figure 15.7. Definition of Saturation Factor, S, for Entry as Generator Data

15.4.3. Magnetic Saturation

All PSS®E generator models except GENCLS recognize that magnetic saturation affects the various mutual and leakage inductances within the machine. The specific assumptions regarding which inductances are affected by saturation, and the relative effect of that saturation, are different in the salient pole and solid rotor models.

- GENSAL and GENTRA assume that saturation affects only the direct axis and that the mutual inductances vary as a function of the flux linkage, E'_q, behind transient reactance.

- GENROU, GENROE, GENSAE, and GENDCO assume that saturation affects both direct and quadrature axis reactances and that the mutual inductances vary as a function of the flux linkage behind subtransient reactance.

- GENROU, GENDCO, GENSAL, and GENTRA assume the saturation curve to be quadratic, while GENROE and GENSAE assume the saturation curve to be exponential. When the quadratic saturation is used, saturation is calculated using the equation:

$$S = \frac{B(E - A)^2}{E}$$

where *E* is the input and *A* and *B* are such that the points (1.0, $S_{1.0}$) and (1.2, $S_{1.2}$) lie on the curve as shown for the exciter in Section 17.3, “The ac Excitation Systems”.

When the exponential saturation is used, saturation is calculated by the equation:

$$S = S_{1.0} \times E^X \qquad (15.1)$$

where:

$$X = \frac{\ln\left(\frac{S_{1.2}}{S_{1.0}}\right)}{\ln(E_{1.2})}$$

.and E is the input.

All six of these generator models recognize that the extent of the saturation effect depends upon both rotor (field) and stator currents. Accordingly, they derive the effective saturated parameters of the machine at each instant by internal calculation from the specified (constant) *unsaturated* values of machine reactances and the instantaneous internal flux level. The user should enter *unsaturated* values of *all* machine reactances in setting up PSS®E data, and must enter an appropriate set of open-circuit magnetization curve data for each machine.

15.4.4. Generator Rotor Speed Damping

All generator models calculate the rotor acceleration by:

$$2H\frac{dn}{dt} = \frac{P_{mech} - D_e n}{1 + n} - T_{elec} \qquad (15.2)$$

where:

$P_{mech} =$ (P_{mech}) nominal speed – $D_t\, n$.

$T_{elec} =$ The generator rotor electrical torque.

n = The per unit speed deviation of the generator.

$$D_e = \frac{\partial P_e}{\partial n}$$

Represents the variation of electrical load with frequency, as seen from the generator.

$$D_t = \frac{\partial P_t}{\partial n}$$

Represents the variation of turbine power with shaft speed.

D_e = Specified in generator data.

D_t = Entered as part of the turbine-governor model data.

The parameter, D_e, gives an approximate representation of the damping effect contributed by the speed sensitivity of system loads. The parameter should not be used to represent the effect of damping torques developed within the synchronous machines; these torques are modeled explicitly by GENSAL, GENROU, GENDCO, GENSAE, and GENROE and are included in the T_{elec} term of Equation 15.2.

The value of D_e could range from near zero for systems with predominantly resistive load to approximately two for systems with a large percentage of pumping, fan, and other industrial load.

The limitations of the use of D_e to represent load damping effects are discussed in Reference 3 of Section 15.4.1, "Source Impedance". If load damping is considered to be critical, it is advisable to model load speed variation effects on the basis of local bus frequency by calling the load model subroutine such as LOADF from subroutine CONET.

15.4.5. Generator Model Details

GENSAL and GENSAE (Salient Pole Machines)

GENSAL and GENSAE represent salient pole machines at the subtransient level. GENSAL and GENSAE require that the subtransient reactance specified in the machine data be exactly equal to the reactive part of the corresponding ZSORCE as used in the power flow case. GENSAL and GENSAE treat the unit as follows:

- Online when the terminal bus type is 2 and machine status is 1.
- Off-line when the terminal bus type is 1 or 4 or machine status is 0.

When GENSAL or GENSAE represents several identical units on a plant bus (in a hydro plant, for example), all data should be entered with respect to the base MVA of a single unit, and the value of MBASE entered in the power flow case should be the sum of the ratings of all connected units.

Reducing the value of MBASE has the effect in GENSAL or GENSAE of tripping the corresponding fraction of the units connected to the bus. The value of MBASE should not be increased during a simulation run.

The tripping and subsequent reconnection of *all* units represented by a call to GENSAL or GENSAE may be implemented by changing the bus type code to 1 (for tripping) and then returning it to 2 (for reclosing) without changing the value of MBASE, or by changing the unit status to 0 (for tripping) and returning it to 1 (for reclosing).

The values of T''_{do} and T''_{qo} entered for GENSAL or GENSAE should not be less than four times the integration time step, DELT. Typical values of DELT for simulation runs using GENSAL or GENSAE are:

0.01 sec

(1/2 cycle at 50 Hz)

0.00833 sec

(1/2 cycle at 60 Hz)

If the value of DELT is too big (with regard to GENSAL or GENSAE) in any given study, most likely it will be revealed by SUSPECT INITIAL CONDITIONS messages from activity STRT referring to STATEs K+1 and K+2 of GENSAL or GENSAE models. Three available remedies exist:

1. If only STATE (K+2) indicates suspect initial conditions, and if valid data are available, use GENROU or GENROE to obtain a better *q*-axis representation.

2. Decrease DELT.

3. Increase T''_{do} or T''_{qo} if these data values themselves are suspect or assumed values. T''_{do} and T''_{qo} seldom exceed 0.1 sec for typical generators.

GENROU and GENROE (Solid Rotor Generators)

GENROU and GENROE represent solid rotor generators at the subtransient level. Apart from the additional *q*-axis data values, T'_{qo} and x'_q, GENROU and GENROE are used in exactly the same way as GENSAL.

GENCLS (Classical Generator Model)

GENCLS is the classical constant voltage behind transient reactance generator model. Setting the type code of the terminal bus to 1, or the generator status flag to zero, removes the unit from service.

GENCLS initializes EFD(I) to the initial condition value of E'_q for the generator. After being initialized in STRT, EFD(I) for GENCLS models should not be changed during a run. It is not valid to use an excitation system to vary EFD in conjunction with the GENCLS model.

GENTRA (Transient Saliency Level Generator Model)

GENTRA is a two-rotor model that neglects the amortisseur windings. Use of this model will not reduce time in transient stability studies. Because there is no state in the *q*-axis, the model must have its own acceleration procedure and may require more power flow iterations. The model should not be used beyond 1 sec. Because the damping contributed by the amortisseur windings is neglected, a larger time step to extend dynamic stability cases would not be justified. A typical value for the acceleration factor is 0.3 but a smaller value may be necessary. Care should be taken in using this model. A higher-order model with assumed data may be preferable. [1]

GENDCO (Solid Rotor Generator Model Including Stator dc Offset Effects)

GENDCO is a detailed round rotor model that includes dc offset effects. The model includes shaft torsional effects when it is associated with a call to the model SHAF25. The model is intended for use only in shaft torsional studies. The time constant, T_a, for this model should normally be zero except after a balanced si-

[1] "Model Selection and Data Assembly for Power System Simulations," J.M. Undrill and T.F. Laskowski, *IEEE Transactions on Power Apparatus and Systems*, Sept. 82, pp. 3333–3341.

multaneous three-phase switch. The dc offset approximation is not valid for any nonsymmetrical unbalances such as line-ground faults; i.e., GENDCO should always have a T_a equal to zero in these situations.

Simulation Technique in PSS®E for Shaft Studies

The key requirement in shaft impact torque studies is correct dynamic characterization of sudden changes in generator electromagnetic torque. The transient electromagnetic torque profile of a generator following a disturbance on the transmission network contains many components, some of which decay rapidly to zero, and some of which vary quite slowly and persist as long as rotor angles continue to move. The transient torque produced by each switching or sudden change (such as fault) on the transmission may be visualized as containing the following components that are pertinent to shaft impact studies:

1. A square step change of torque.

2. A slow variation of torque in accordance with the relative angular positions of generator rotors throughout the power system. This component falls in the frequency spectrum between about 0.1 and 20 rad/sec.

3. A series of exponentially decaying components that round-off the corner associated with component i. These components are associated with changing flux linkages in circuits (discrete or within the iron mass) on the generator rotor.

4. A power frequency (60 Hz) oscillating component associated with the decaying dc offset component of current produced in the generator stator by a network disturbance.

5. A double power frequency (120 Hz) component associated with the negative-sequence currents induced by an unbalanced fault.

The PSS®E dynamic simulation program represents torque components 1, 2, and 3, including the subtransient part of component 3, in all of its generator models (except the classical model), but does not reproduce components 4 and 5. Exact reproduction of component 4, the dc offset effect, would require simulation of the entire transmission system on a differential equation basis as used in switching surge studies. This simulation would be prohibitively expensive in studies involving extensive networks and requiring examination of transients for the period of about 0.5 sec over which shaft impacts are of interest.

The PSS®E generator models GENDCO and SHAF25 handle the dc offset torque component by taking advantage of the fact that the initial amplitude of this torque component can be determined exactly from a pair of network solutions made for the instants immediately before and immediately after the network switching. Because the corresponding rate of decay of the dc offset torque component cannot be similarly determined, models SHAF25 and GENDCO require the user to enter an estimate of the time constant governing their decay. This time constant is loosely approximated by the network R/X ratio as seen by the generator. A representative value of this time constant is 0.15 sec.

The last component of generator torque associated with negative sequence currents is of significance in shaft impact studies only if a shaft has a natural frequency very close to 120 Hz. It is neglected by the dynamic models of PSS®E.

Figure 15.8, "Composition of Generator Transient Torque in Response to Switching" illustrates the way in which a generator's response to a balanced network switching is made up by the addition of components 1 through 4.

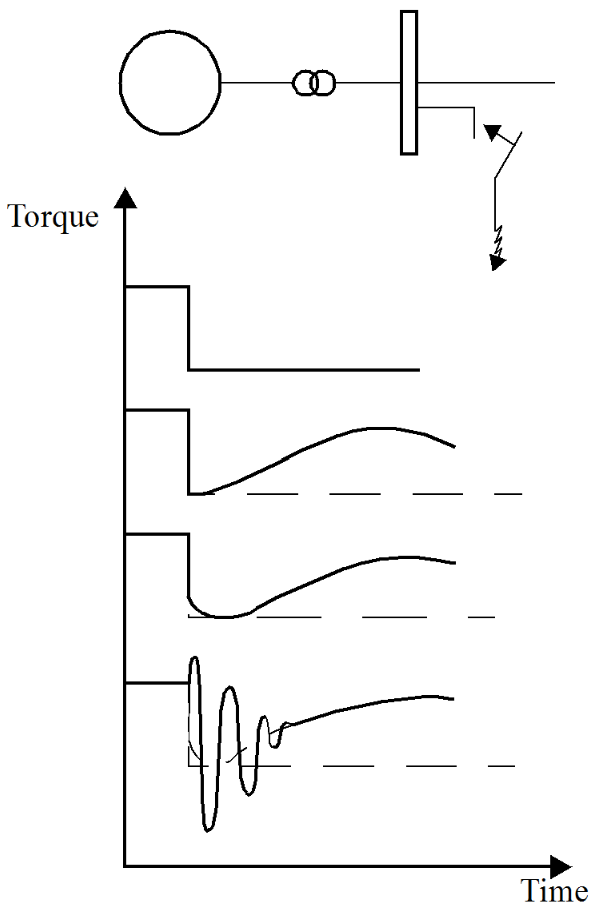


Figure 15.8. Composition of Generator Transient Torque in Response to Switching

Components 1, 2, and 3 are considered to be significant in conventional transient stability studies. Component 3 includes torques decaying with transient and subtransient components. Component 1 is of concern in connection with steady-state stability because it determines the final load on the generator. Component 2 is of concern principally from the viewpoint of transient stability. Component 3 is of concern in dynamic stability studies because, in addition to its rounding off of the first component, it contributes to the damping of rotor angle swings.

Component 4, while it can be an oscillation with a large initial peak-to-peak amplitude, is usually neglected in transient stability studies because it decays rapidly to zero, has an average close to zero, and because its initial amplitude is strongly limited by the presence of impedance between the generator and the point of switching. Component 5 is normally neglected in transient stability studies.

Shaft impact torques are influenced principally by components 1 and 4 of the generator electromagnetic torque transient. Accordingly, shaft impact studies require generators to be modeled at a level of detail where components 1 through 4 of the torque transient can be represented. The subtransient part of component 3 should be represented accurately because it may not have decayed to zero by the time of the next switching, and hence can influence the magnitude of the step component of torque induced by this event.

FRECHG (Frequency Changer)

The frequency changer, FRECHG, models a motor-generator set with a salient pole synchronous machine at each end of a common shaft. Each of the synchronous machines has its own electromechanical characteristic but the mechanical speeds of the two must be the same. A 60/50-Hz frequency changer could, therefore, be built using a 12-pole machine for the 60-Hz side and a 10-pole machine for the 50-Hz side.

This subtransient level frequency changer model recognizes the components of torque produced by the rotor body and amortisseur winding currents in both of the synchronous machines.

Data for each machine should be entered on its own base. The inertia value entered for each machine should be that of the entire shaft. Because the model allows different size machines, the only data requirement for the set of salient pole machines is that data for the inertias be entered so that the kinetic energy equation K.E. = $1/2\ I\ \omega^2$ is satisfied on both ends (*H* is entered for the entire shaft).

Losses in the set are negligible so that in the power flow the real electrical power transferred through the air gap of the motor and generator should have the same magnitude (i.e., after specifying an armature resistance in ZSORCE, the user must calculate and specify the electrical power at the terminals such that the sets have the same internal power).

If during initialization either machine is off-line, an appropriate message is printed and the set is assumed off-line. Either machine can be tripped during a simulation by setting the machine status to zero.

CGEN1 and TGEN1 (Third-Order Equivalent Circuit Model)

The third-order equivalent circuit models, CGEN1 and TGEN1, represent the most detailed rotor circuit structure suggested for usage in power system stability studies. Proponents of models derived from standstill frequency response tests have at times used third-order models to better fit the test data. The CGEN1 and TGEN1 models were developed in response to individual user requests. Inclusion of those models in the PSS®E model library should not be interpreted as an endorsement of its use in preference to the widely used GENROU and GENSAL models.

The format for this model departs from the traditional set of time constants and reactances as used by GENROU and GENSAL. Instead, the rotor is represented by the equivalent circuits as shown in Figure 15.9, “CGEN1 Equivalent Circuits” for the two axes with the data being entered as per-unit values for the resistances and reactances. The data sheet for this model is shown in Figure 15.10, “CGEN1 Data Sheet”. Some of the resistances and inductances in the equivalent circuit can be set to zero. while other quantities requiring nonzero values are indicated by >0 on the data sheet. Allowing some quantities to be set to zero permits this model to represent a second-order circuit such as being modeled in GENROU.

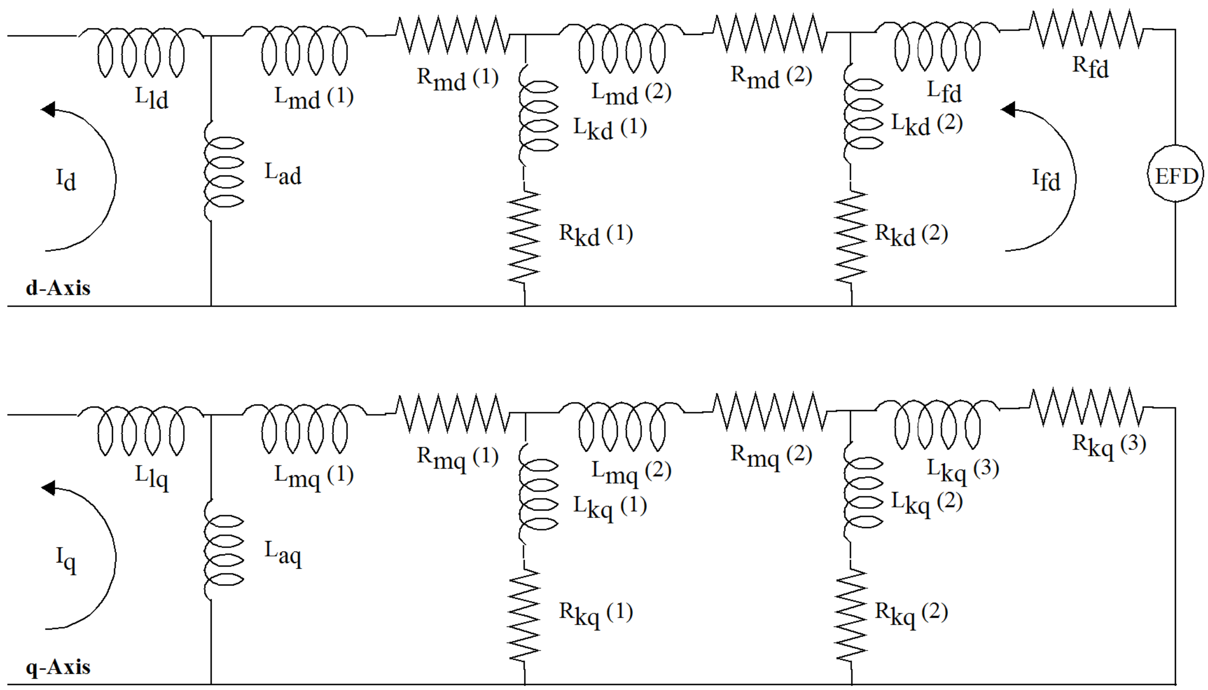
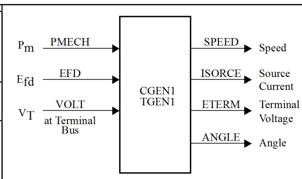


Figure 15.9. CGEN1 Equivalent Circuits

CGEN1

Third-Order Complex Generator Model

This model is located at system bus	#____	IBUS,	
machine	#____	I,	
This model uses CONs starting with	#____	J,	
and STATEs starting with	#____	K,	
and VARs starting with		L.	
The machine MVA base is ____________ for each of ____________ units = ____________ MBASE.			
ZSORCE for this machine is__________+ j __________on the above MBASE.			

CONs	#	Value	Description
J		4	Inertia, H
J+1		0.1	S(1.0)
J+2		0.4	S(1.2)
J+3		0.17	$L_{ld} > 0$
J+4		1.63	$L_{ad} > 0$
J+5		0.00081	$R_{fd} > 0$
J+6		0.20234	$L_{fd} > 0$

CONs	#	Value	Description
J+7		0	R_{md} (1)
J+8		0	L_{md} (1)
J+9		0.01194	R_{kd} (1)
J+10		0.09	L_{kd} (1)
J+11		0	R_{md} (2)
J+12		0	L_{md} (2)
J+13		0	R_{kd} (2)
J+14		0	L_{kd} (2)
J+15		0.17	$L_{lq} > 0$
J+16		1.58	$L_{aq} > 0$
J+17		0.011036	R_{kq} (3) > 0
J+18		0.500333	L_{kq} (3) > 0
J+19		0	R_{mq} (1)
J+20		0	L_{mq} (1)
J+21		0.00997	R_{kq} (1)
J+22		0.07125	L_{kq} (1)
J+23		0	R_{mq} (2)
J+24		0	L_{mq} (2)
J+25		0	R_{kq} (2)
J+26		0	L_{kq} (2)

STATEs	#	Description
K		Δ speed (pu)
K+1		Angle (radians)
K+2		ψ_{rd} (1)
K+3		ψ_{rd} (2)
K+4		ψ_{rd} (3)
K+5		ψ_{rq} (1)
K+6		ψ_{rq} (2)
K+7		ψ_{rq} (3)

VARs	#	Description
L		Internal memory
L+1		Internal memory

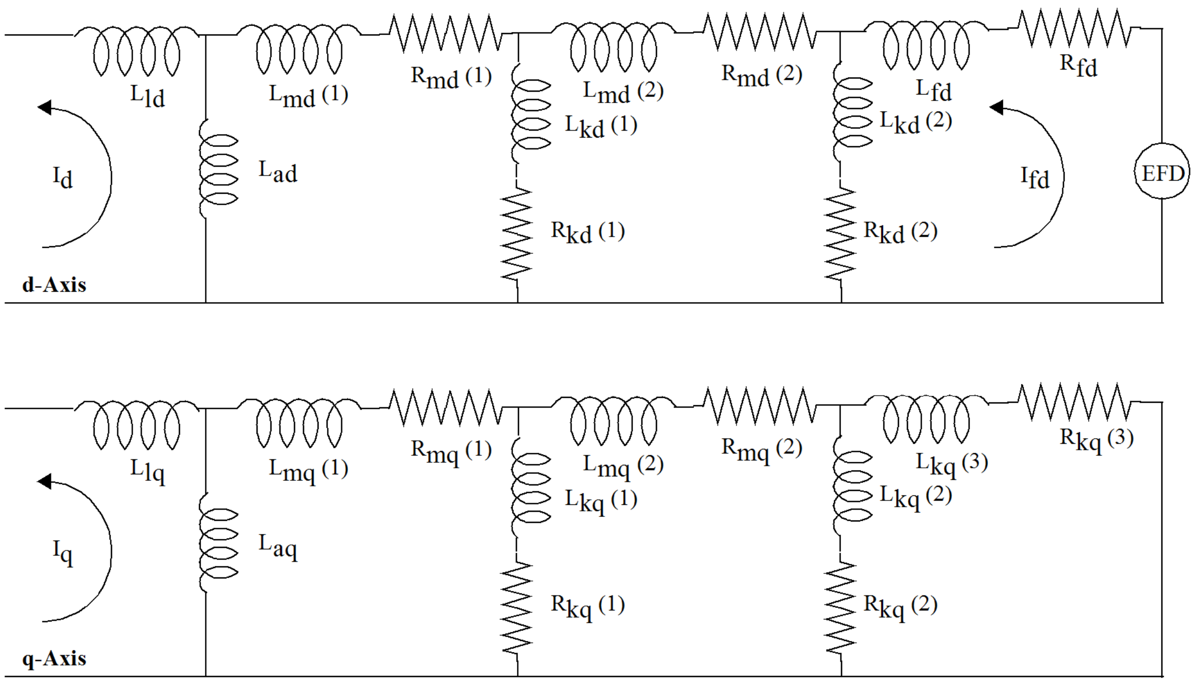
All constants except S(1.0) and S(1.2) are in pu machine MVA base.

Set R_{md} (2), L_{md} (2), R_{kd} (2) and L_{kd} (2) to 0 for 2nd order d-axis model.

Set R_{mq} (2), L_{mq} (2), R_{kq} (2) and L_{kq} (2) to 0 for 2nd order q-axis model.

See diagram below for definition of various resistances and inductances.

IBUS, 'CGEN1', I, H, S(1.0), S(1.2), L_{ld}, L_{ad}, R_{fd}, L_{fd}, R_{md} (1), L_{md} (1), R_{kd} (1), L_{kd} (1), R_{md} (2), L_{md} (2), R_{kd} (2), L_{kd} (2), L_{lq}, L_{aq}, R_{kq} (3), L_{kq} (3), R_{mq} (1), L_{mq} (1), R_{kq} (1), L_{kq} (1), R_{mq} (2), L_{mq} (2), R_{kq} (2), L_{kq} (2)/



CGEN1 Equivalent Circuit

Figure 15.10. CGEN1 Data Sheet

Using the feature to represent a second-order response, this model was compared with GENROU by simulation runs. Starting with derived parameters, the equivalent circuit parameters were calculated to obtain the same rotor response. The data for the derived parameters are the following:

T'_{do} = 6 sec

T''_{do} = 0.06 sec

T'_{qo} = 0.5 sec

T''_{qo} = 0.12 sec

T = 4 MW-sec/MVA

X_d = 1.8 pu

$X'd$ = 0.35 pu

$X''d$ = 0.23 pu

$X_q = 1.75$ pu

$X'_q = 0.55$ pu

$X''_q = 0.26$ pu

$X_l = 0.17$ pu

$S(1.0) = 0.1$

$S(1.2) = 0.4$

To calculate the equivalent circuit parameters the following equations were used:

$$L_{ad} = L_d - L_l$$

$$L_{fd} = \frac{1}{\frac{1}{L'_d - L_l} - \frac{1}{L_{ad}}}$$

$$L_{sd}(1) = \frac{1}{\frac{1}{L''_d} - L_l - \frac{1}{L_{ad}} + \frac{1}{L_{df}}}$$

$$r_{fd} = \frac{L_{ad} + L_{fd}}{T'_{do} \times \omega_o}$$

$$r_{sd}(1) = \frac{L_{sd}(1) + \frac{L_{ad} \times L_{fd}}{L_{ad} + L_{fd}}}{T''_{do} \times \omega_o}$$

$$L_{aq} = L_q - L_l$$

$$L_{sq}(3) = \frac{1}{\dfrac{1}{L'_q - L_l} - \dfrac{1}{L_{aq}}}$$

$$L_{sq}(1) = \frac{1}{\dfrac{1}{L''_q - L_l} - \dfrac{1}{L_{aq}} - \dfrac{1}{L_{sq}(3)}}$$

$$r_{sq}(3) = \frac{L_{aq} + L_{sq}(3)}{T'_{qo} \times \omega_o}$$

$$r_{sq}(1) = \frac{L_{sq}(1) + \dfrac{L_{aq} \times L_{sq}(3)}{L_{aq} + L_{sq}(3)}}{T''_{qo} \times \omega_o}$$

The values for equivalent circuits that will produce the same response as GENROU with the above data are shown in Figure 15.11, "Equivalent Circuit for Machine Model Used in the Simulation". The disturbance for the simulation runs was a three-phase fault (on the infinite bus) for three cycles. The field voltage was kept constant in the simulation runs. The plots shown in Figure 15.12, "Comparison Between GENROU and CGEN1 (Sheet 1 of 2)" reveal that the response of the two models are the same. Because the representation of saturation is different for the two models, the initial values for the rotor angle and the field current were slightly different. In the CGEN1 and TGEN1 model the saturation is accounted by changing the inductances L_{ad} and L_{aq} by determining the *K* factors from the open circuit saturation curves while the GENROU model accounts for saturation by adding a term at the summing junction as shown in Figure 15.12, "Comparison Between GENROU and CGEN1 (Sheet 1 of 2)". Also, the air gap flux is used to account for saturation in CGEN1 while in GENROU it is the subtransient flux.

Another feature of the CGEN1 and TGEN1 model is that it can represent subtransient saliency, i.e., $L''_d \neq L''_q$. A simulation run was made comparing the response for a machine with and without subtransient saliency using an equivalent circuit for which the value for L''_q would be 0.26 pu and L''_d = 0.23 pu. The plots shown in Figure 15.14, "Comparison Between CGEN1 With and Without Subtransient Saliency (Sheet 1 of 2)" reveal hardly any differences.

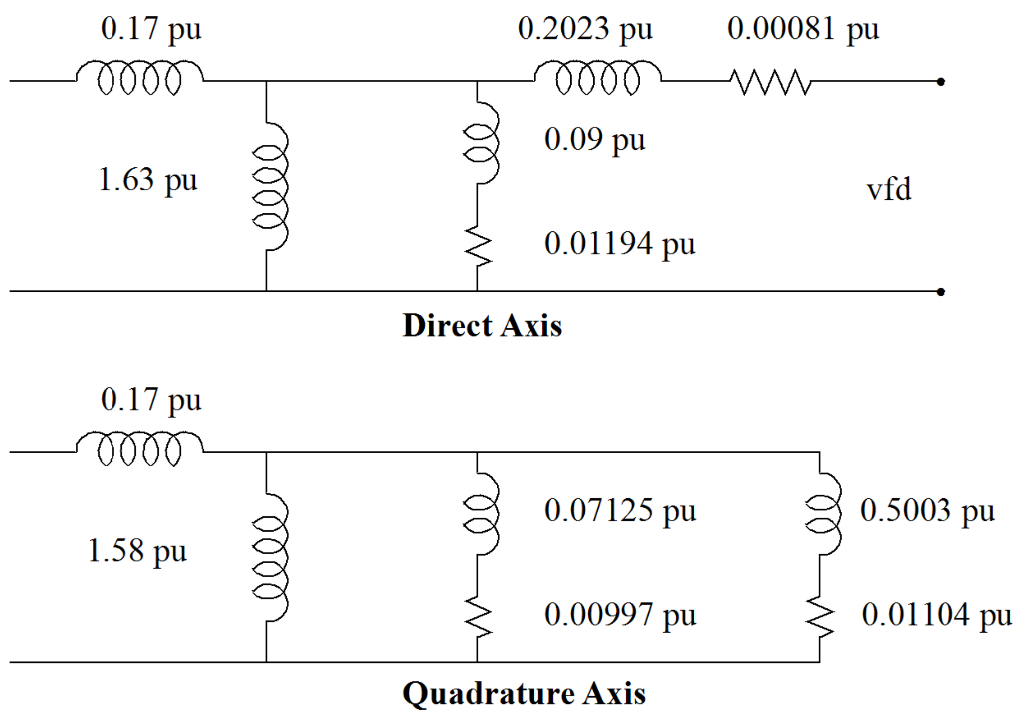


Figure 15.11. Equivalent Circuit for Machine Model Used in the Simulation

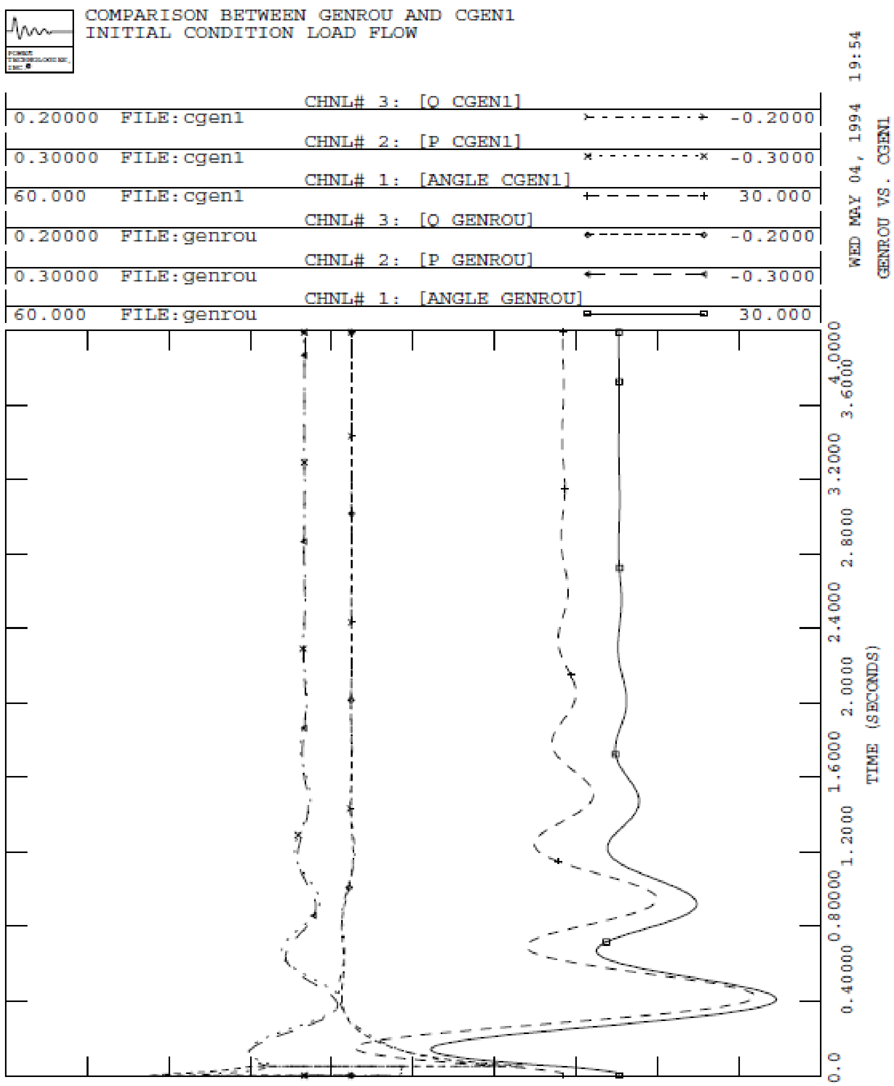


Figure 15.12. Comparison Between GENROU and CGEN1 (Sheet 1 of 2)

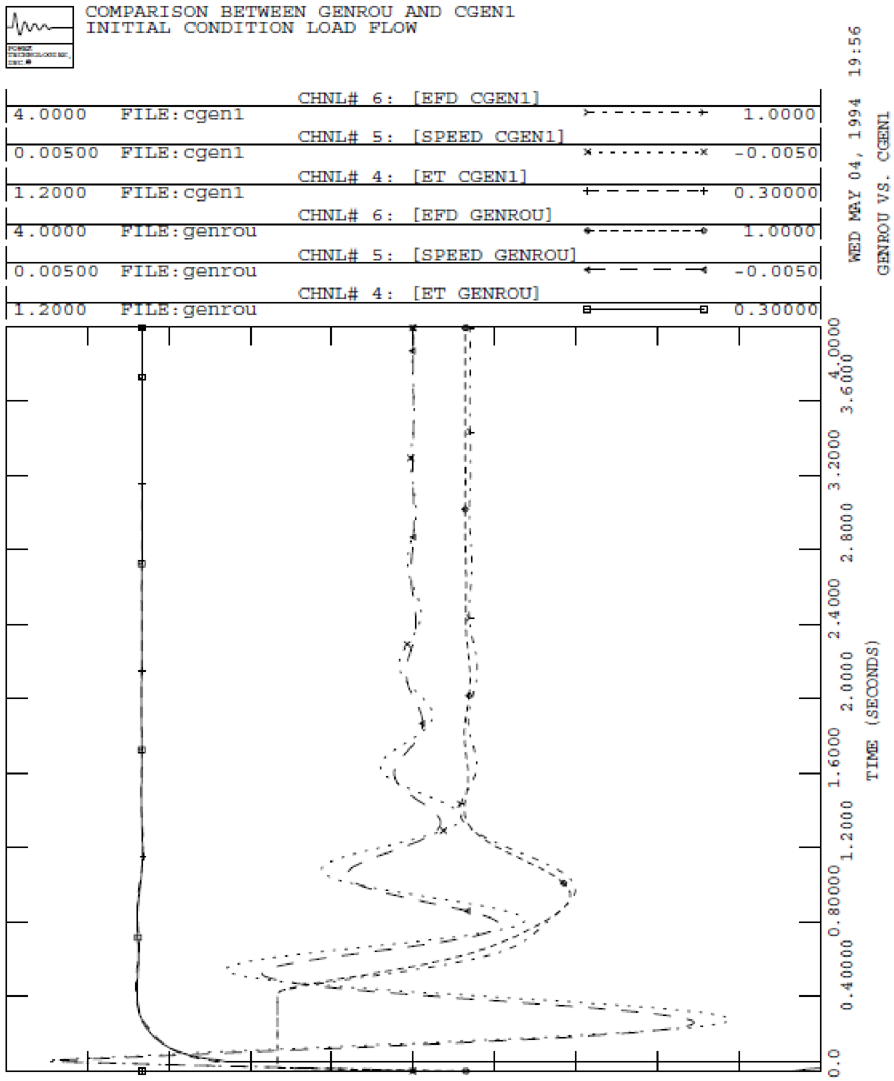


Figure 15.13. Comparison Between GENROU and CGEN1 (Sheet 2 of 2)

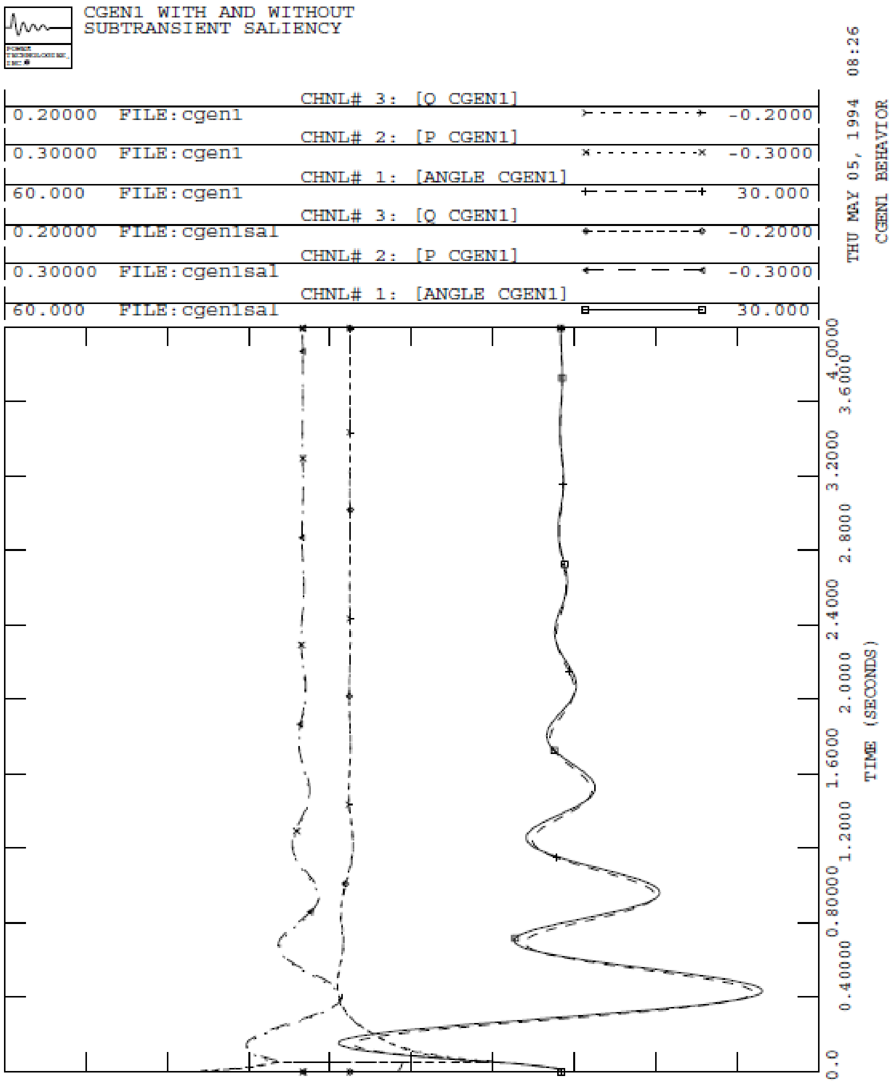


Figure 15.14. Comparison Between CGEN1 With and Without Subtransient Saliency (Sheet 1 of 2)

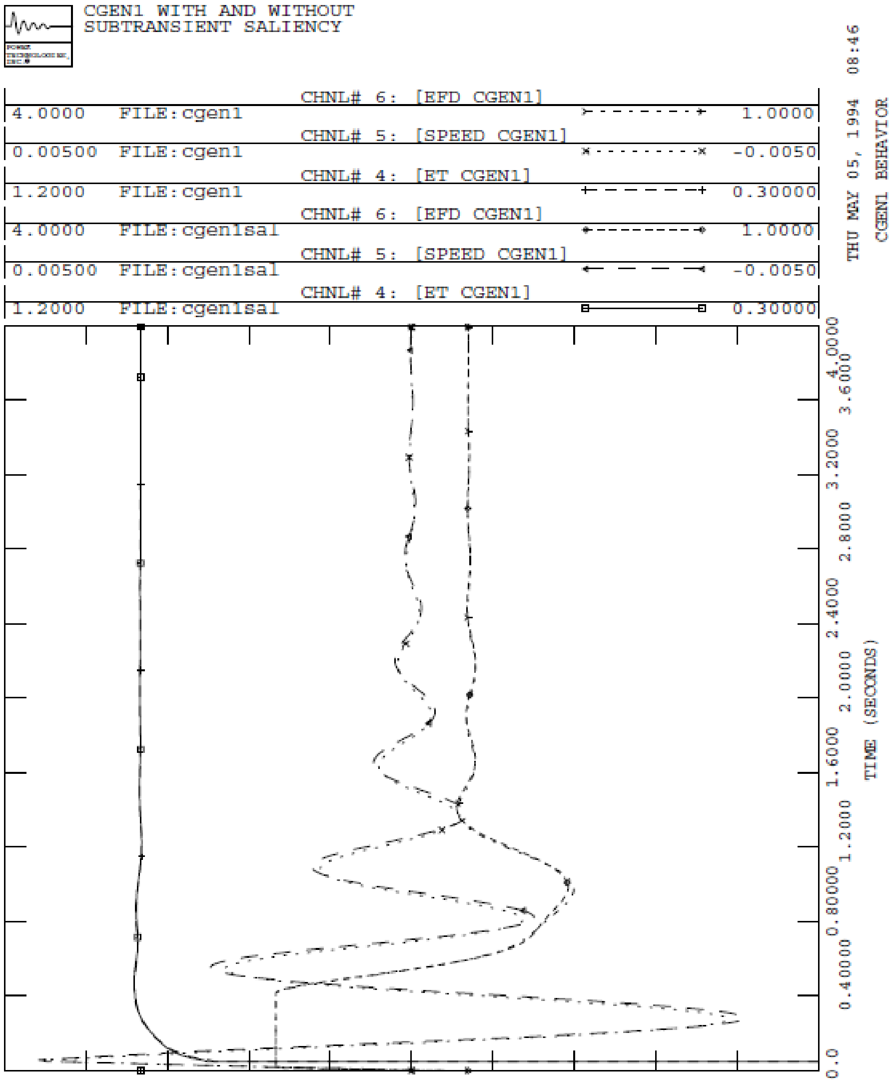


Figure 15.15. Comparison Between CGEN1 With and Without Subtransient Saliency (Sheet 2 of 2)

The run times for the various models calibrate the performance of the two models. The fastest simulation run is obtained using GENROU. When the CGEN1 and TGEN1 model is used without subtransient saliency, the ratio of CPU time was 1.98:1. With subtransient saliency the ratio was 2.07:1.

The time step used in the simulation runs was equal to a half cycle for a 60-Hz system. As mentioned in the section called “GENSAL and GENSAE (Salient Pole Machines)”, the values for Δ should be at 1/4 of the smallest short circuit time constant. To determine the smallest short circuit time constant, one approach is to calculate the equivalent L/R for each rotor resistance with the stator shorted and the other rotor resistances set to zero. For example with the model used in the simulation the value for the time constant would be:

$$T''_d = \frac{\left(\dfrac{1}{\dfrac{1}{1.63} + \dfrac{1}{0.17} + \dfrac{1}{0.2023}}\right) + 0.09}{0.01194 \times 337} = 0.0394 \text{ sec}$$

$$T'_d = \frac{\left(\dfrac{1}{\dfrac{1}{1.63} + \dfrac{1}{0.17} + \dfrac{1}{0.09}}\right) + 0.2023}{0.00081 \times 377} = 0.8485 \text{ sec}$$

$$T''_q = \frac{\left(\dfrac{1}{\dfrac{1}{1.58} + \dfrac{1}{0.17} + \dfrac{1}{0.5003}}\right) + 0.07125}{0.0097 \times 377} = 0.0502 \text{ sec}$$

$$T'_q = \frac{\left(\dfrac{1}{\dfrac{1}{1.58} + \dfrac{1}{0.17} + \dfrac{1}{0.07125}}\right) + 0.5003}{0.01104 \times 377} = 0.1319 \text{ sec}$$

As can be seen from the above, the smallest value is greater than four times the time step and there should be no numerical problems.

15.5. Models CIMTR1 and CIMTR3 (Induction Generators)

CIMTR1 and CIMTR3 model either a single-cage or double-cage induction generator including rotor flux dynamics. In the power flow, a generator with positive electrical power should be used. To model a single-cage machine, either T ″ or *X* ″ should be set to zero and ZSORCE in the power flow should be set to *X* ′ . To model a double-cage machine, a value must be provided for both T ″ and *X* ″ , and ZSORCE of the power flow should be set to *X* ″ . For this model, an extra CON (labeled SWITCH) is used only for minimization of computer code and does not affect the model. None of the standard PSS ®E governor models can be used with this model because they assume zero speed deviation during initialization.

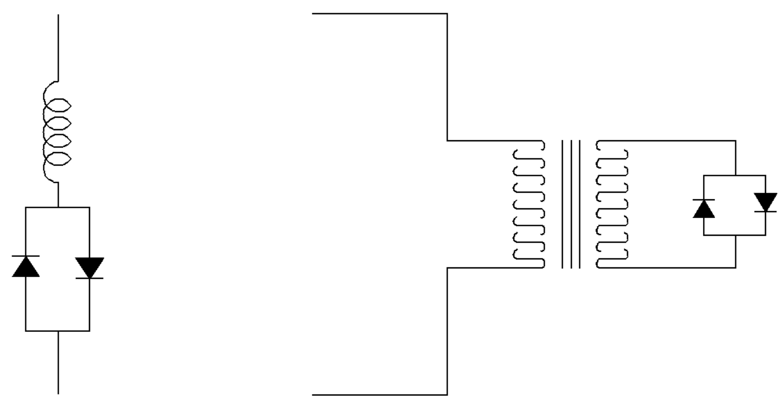
A double-cage machine will have time constants much smaller than T ″ and, therefore, a time step less than the normal value of 1/2 cycle may be necessary.

CIMTR3 uses one extra state variable but is more accurate than CIMTR1. It is recommended for large frequency deviations and is required for extended term. CIMTR3 also has an initial CON where the mechanical power is entered at synchronous speed. This CON is ignored if the machine is in-service in the power flow (i.e., JCODE > 2 and MCSTAT = 1). The machine can be started by simply placing it in service. Starting the machine in state space will generally require a very small time step, sometimes in the order of 1/16 of a cycle. When using the extended algorithms to start the motor, 1/2 cycle usually works. This model cannot be the only machine in an island when using the constant island frequency mode.

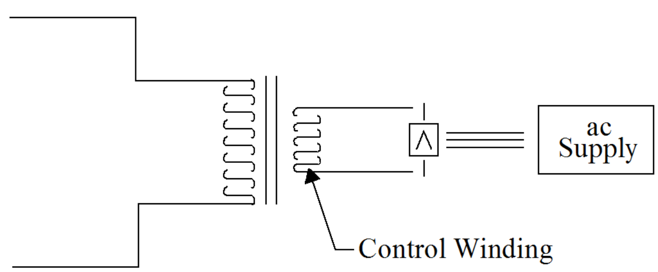
Chapter 16
Static var Devices

16.1. Principles

A static var generator (SVG or SVS or SVC) is a shunt reactor operating subject to some form of control to regulate the voltage at a bus. While there is a wide variety of ways of building an SVG, shunt reactors or special transformers are used in combination with controlled thyristors. Some representative arrangements are shown in Figure 16.1, "Control of Reactor Current by Thyristors". Figure 16.1, "Control of Reactor Current by Thyristors"a shows arrangements in which the thyristors are in series with a reactor and control the current in it directly. Figure 16.1, "Control of Reactor Current by Thyristors"b shows an alternative arrangement in which the thyristor elements exert control by altering the degree of saturation in the core of the reactor. In all arrangements the effect of controlled firing of the thyristors is to control the effective fundamental frequency admittance of the thyristor-reactor unit as seen from its high-voltage terminals.



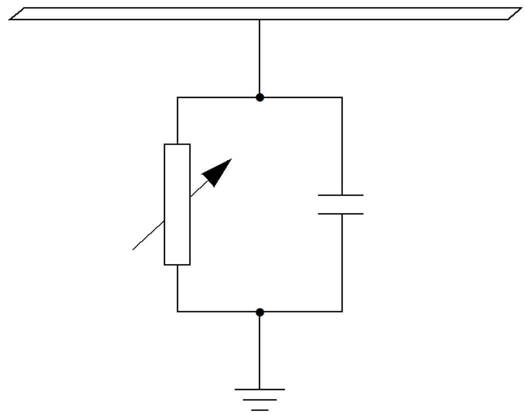
a. Reactors With Current Controlled Directly by



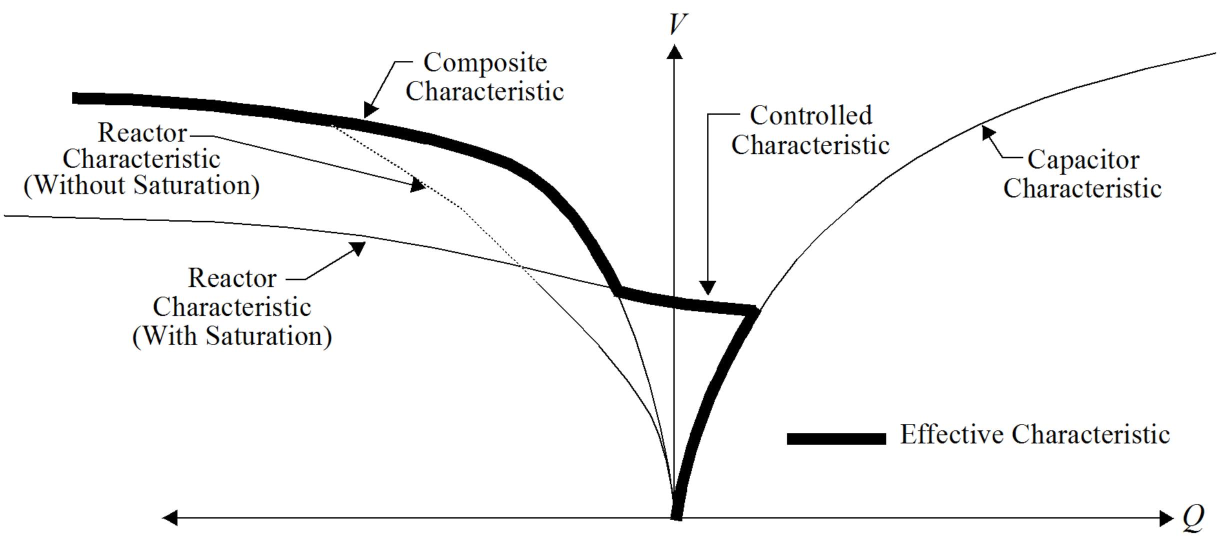
b. Reactors With Current Controlled by Saturation Induced by dc Control

Figure 16.1. Control of Reactor Current by Thyristors

The controllable shunt reactor may be used as an alternative to a synchronous condenser to control voltage on a transmission system. One basic application and its overall characteristic are shown in Figure 16.2, "Static var Source Application". With the reactor turned off, the installation is a shunt capacitor that will supply reactive power to the system. The reactor may be turned on to absorb reactive power, giving the flat section of the characteristic until it is fully on. After the reactor is fully on, the characteristic is that of the reactor, which may saturate extensively at high voltages, in parallel with the capacitor. While the characteristic shown in Figure 16.2, "Static var Source Application" is achieved by turning the reactor on in proportion to bus voltage, virtually any static and dynamic characteristic can be obtained within the range offered by the rating of the reactor and capacitor.



a. Controlled Reactor and Capacitor to Provide Controlled var



b. Composite Characteristics of Controlled Reactor and Capacitor

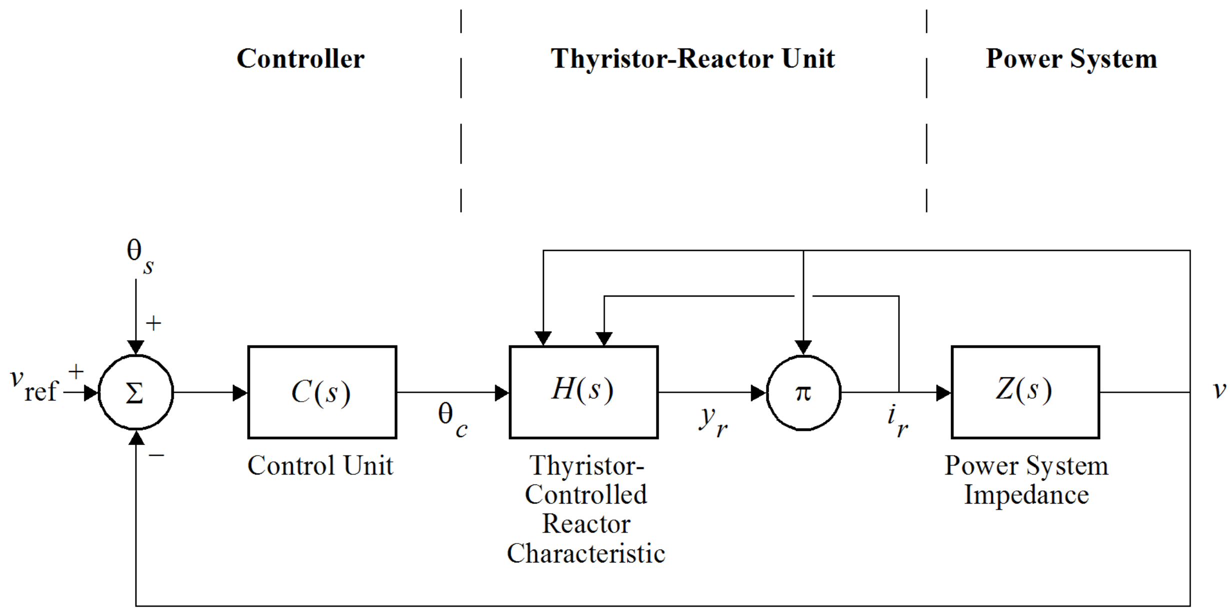
Figure 16.2. Static var Source Application

16.2. Dynamic Characteristics

16.2.1. Representation

As with dc transmission terminals, the dynamic behavior of controlled reactors should be viewed at two distinct levels. The firing and commutation of the thyristors is a broad bandwidth process for which the response is very rapid in relation to the bandwidth of simulation in PSS®E. The operating point of this process is set by a control unit where bandwidth is generally within that of PSS®E. The overall behavior of the controlled reactor is as shown in Figure 16.3, "Controlled Reactor Dynamics".

The inherent dynamic characteristics, H(s) and Z(s), of the thyristor-reactor unit and the system interact with one another in a complex and nonlinear way over a broad bandwidth. The reference to this combination is provided by the control unit C(s), where behavior is designed over the bandwidth recognized by PSS®E. Because the details of H(s) and Z(s) at frequencies above 30 r/s are unseen by PSS®E, all controlled reactor models in PSS®E take the general form shown in Figure 16.4, "Form of Static var System Representation Used in PSS®E". The overall characteristic of the controlled reactor is approximated by a single time constant and limits, as appropriate, relating fundamental frequency admittance to the output signal of the control unit. The control unit may be modeled in detail.



v = Bus voltage

i_r = Controlled reactor current

y_r = Effective controlled reactor admittance

θ_c = Reference signal for thyristor firing control

θ_s = Supplementary input signal

v_{ref} = Reference voltage

Figure 16.3. Controlled Reactor Dynamics

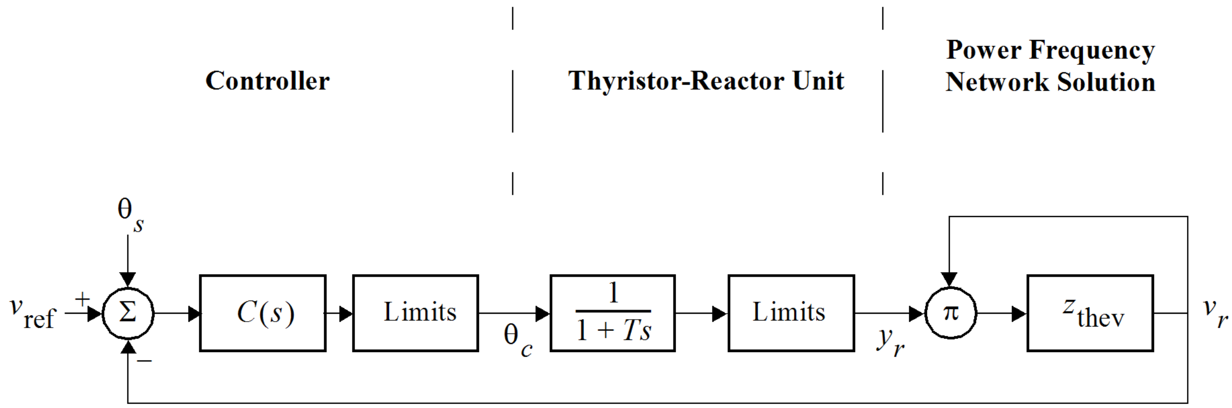


Figure 16.4. Form of Static var System Representation Used in PSS®E

16.2.2. Key Time Constant

Consider a static var device controlled by a pure gain transfer function, as shown in Figure 16.5, "Simple Static var Device Control Arrangement".

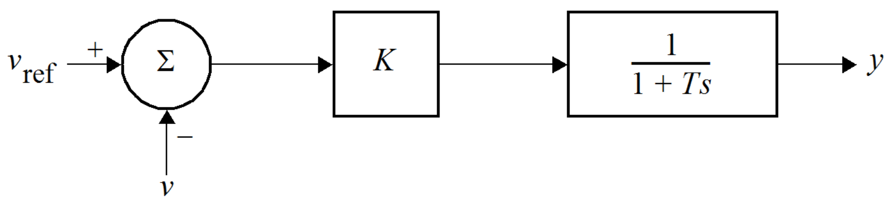


Figure 16.5. Simple Static var Device Control Arrangement

The var flow into this device is:

$q = v^2 y$

and, for small perturbations about an operating point, v_o, y_o:

$\Delta q = 2 v_o y_o \, \Delta v + v_o^{2} \, Dy$

Assume that v_o is approximately unity, giving:

$\Delta q = 2 y_o \, \Delta v + \Delta y$

where y_o is the admittance of the static var device at the unperturbed operating point. The controller and time constant give:

$$\Delta y = \frac{-K(\Delta_{ref} - \Delta v)}{1 + Ts}$$

and the power system apparent impedance (or admittance) gives:

$- q = Y_o v^2$

Taking $v_o = 1$ gives:

$- \Delta q = 2Y_o \Delta v$

where *Yo* is the effective admittance of the system as seen from the terminals of the static var device.

Combining the perturbation equations gives:

$$\Delta v = \frac{K \Delta v_{ref}}{K + 2(Y_o + y_o) + 2(Y_o + y_o)Ts}$$

The overall time constant of the static device and this simple controller is, then:

$$\tau = \frac{2(Y_o + y_o)T}{K + 2(Y_o + y_o)}$$

This result indicates that caution is needed in simulating static var devices. Representative application data for a static var device on a moderately weak system might give:

$Y_o = 5$

$y_o = 1$

The approximating time constant, T, is generally quite short, say 0.05 sec. Close control of voltage requires a high value of *K*. With *K* set to 50, the effective time constant would be:

$$\tau = \frac{2 \times (5 + 1) \times 0.05}{50 + 2 \times (5 + 1)}$$

$$= 0.05 \times \frac{12}{62} = 0.01 \text{ sec}$$

This time constant is too short to be represented in simulations using the usual PSS®E integration step of 0.00833 sec. Hence, a static var device with a high gain controller may require that the PSS®E integration step width be reduced, in order to maintain numerical stability of the simulation.

16.3. Static var Device Models

16.3.1. System Interface

The PSS®E dynamic models require that each SVG be represented by either a switched shunt or a generator in the power flow case. The recommended approach is to use the switched shunt in the power flow. The following rules apply to using the switched shunt model:

1. The switched shunt control mode should be continuous (MODSW = 2).

2. All steps and blocks at that switched shunt are assumed to be controlled by the PSS®E dynamic model.

Any fixed reactors or capacitors should be modeled independently of the switched shunt. Voltage at the SVG terminals or remotely controlled bus is obtainable via the standard CHAN selection of voltage at a bus. Admittance of the device can be obtained by assignment of the appropriate var to a channel.

The following rules apply to the assignment of the generator attributes:

1. The bus at which the SVG is connected must be of Type 2 or 3 and must have a generator assigned and online to represent the SVG.

2. The generator's MBASE value must equal the MVA rating of the controlled inductor element of the SVG installation.

3. The step-up transformer element of the generator must not be used; its parameters (ZTRAN and GENTAP) must be zero and unity, respectively.

4. The ZSORCE value of the generator must be set to a large number, such as (0 + j999) per unit, to assure that the SVG is not a current source in switching solutions.

5. The var limits assigned to the generator must reflect:

   - The effective admittance of the controlled reactor in its full on/off conditions.

   - The admittance of any shunt capacitors that will be represented as a part of the SVG. (Shunt devices connected independently at the bus do not affect the var limits associated with the SVG.)

   - The nature of any current and/or MVA limits inherent in the SVG gating controls and the actual voltage at the bus.

The SVG model CSVGN1 allows shunt capacitance to be represented as a part of the SVG. Hence, an installation of the form shown in Figure 16.2, "Static var Source Application"could be represented by any of the following:

either	a generator representing the net effect of the inductor and capacitor, with its var limits set in accordance with their joint admittance.
or	a fixed bus-connected shunt capacitor and a generator where var limits are set in accordance with the operating range of the reactor alone.
or	a switched shunt capacitor on the bus and a generator where var limits are set in accordance with the operating range of the reactor alone.

For SVG models represented by a generator in the power flow, the voltage at the SVG bus, complex power flow into it, its compensated terminal voltage, and so on, are handled, and are available for output channels, exactly as if the device were a synchronous machine. The models, however, represent internal dynamic behavior that is very different from that of a synchronous machine.

16.3.2. Handling SVGs in Power Flow Solutions

Switched shunts representing SVGs in the power flow do not require any special handling of boundary conditions, therefore, this representation is recommended.

Generators representing SVGs should be treated with special care in power flow solutions because the constant-Q reactive power limits used as the standard generator boundary condition are unlikely to be a true representation of the limits affecting an SVG. If the SVG is modeled as a reactor-capacitor compendium, for example, its reactor fully off condition would normally produce a reactive power versus voltage boundary condition corresponding to a capacitive admittance. If, on the other hand, all capacitance is represented by independent bus-connected devices, the reactor fully off limit would match the standard var limit condition with QMAX = 0. In the maximum reactor load condition, the true form of the power flow boundary condition depends on the nature of the gating controls of the SCR unit. If gated wide open, the reactor would present an inductive susceptance boundary condition. Protective logic in the gating controls may prevent this condition, however, and produce a constant current or other boundary characteristic.

The SVG model, CSVGN1, does not represent any protective or current-limiting control logic. It allows the reactor to be gated fully on regardless of the current and voltage on it. To represent this condition, the generator var limits should ideally be set in accordance with:

$Q_{max} = (B_c - B_{off})\, v_{off}{}^2 \times SBASE$

$Q_{min} = (B_c - B_{on})\, v_{on}{}^2 \times SBASE$

where:

B_c

= Admittance of capacitor included in SVG installation, system base.

B_{off}

= Effective admittance of controlled inductor when gated fully off, system base.

B_{on}

= Effective admittance of controlled inductor when gated fully on, system base.

v_{off}, v_{on}

= Voltage at SVG bus when controlled reactor is at off and on limit, respectively.

Because the power flow logic does not handle variable var limits, a pair of reasonable constant var limits must be chosen. These limits should be chosen so that the SVG always appears in the power flow solution to be operating within its continuous regulation range. If limited behavior is called for, this practice should have the unit operating within its regulating range, but just short of the limit. The var limits should then be:

$Q_{max} = (B_c - B_{off})\, v_{sched}{}^2 \times SBASE$

$Q_{min} = (B_c - B_{on})\, v_{sched}{}^2 \times SBASE$

If an initial power flow solution results in an SVG loading on the high var limits with voltage below schedule, a corrected power flow with SVG output just within limit can usually be produced by the following process:

1. Using CHNG to reduce the scheduled voltage to a value slightly below the actual value from the var-limited solution.

2. Adjusting the high var limit to correspond to the new scheduled voltage.

3. Resolving and repeating the procedure as necessary.

16.3.3. Model CSVGN1

The CSVGN1 model represents an SCR-controlled shunt reactor and a parallel connected capacitor, if present. The SCR gate is controlled by voltage error with an auxiliary signal. The voltage reference is contained in the VREF array, and the auxiliary signal is obtained from the VOTHSG array, exactly as if the device was a synchronous machine.

The physical size of the reactor is specified by the base MVA, MBASE, assigned to the SVG in the power flow data. The size of the capacitor is given by the parameter CBASE (CON(J+9)) in the model data. This constant is zero if no capacitor is represented by the model.

The limits V_{MAX} and V_{MIN} specify the active range of the voltage control loop. Normal values of V_{MAX} and V_{MIN} are unity and zero, respectively, though they could have more restrictive values if the controls are adjusted for an active range corresponding to only a part of the reactor's rating. The minimum admittance limit, R_{MIN}, specifies the effective admittance of the reactor when the SCR control element is turned completely off. The value of R_{MIN} would be zero, or very nearly zero, in units where the SCR element controls main current directly and can turn the reactor completely off and nonzero in elements where the SCR controls work through a secondary winding and allow the reactor to draw magnetizing current even in the off condition.

The time constant, T_5, allows a rough approximation of delays in the reactor's response to control signals. Its value should, in the light of the fast response observed in most tests of SVG units, be 0.05 sec. or less. The time constants T_1 through T_4 provide for transient gain reduction in the control loop and hence allow for a high value, K, of steady-state voltage control gain.

16.3.4. Model CSVGN3

This static var model is identical to CSVGN1 except for an extra controller. For this model, if the voltage magnitude deviates from nominal by V_{ov} per unit, the reactor will be either gated all the way on or off.

16.3.5. Model CSVGN4

This static var model is identical to CSVGN3 except that it allows the static var source to try to regulate the voltage on a remote bus. If the remote bus specified is out-of-service (this includes being disconnected during a simulation) there will be no regulation, i.e., the reactor will remain at its admittance at the time of bus disconnection. When this occurs, an appropriate message is printed. If the remote bus cannot be found, the model will try to hold its own voltage. If a remote bus is specified, its voltage is placed in array ECOMP and the terminal bus of the static var source is placed in ETERM. Both ECOMP and ETERM values may be assigned to channels.

16.3.6. Models CSVGN5 and CSVGN6

CSVGN5 and CSVGN6 are static var system models that were written for a corresponding model in the WSCC stability program. The features of these models include a fast override and remote bus voltage control. For a specified remote bus that is out-of-service or not in the network, these models use the same rules as CSVGN4. The fast override is activated when the voltage error exceeds a threshold values during major disturbances such as faults near the SVC or switching.

The corresponding WSCC model does not separate the equipment to identify capacitor banks and reactors. To maintain the WSCC model structure and to include frequency dependence, CSVGN5 assumes that the output is equal to BMAX and the thyristor-controlled reactor is shut off. If BMAX is positive then the capacitor banks are equal to BMAX times the MVA rating in the power flow from the generator slot. If BMAX is negative, then the equipment is assumed to consist of just reactors.

CSVGN5 requires nonzero values for the parameters VEMAX, TS3, KSVS, BMAX, B ′ MAX, B ′ MIN, BMIN, and TS6. The time constants, TS3 and TS6, must be greater than twice DELT to avoid numerical instability. The other time constants, KSD and DV, may be set to zero. If DV is set to zero then the threshold limits for the fast override are calculated as follows:

1. Upper limit = B ′ MAX/KSVS.

2. Lower limit = B ′ MIN/KSVS.

By setting a nonzero value for DV, the limits are then equal plus or minus the value of DV.

CSVGN6 is different from CSVGN5 in that controller limits are nonwindup. Additional data is specified to have additional shunt equipment switched in-service and a bias is also provided.

16.3.7. Model CSSCS1

CSSCS1 incorporates all the features of CSVGN1, CSVGN3, and CSVGN4. This model is to be used when the static var system is modeled as a switched shunt in the continuous mode in the power flow. The CSSCS1 model assumes that the full range of the switched shunt is continuously controllable.

16.4. Example Case

Figure 16.6, “Sample System for Application of Model CSVGN1 to Represent Static var Generator” shows a small power system model for use in illustrating the application of model CSVGN1. This system model corresponds to a long distance transmission scheme of about 300 miles at 500 kV. The receiving system has only a very small amount of local generation and cannot meet reactive power demands at high load without additional reactive sources. These sources must be controlled in order to maintain proper management of voltage during light load operation and hence must be synchronous condensers or SVGs.

Figure 16.7, “Power Flow Data for CSVGN1 Application Example” shows the base case power flow data and solution for dynamic simulations. Type 2 buses 4 and 5 represent the tertiary terminals of the receiving transformers, each has a generator connected to represent an SVG. Each SVG consists of a 500-Mvar SCR-controlled reactor with a large capacitor connected in parallel with it. The capacitors do not appear in the power flow case because they are treated as an internal part of the SVG and will be so modeled by CSVGN1. The scheduled voltage at buses 4 and 5 is 1.0 pu. The high var limit is set at 500 Mvar, which is the maximum output to be allowed from the SVG in steady-state conditions, the size of the capacitor bank is not defined. If the capacitor should have a rating of 500 Mvar, the var limit setting would be interpreted as a fixed approximation to a variable limit. In this case, however, expect to use a capacitor rating greater than 500 Mvar in heavy load studies; the limit is simply a convenience to ensure that the SVG is initialized well within its dynamic range. The low var limits are set at zero because they are not expected to be active in heavy load cases and the shunt capacitor rating has not yet been selected.

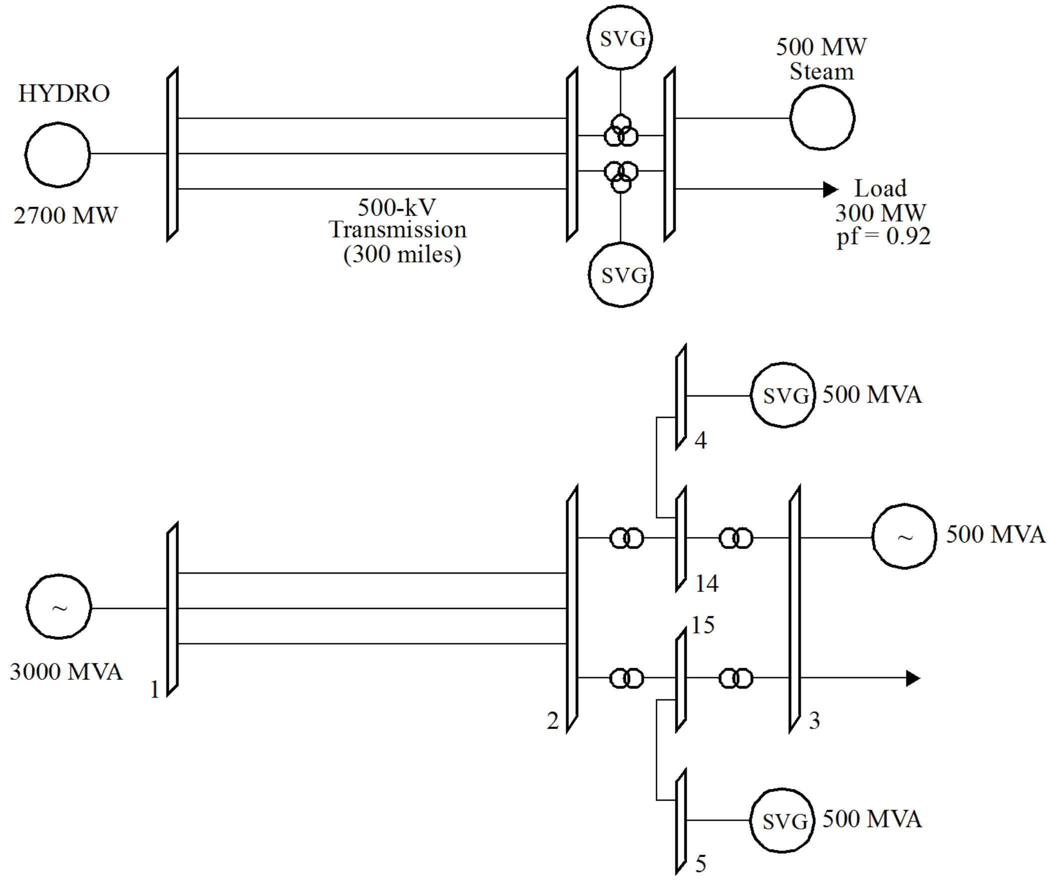


Figure 16.6. Sample System for Application of Model CSVGN1 to Represent Static var Generator

Generator buses for SVGs

```
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED DEC 06, 1995  12:04
 LONG DISTANCE RADIAL TRANSMISSION WITH                                BUS DATA
 STATIC VAR GENERATOR VOLTAGE SUPPORT
  BUS#    NAME    BSKV  CODE LOADS  VOLT   ANGLE       S H U N T  AREA ZONE
     1 HYDRO    500.00   3     0  1.0250    0.0      0.0      0.0    1    1
     2 RECEIVE  500.00   1     0  0.9167  -41.7      0.0      0.0    1    1
     3 LOAD     230.00  -2     1  0.9643  -46.1      0.0    500.0    2    1
     4 TERT1    33.000   2     0  1.0000  -40.9      0.0      0.0    2    1
     5 TERT2    33.000   2     0  1.0000  -40.9      0.0      0.0    2    1
    14 TRMID1            1     0  0.9908  -40.9      0.0      0.0    2    1
    15 TRMDI2            1     0  0.9908  -40.9      0.0      0.0    2    1

--------------------------------------------------------------------------------

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED DEC 06, 1995  12:04
 LONG DISTANCE RADIAL TRANSMISSION WITH                               LOAD DATA
 STATIC VAR GENERATOR VOLTAGE SUPPORT
  BUS#    NAME   BSKV ID COD ST    MVA-LOAD      CUR-LOAD       Y - LOAD  AREA ZONE
     3 LOAD       230 1  -2  1 3000.0 1300.0   0.0     0.0    0.0    0.0     2    1

--------------------------------------------------------------------------------

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED DEC 06, 1995  12:04
 LONG DISTANCE RADIAL TRANSMISSION WITH                              GENERATING
 STATIC VAR GENERATOR VOLTAGE SUPPORT                                PLANT DATA
  BUS#    NAME   BSKV COD MCNS PGEN    QGEN   QMAX   QMIN VSCHED  VACT. REMOT PCT Q
     1 HYDRO      500   3    1 2690.2 1029.6 1500.0 -500.0 1.0250 1.0250
     3 LOAD       230  -2    1  450.0  200.0  200.0    0.0 1.0000 0.9643
     4 TERT1     33.0   2    1    0.0  461.6  500.0    0.0 1.0000 1.0000
     5 TERT2     33.0   2    1    0.0  461.6  500.0    0.0 1.0000 1.0000
```

Generators representing SGVs

```
--------------------------------------------------------------------------------

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED DEC 06, 1995  12:04
 LONG DISTANCE RADIAL TRANSMISSION WITH                               GENERATOR
 STATIC VAR GENERATOR VOLTAGE SUPPORT                                 UNIT DATA
  BUS#    NAME   BSKV COD ID ST PGEN QGEN QMAX QMIN PMAX PMIN MBASE Z S O R C E    X T R A
N   GENTAP
     1 HYDRO      500   3   1  1 2690 1030 1500 -500 9999-9999 3000 0.0000 0.2000 0.0000
0.1500 1.0250
     3 LOAD       230 -2   1  1  450  200  200    0 9999-9999  500 0.0000 0.2000 0.0000
0.1500 1.0125
     4 TERT1     33.0  2   1  1    0  462  500    0 9999-9999  500 0.0000 1.0000
     5 TERT2     33.0  2   1  1    0  462  500    0 9999-9999  500 0.0000 1.0000
```

MBASE equal to SVG reactor rating

```
--------------------------------------------------------------------------------

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED DEC 06, 1995  12:04
 LONG DISTANCE RADIAL TRANSMISSION WITH                             BRANCH DATA
 STATIC VAR GENERATOR VOLTAGE SUPPORT
  FROM     TO CKT NAME      NAME       LINE R  LINE X CHRGING TP ST RATA RATB RATC
     1*     2  1  HYDRO     RECEIVE    0.0050  0.0720  5.5000     1 2000 1000 2500
     1*     2  2  HYDRO     RECEIVE    0.0050  0.0720  5.5000     1 2000 1000 2500
     1*     2  3  HYDRO     RECEIVE    0.0050  0.0720  5.5000     1 2000 1000 2500
     2*    14  1  RECEIVE   TRMID1     0.0000 -0.0010  0.0000  F  1 1500 2000 2500
     2*    15  1  RECEIVE   TRMDI2     0.0000 -0.0010  0.0000  F  1 1500 2000 2500
     3     14* 1  LOAD      TRMID1     0.0000  0.0068  0.0000  T  1 1500 2000 2500
     3     15* 1  LOAD      TRMDI2     0.0000  0.0068  0.0000  T  1 1500 2000 2500
     4     14* 1  TERT1     TRMID1     0.0000  0.0020  0.0000     1    0    0    0
     5     15* 1  TERT2     TRMDI2     0.0000  0.0020  0.0000     1    0    0    0

--------------------------------------------------------------------------------

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED DEC 06, 1995  12:04
 LONG DISTANCE RADIAL TRANSMISSION WITH                        TRANSFORMER DATA
 STATIC VAR GENERATOR VOLTAGE SUPPORT
  FROM     TO CKT TP RATIO  ANGLE RG  CONT   RMAX    RMIN    VMAX    VMIN   STEP TABLE
CR         CX
     2     14   1  F 0.9250   0.00 1       3 1.0750  0.9250  1.0000  0.9800 0.00625
     2     15   1  F 0.9250   0.00 1       3 1.0750  0.9250  1.0000  0.9800 0.00625
     3     14   1  T 1.0000   0.00 1       0 1.5000  0.5100  1.5000  0.5100 0.00625
     3     15   1  T 1.0000   0.00 1       0 1.5000  0.5100  1.5000  0.5100 0.00625

--------------------------------------------------------------------------------

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED DEC 06, 1995  12:04
 LONG DISTANCE RADIAL TRANSMISSION WITH                       LINE SHUNT DATA
 STATIC VAR GENERATOR VOLTAGE SUPPORT
 X------FROM------X X--------TO-------X CKT    LINE G,B  (FROM)    LINE G,B  (TO) ST
     1 HYDRO      500     2 RECEIVE  500  1    0.0000  -2.0000   0.0000    0.0000 1
     1 HYDRO      500     2 RECEIVE  500  2    0.0000  -2.0000   0.0000    0.0000 1
     1 HYDRO      500     2 RECEIVE  500  3    0.0000  -2.0000   0.0000    0.0000 1
```

Line-connected shunt reactors at sending end

Figure 16.7. Power Flow Data for CSVGN1 Application Example

Figure 16.8, “Base Case for CSVGN1 Application Example” shows the initial condition power flow solution with the SVGs appearing as conventional generators at buses 4 and 5. This power flow case is ready for conversion to a dynamics initial condition with activities CONG and CONL in the conventional manner. Figure 16.9, “Dynamic Simulation Setup Main Elements” shows the main elements of the dynamic simulation setup. The CSVGN1 data is entered in appropriate records in the Dynamics Data File in the same way as for a generator. DYRE creates calls in both CONEC and CONET but, apart from this, the SVG model is linked to the power flow case in the same way as the conventional generator model, GENROU. The SVG reactive power output and terminal voltage are available in the generator condition arrays, QGEN, ETERM, etc., and can be assigned directly to output channels. CSVGN1 incorporates both voltage regulator and main SVG modeling, and uses arrays VREF and VOTHSG as appropriate. The CSVGN1 leaves the values of PGEN and EFD at zero, because it is only a reactive power device and uses no excitation voltage.

Figure 16.10, “Initialization of Dynamic Simulation Run Using CSVGN1” shows the initialization of a dynamic simulation run. The two SVGs at buses 4 and 5 are handled as generators in STRT and their terminal reactive flow and voltage are displayed as channels by selecting the corresponding generator QGEN and ETERM arrays.

Figure 16.11, “System Response to Fault at Bus 2 Opening of One 500-kV Line and Line Reclosure, 500-Mvar Capacitor” shows simulation results obtained with the setup shown in Figure 16.10, “Initialization of Dynamic Simulation Run Using CSVGN1”. A single line-to-ground fault was applied at the receiving 500-kV bus and cleared after three cycles by opening one of the 500-kV lines. The circuit was reclosed at t = 2.0.

Figure 16.11, “System Response to Fault at Bus 2 Opening of One 500-kV Line and Line Reclosure, 500-Mvar Capacitor” also shows system response when the capacitor element of the SVG is sized at 500 MVA and the gain of the voltage regulator gain (CON(J)) is set at 100. The reactor is nearly off initially and remains so throughout the period when the third 500-kV line is out-of-service. The combined control action of the SVGs and the voltage regulator of the receiving-end generator is not able to restore voltage to nominal while the line is opened. On reclosing the line, the reactor element of the SVG is turned on in response to the voltage rise and the load bus voltage is restored to nominal value in 5 sec.

Figure 16.12, “System Response to Fault at Bus 2 as Figure 16.11, “System Response to Fault at Bus 2 Opening of One 500-kV Line and Line Reclosure, 500-Mvar Capacitor” but with 800-Mvar Capacitors in SVGs” shows the system response when the capacitor elements of the SVGs are sized at 800 Mvar. Here the voltage falls to a somewhat lower instantaneous minimum while the 500-kV line is opened, but is restored much more rapidly to nominal value when it is reclosed.

```
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED DEC 06, 1995  12:10
LONG DISTANCE RADIAL TRANSMISSION WITH                                   RATING
STATIC VAR GENERATOR VOLTAGE SUPPORT                                      SET A

BUS      1 HYDRO     500 AREA CKT     MW     MVAR     MVA  %I 1.0250PU   0.00     1
 GENERATION                 1      2690.2  1029.6R 2880.5  96 512.50KV
 TO      2 RECEIVE   500    1  1    896.7    343.2   960.2  47
 TO      2 RECEIVE   500    1  2    896.7    343.2   960.2  47
 TO      2 RECEIVE   500    1  3    896.7    343.2   960.2  47

BUS      2 RECEIVE   500 AREA CKT     MW     MVAR     MVA  %I 0.9167PU -41.66     2
                            1                                 458.33KV
 TO      1 HYDRO     500    1  1   -850.0     20.1   850.2  46
 TO      1 HYDRO     500    1  2   -850.0     20.1   850.2  46
 TO      1 HYDRO     500    1  3   -850.0     20.1   850.2  46
 TO     14 TRMID1           2  1   1275.0    -30.1  1275.4  93 0.9250LO
 TO     15 TRMDI2           2  1   1275.0    -30.1  1275.4  93 0.9250LO

BUS      3 LOAD      230 AREA CKT     MW     MVAR     MVA  %I 0.9643PU -46.12     3
 GENERATION                 2       450.0    200.0H  492.4  98 221.79KV
 TO LOAD-PQ                        3000.0   1300.0  3269.6
 TO SHUNT                             0.0   -464.9   464.9
 TO     14 TRMID1           2  1  -1275.0   -317.5  1313.9  91 1.0000UN
 TO     15 TRMDI2           2  1  -1275.0   -317.5  1313.9  91 1.0000UN

BUS      4 TERT1    33.0 AREA CKT     MW     MVAR     MVA  %I 1.0000PU -40.92     4
 GENERATION                 2         0.0    461.6R  461.6  92 33.000KV
 TO     14 TRMID1           2  1      0.0    461.6   461.6

BUS      5 TERT2    33.0 AREA CKT     MW     MVAR     MVA  %I 1.0000PU -40.92     5
 GENERATION                 2         0.0    461.6R  461.6  92 33.000KV
 TO     15 TRMDI2           2  1      0.0    461.6   461.6

BUS     14 TRMID1            AREA CKT     MW     MVAR     MVA  %I 0.9908PU -40.92    14
                            2                                       KV
 TO      2 RECEIVE   500    1  1  -1275.0     13.5  1275.1  86 0.9250UN
 TO      3 LOAD      230    2  1   1275.0    443.8  1350.0  91 1.0000LK
 TO      4 TERT1    33.0    2  1      0.0   -457.3   457.3

BUS     15 TRMDI2            AREA CKT     MW     MVAR     MVA  %I 0.9908PU -40.92    15
                            2                                       KV
 TO      2 RECEIVE   500    1  1  -1275.0     13.5  1275.1  86 0.9250UN
 TO      3 LOAD      230    2  1   1275.0    443.8  1350.0  91 1.0000LK
 TO      5 TERT2    33.0    2  1      0.0   -457.3   457.3

--------------------------------------------------------------------------------

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED DEC 06, 1995  12:10
LONG DISTANCE RADIAL TRANSMISSION WITH
STATIC VAR GENERATOR VOLTAGE SUPPORT

MACHINE SUMMARY:
  BUS    NAME BSVLT ID      MW      MVAR  ETERM CURRENT    PF   MVABASE    X T R A N    GENTAP
    1 HYDRO     500 1  2690.2  1444.5 1.0600  2880.5  0.8810  3000.0 0.0000 0.1500 1.0250
    3 LOAD      230 1   450.0   280.2 1.0252   517.1  0.8489   500.0 0.0000 0.1500 1.0125
    4 TERT1    33.0 1     0.0   461.6 1.0000   461.6  0.0000   500.0
    5 TERT2    33.0 1     0.0   461.6 1.0000   461.6  0.0000   500.0
SUBSYSTEM TOTALS       3140.2  2647.8                         4500.0
```

SVGs within regulating range

Figure 16.8. Base Case for CSVGN1 Application Example

CSVGN1

Static Shunt Compensator

This device is located at system bus	# 4	IBUS,	
machine	#_____	I,	
This model uses CONs starting with	#_____	J,	

and STATEs starting with	#_____	K,	
and VAR	#_____	L,	
and ICON	#_____	M.	
The reactor Mvar base = 500 MBASE.			

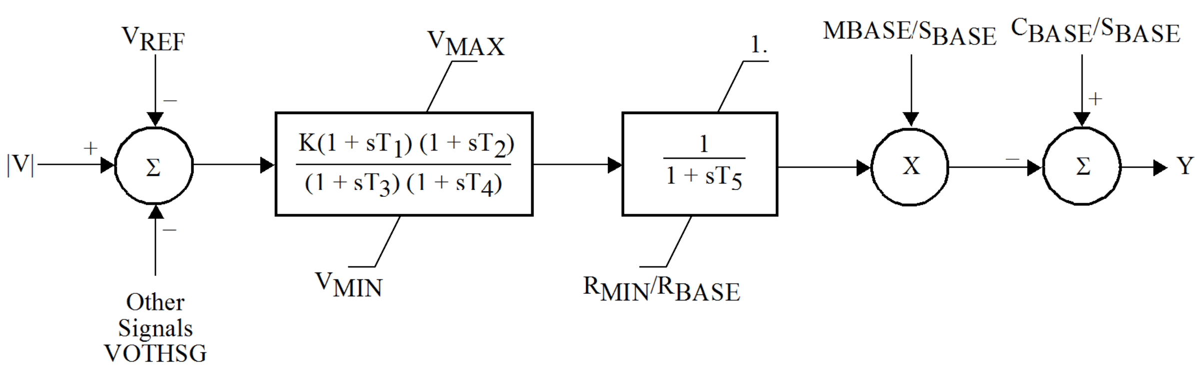
CONs	#	Value	Description
J		100	K
J+1		1	T_1
J+2		0	T_2
J+3		10	T_3 (>0)
J+4		0	T_4
J+5		0.05	T_5
J+6		0.	R_{MIN} (reactor minimum Mvar)
J+7		1.	V_{MAX}
J+8		0.	V_{MIN}
J+9		500.	C_{BASE} (capacitor Mvar)

STATEs	#	Description
K		First regulator
K+1		Second regulator
K+2		Thyristor

VARs	#	Description
L		Y (model output)

ICON	#	Description
M		Memory

IBUS, 'CSVGN1', I, K, T_1, T_2, T_3, T_4, T_5, R_{MIN}, V_{MAX}, V_{MIN}, C_{BASE}/



```
1 'GENSAL' 1 5 .05 .06 4 1 1.8 1.6 .5 .2 .1 .03 .05/
3 'GENROU' 1 6 .05 1.5 .05 3 1 1.5 1.45 .4 .6 .2 .1 .03 .3/
4 'CSVGN1' 1 100 1 0 10 0 .05 0 1. 0. 500./
5 'CSVGN1' 1 100 1 0 10 0 .05 0 1. 0. 500./
1 'SEXS' 1 .1 10 100 .1 0 3/
3 'SEXS' 1 .1 10 100 .1 0 3/
```

Note machine numbers for CSVGN1 as for generators

Figure 16.9. Dynamic Simulation Setup Main Elements

```
Executing activity STRT


    PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      TUE DEC 12, 1995  11:45
LONG DISTANCE RADIAL TRANSMISSION WITH
STATIC VAR GENERATOR VOLTAGE SUPPORT

INITIAL CONDITION LOAD FLOW USED  1 ITERATIONS

-------------------------MACHINE INITIAL CONDITIONS--------------------------
X------ BUS -----X ID  ETERM   EFD    POWER    VARS   P.F.  ANGLE   ID     IQ
    1 HYDRO    500  1 1.0600 2.4913 2690.26 1029.57 0.9339  44.43 0.8729 0.4001
    3 LOAD     230  1 1.0252 2.4828  450.01  199.99 0.9138  -5.58 0.9334 0.4451
    4 TERT1   33.0  1 1.0000 0.0000    0.00  461.57 0.0000   0.00 0.6976-0.6046
    5 TERT2   33.0  1 1.0000 0.0000    0.00  461.57 0.0000   0.00 0.6976-0.6046

INITIAL CONDITIONS CHECK O.K.

  TIME X- VALUE --X X--------- IDENTIFIER ---------X X- VALUE --X X--------- IDENTIFIER ---------X
-0.0167  0.91667     VOLT     2 [RECEIVE 500.00]        44.435     ANGL     1 [HYDRO   500.00] MC 1
    3    -5.5797     ANGL     3 [LOAD    230.00] MC 1   26.903     POWR     1 [HYDRO   500.00] MC 1
    5     4.5001     POWR     3 [LOAD    230.00] MC 1   10.296     VARS     1 [HYDRO   500.00] MC 1
    7     1.9999     VARS     3 [LOAD    230.00] MC 1   4.6157     VARS     4 [TERT1   33.000] MC 1
    9     4.6157     VARS     5 [TERT2   33.000] MC 1   1.0600     ETRM     1 [HYDRO   500.00] MC 1
   11     1.0252     ETRM     3 [LOAD    230.00] MC 1   1.0000     ETRM     4 [TERT1   33.000] MC 1
   13     1.0000     ETRM     5 [TERT2   33.000] MC 1   2.4913     EFD      1 [HYDRO   500.00] MC 1
   15     2.4828     EFD      3 [LOAD    230.00] MC 1  0.00000     SPD      1 [HYDRO   500.00] MC 1
   17     0.00000     SPD      3 [LOAD    230.00] MC 1

-0.0083  0.91667       44.435       -5.5797       26.903       4.5001       10.296
    7     1.9999       4.6158        4.6158       1.0600       1.0252       1.0000
   13     1.0000       2.4913        2.4828     0.18626E-09 -0.17385E-08
```

SVGs are standard synchronous machine in STRT

Figure 16.10. Initialization of Dynamic Simulation Run Using CSVGN1

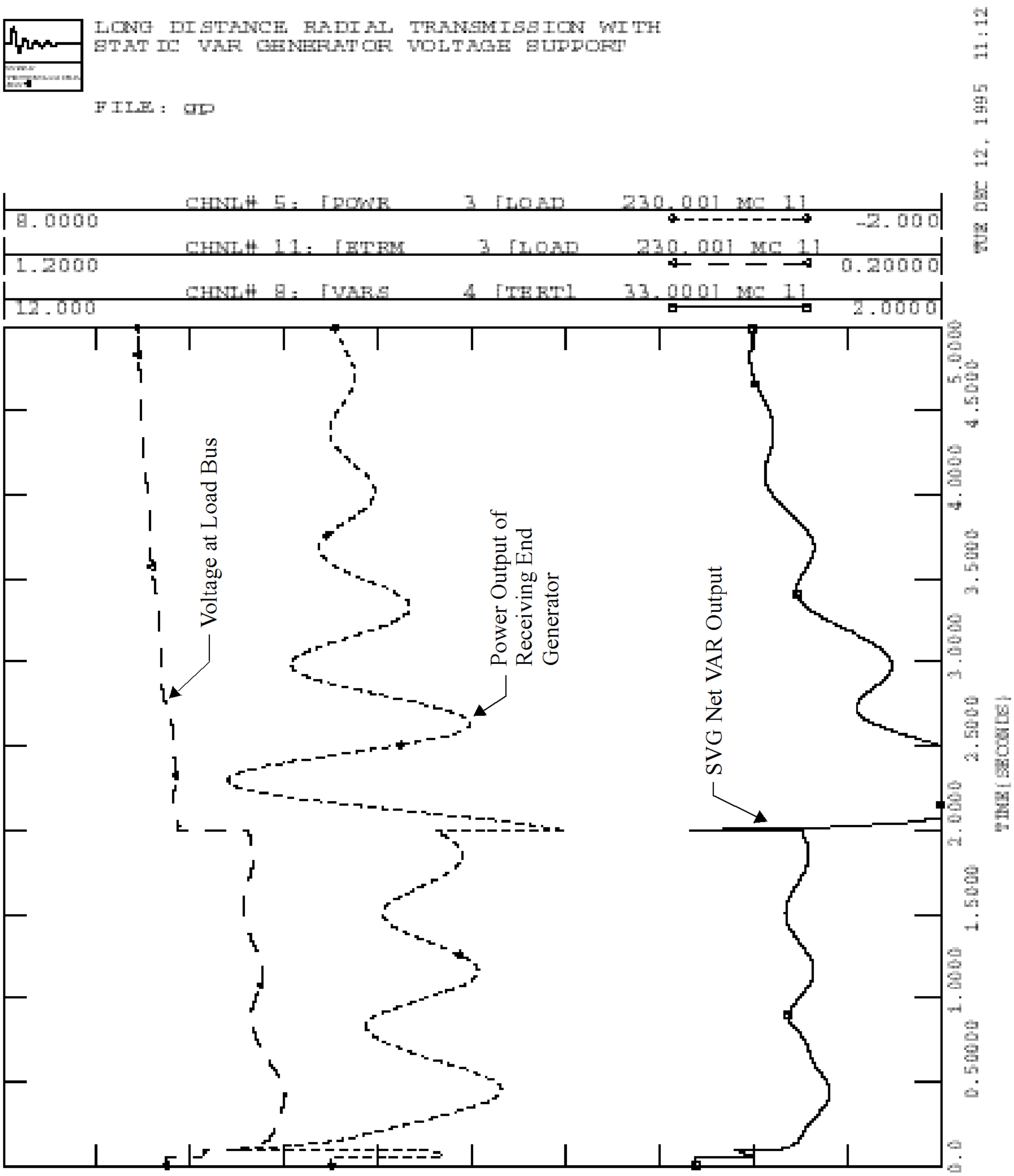


Figure 16.11. System Response to Fault at Bus 2 Opening of One 500-kV Line and Line Reclosure, 500-Mvar Capacitor

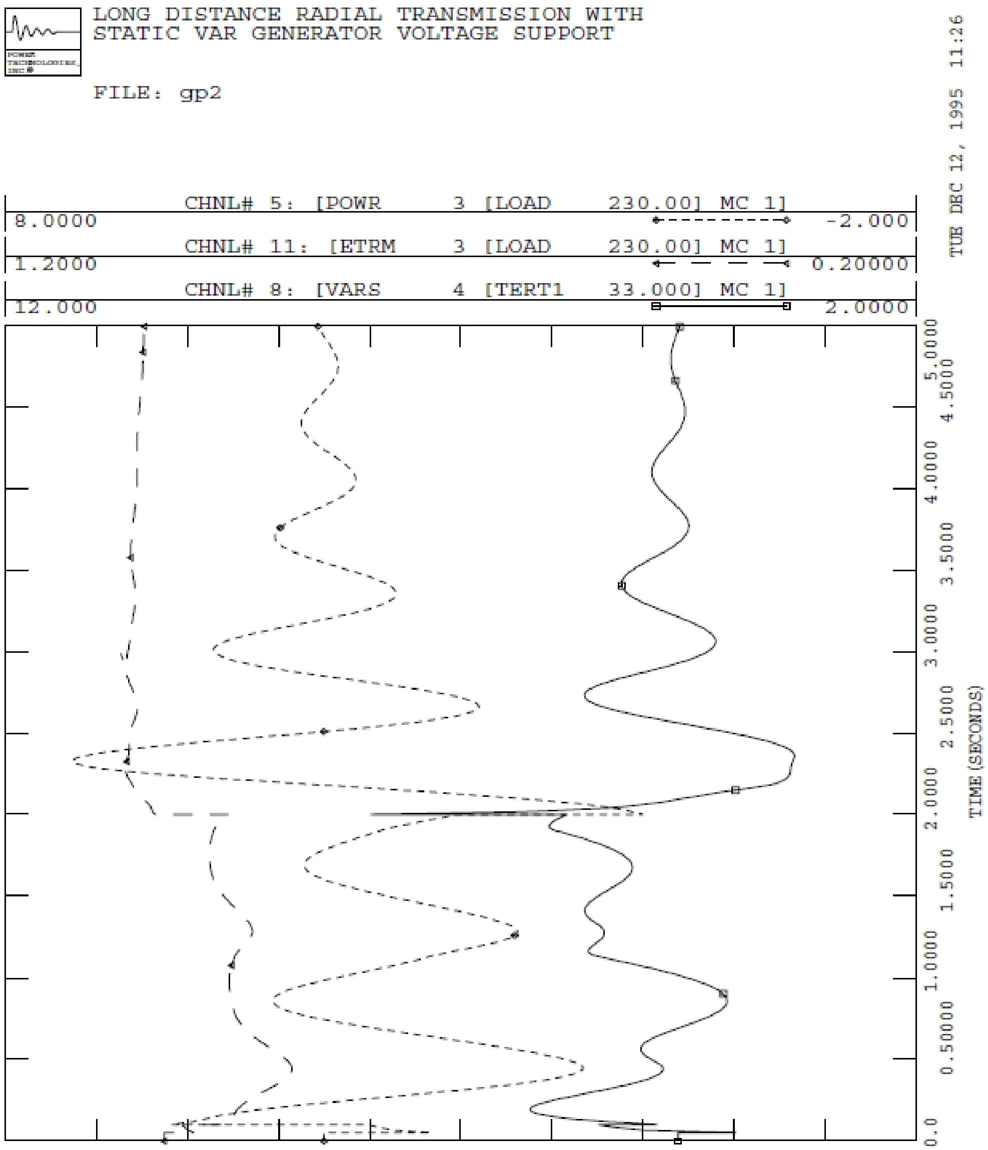


Figure 16.12. System Response to Fault at Bus 2 as Figure 16.11, "System Response to Fault at Bus 2 Opening of One 500-kV Line and Line Reclosure, 500-Mvar Capacitor" but with 800-Mvar Capacitors in SVGs

16.4.1. Example Case 2

A second example case was set up to illustrate the use of the SVC model CSVGN5 and the supplementary signal model STBSVC. The electrical network is shown in Figure 16.13, "One-Line Impedance Diagram", which represents a large hydro plant at the sending end of a long EHV transmission system. SVCs are placed along the EHV transmission to provide voltage support at buses 2, 3, and 4. The receiving system is represented by buses 5 and 15 with local steam generation at bus 5. The range for the SVCs is from -300 Mvar to 600 Mvar. The solved power flow case is shown in Figure 16.14, "Solved Power Flow Case".

The dynamic equipment data obtained from activity DOCU are listed in Figure 16.15, "Dynamic Equipment Data (Sheet 1 of 5)". For the SVCs, the MVA rating is equal to the SVC's maximum output, making B_{MAX} equal to 1 pu. Also, each SVC is controlling the high-side voltage of the transformer to which it is connected. A supplementary control is included for the SVC at bus 2. The input signal is derived from the electrical power of the hydro plant. The disturbance for the simulation runs was a line-to-ground fault at bus 11 using an admittance of –j10,000 MVA. The fault was cleared in six cycles with the outage of one line from bus 11 to bus 12.

Changing the model status with activity DYCH model STBSVC was disabled so that no supplementary signals were produced. The plots for the first simulation run are shown in Figure 16.20, "L-G Fault, No Supplementary Control, Hydro Unit" through Figure 16.22, "L-G Fault, No Supplementary Control, SVC-Bus 12". Plots for the simulation supplementary control for the SVC at bus 2 are shown in Figure 16.23, "L-G Fault, Supplementary Control, Hydro Unit" through Figure 16.25, "L-G Fault, Supplementary Control, Steam Unit". The plot of the rotor angle difference between the hydro unit and the steam unit is shown in Figure 16.26, "Rotor Angle Difference for the Two Runs" for the two runs. Employment of supplementary control increased the damping even though the system is well damped without the device.

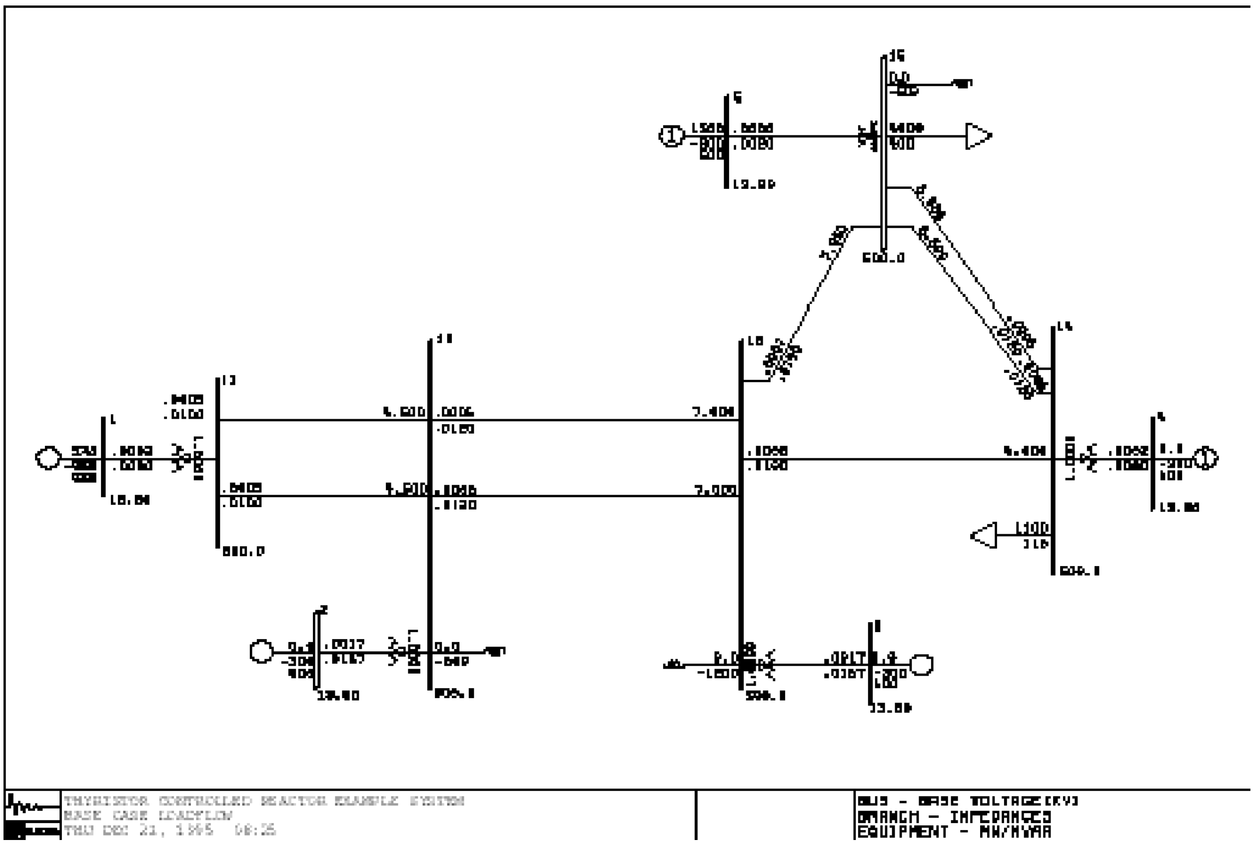


Figure 16.13. One-Line Impedance Diagram

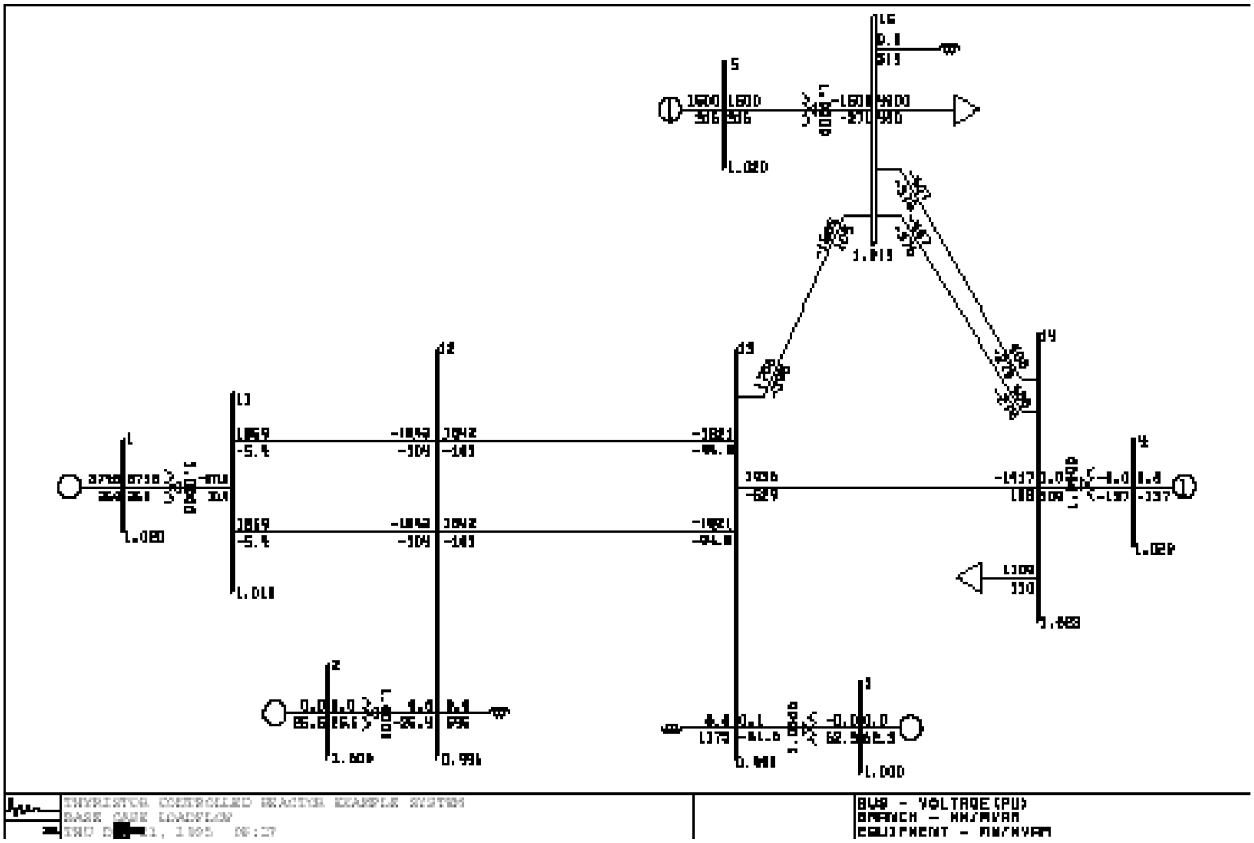


Figure 16.14. Solved Power Flow Case

```
1      PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU DEC 21, 1995
09:45
 THYRISTOR CONTROLLED REACTOR EXAMPLE SYSTEM
 BASE CASE LOADFLOW

 REPORT FOR ALL MODELS AT ALL BUSES        BUS     1 [HYDRO   13.8] PLANT
MODELS


         ** GENSAL **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S
                         1 HYDRO   13.8   1       1-   12     1-    5

            MBASE     Z S O R C E          X T R A N       GENTAP
           4000.0  0.00000+J 0.18000  0.00000+J 0.00000  1.00000

  T'DO   T''DO   T''QO     H    DAMP    XD      XQ     X'D    X''D     XL
 8.000   0.050   0.100   4.00   0.00  0.8000  0.5000  0.3000  0.1800  0.1200

                                 S(1.0)  S(1.2)
                                 0.1000  0.4000


         ** STAB1 **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S
                        1 HYDRO   13.8   1      69-   75     24-   26

      K/T         T        T1/T3       T3       T2/T4       T4       LIMIT
     20.000     3.000      5.000     0.050      5.000     0.050      0.100

          ** SEXS **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S
                        1 HYDRO   13.8   1      95-  100     35-   36

                TA/TB     TB      K       TE      EMIN    EMAX
                0.300   2.500   200.0   0.050   -3.20   4.00
```

a. Bus 1

Figure 16.15. Dynamic Equipment Data (Sheet 1 of 5)

```
1      PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU DEC 21, 1995  09:45
 THYRISTOR CONTROLLED REACTOR EXAMPLE SYSTEM
 BASE CASE LOADFLOW

 REPORT FOR ALL MODELS AT ALL BUSES        BUS     2 [SVC-1   13.8] PLANT MODELS

  ** CSVGN5 **  BUS   NAME  BSKV MACH  C O N ' S     STATE'S   VAR   I C O N'S
                  2 SVC-1  13.8    1   13-   26     6-    9     1     1-    2

       MBASE  REMOTE BUS   TS1    VEMAX    TS2     TS3     TS4     TS5
       600.0        12    0.000   0.150   0.100   5.000   0.000   0.000

          KSVS    KSD    BMAX   B'MAX   B'MIN   BMIN    TS6     DV
         400.0    0.0   1.000   1.000  -0.500  -0.500  0.050   0.150

   ** STBSVC **  BUS   NAME  BSKV MC  C O N ' S     STATE'S   VAR   I C O N'S
                   2 SVC-1   13.8 1   76-   87     27-   31     4     7-   12

   I1 I2 BUS#1  TO BUS  ID  BUS#2     KS1      TS7      TS8      TS9      TS13
    1  0     1       0  '1 '     0  1.0000   0.0000   0.0000   0.1000   1.0000

          TS14     KS3   VSCSMAX     KS2     TS10     TS11     TS12
         4.0000  2.0000   0.1000  0.0000   0.0000   0.0000   0.0000
```

b. Bus 2

Figure 16.16. Dynamic Equipment Data (Sheet 2 of 5)

```
1      PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU DEC 21, 1995  09:45
 THYRISTOR CONTROLLED REACTOR EXAMPLE SYSTEM
 BASE CASE LOADFLOW

 REPORT FOR ALL MODELS AT ALL BUSES        BUS     3 [SVC-2   13.8] PLANT MODELS

  ** CSVGN5 **  BUS   NAME  BSKV MACH  C O N ' S     STATE'S   VAR   I C O N'S
                  3 SVC-2  13.8    1   27-   40    10-   13     2     3-    4

       MBASE  REMOTE BUS   TS1    VEMAX    TS2     TS3     TS4     TS5
       600.0        13    0.000   0.150   0.100   5.000   0.000   0.000

          KSVS    KSD    BMAX   B'MAX   B'MIN   BMIN    TS6     DV
         400.0    0.0   1.000   1.000  -0.500  -0.500  0.050   0.150
```

c. Bus 3

Figure 16.17. Dynamic Equipment Data (Sheet 3 of 5)

```
1      PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU DEC 21, 1995  09:45
 THYRISTOR CONTROLLED REACTOR EXAMPLE SYSTEM
 BASE CASE LOADFLOW

 REPORT FOR ALL MODELS AT ALL BUSES        BUS     4 [SVC-3   13.8] PLANT MODELS


  ** CSVGN5 **  BUS   NAME  BSKV MACH  C O N ' S     STATE'S   VAR   I C O N'S
                  4 SVC-3  13.8   1    41-   54    14-   17    3     5-    6

       MBASE  REMOTE BUS   TS1    VEMAX    TS2     TS3     TS4     TS5
       600.0        14    0.000   0.150   0.100   5.000   0.000   0.000

         KSVS    KSD    BMAX   B'MAX   B'MIN    BMIN    TS6      DV
         400.0   0.0   1.000   1.000  -0.500  -0.500   0.050   0.150
```

d. Bus 4

Figure 16.18. Dynamic Equipment Data (Sheet 4 of 5)

```
1      PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU DEC 21, 1995  09:45
 THYRISTOR CONTROLLED REACTOR EXAMPLE SYSTEM
 BASE CASE LOADFLOW

 REPORT FOR ALL MODELS AT ALL BUSES        BUS     5 [STEAM   13.8] PLANT MODELS


        ** GENROU **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S
                        5 STEAM  13.8   1     55-   68    18-   23

            MBASE      Z S O R C E          X T R A N        GENTAP
           4000.0  0.00000+J 0.34000  0.00000+J 0.00000  1.00000

 T'D0 T''D0  T'Q0 T''Q0    H   DAMP   XD      XQ      X'D     X'Q    X''D     XL
 5.60 0.060  0.63 0.060   4.00  0.00 1.6000 1.5500 0.4900 0.6500 0.3400 0.2000

                               S(1.0)  S(1.2)
                               0.1000  0.4000


        ** STAB1 **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S
                       5 STEAM  13.8   1     88-   94    32-   34

    K/T         T        T1/T3       T3       T2/T4      T4       LIMIT
   20.000     3.000     5.000     0.050     5.000     0.050     0.100


         ** SEXS **  BUS   NAME  BSKV MACH   C O N ' S     STATE'S
                       5 STEAM  13.8   1     101-  106    37-   38

              TA/TB    TB      K       TE     EMIN   EMAX
              0.300   2.500  200.0   0.050   -3.20   4.00
```

e. Bus 5

Figure 16.19. Dynamic Equipment Data (Sheet 5 of 5)

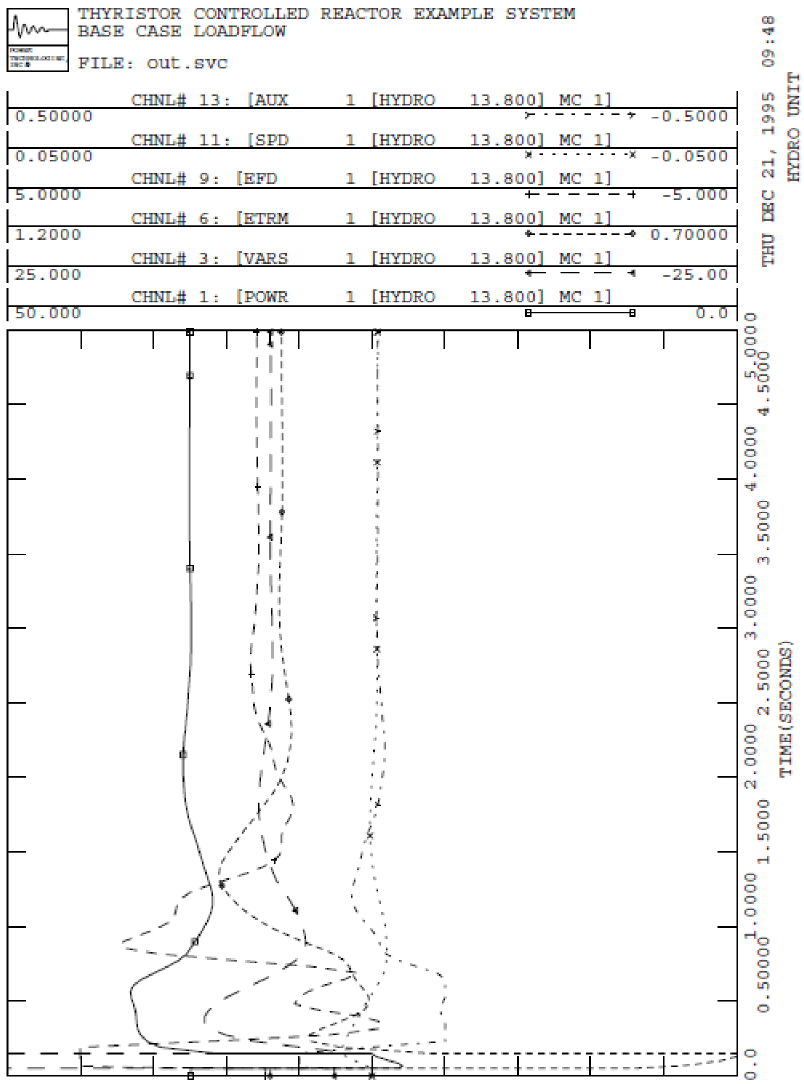


Figure 16.20. L-G Fault, No Supplementary Control, Hydro Unit

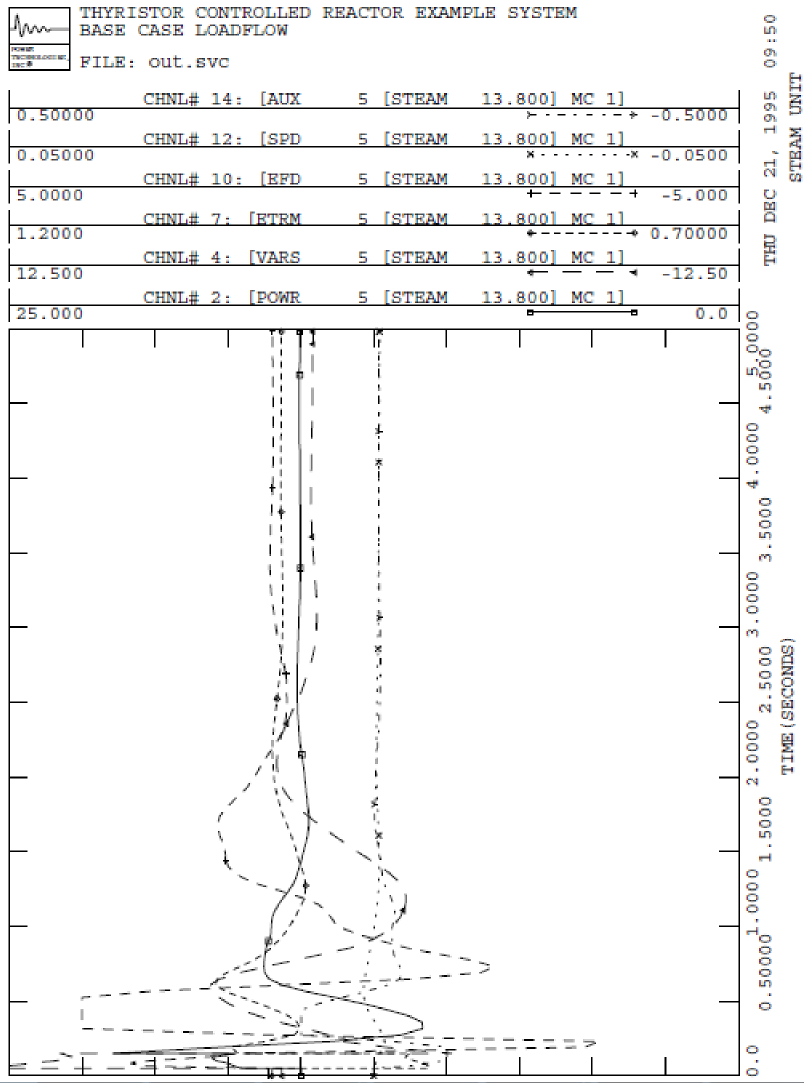


Figure 16.21. L-G Fault, No Supplementary Control, Steam Unit

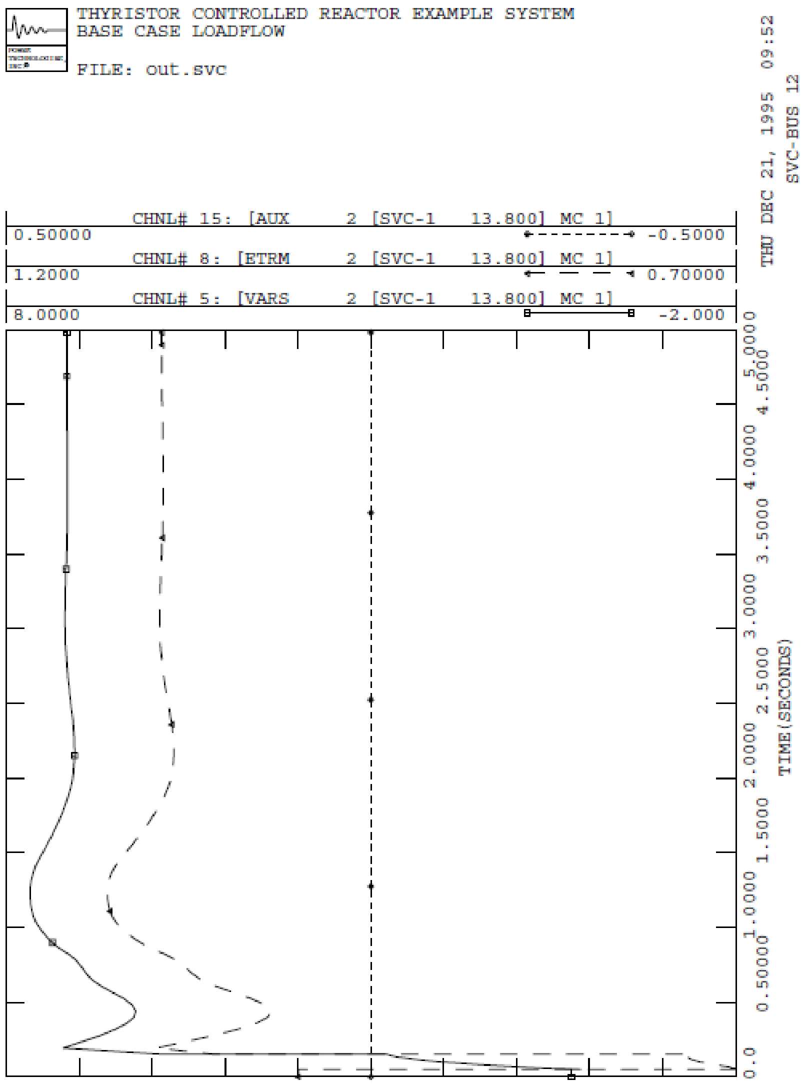


Figure 16.22. L-G Fault, No Supplementary Control, SVC-Bus 12

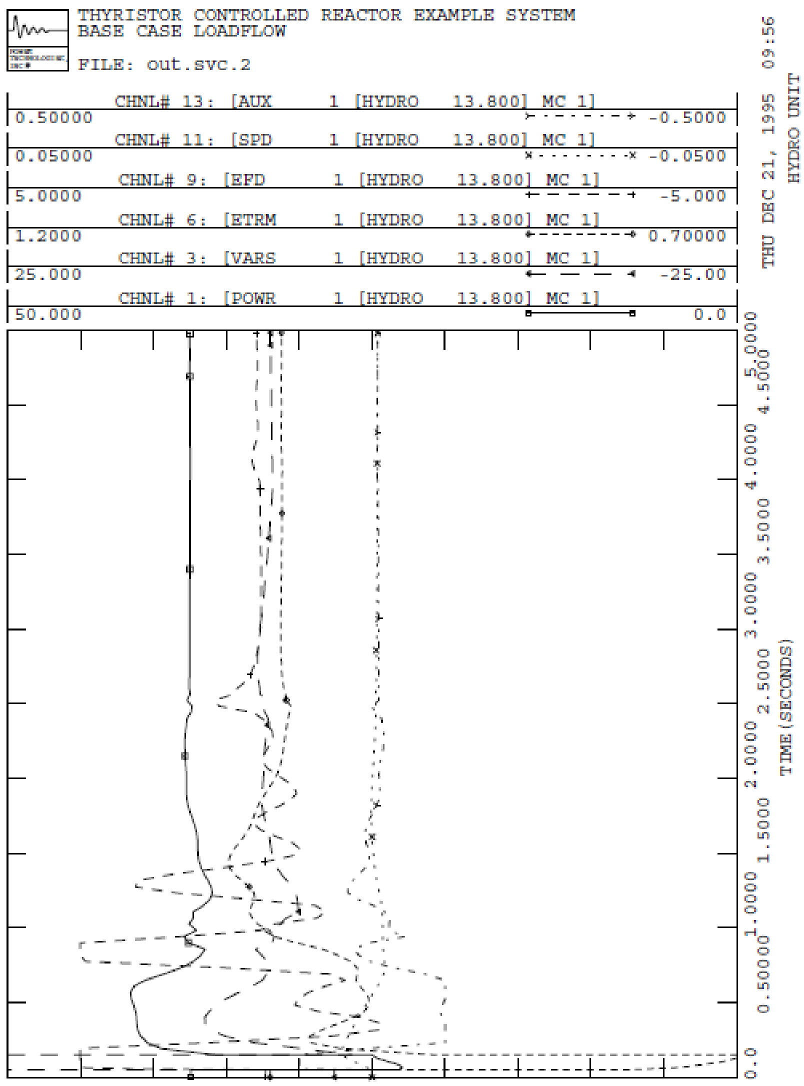


Figure 16.23. L-G Fault, Supplementary Control, Hydro Unit

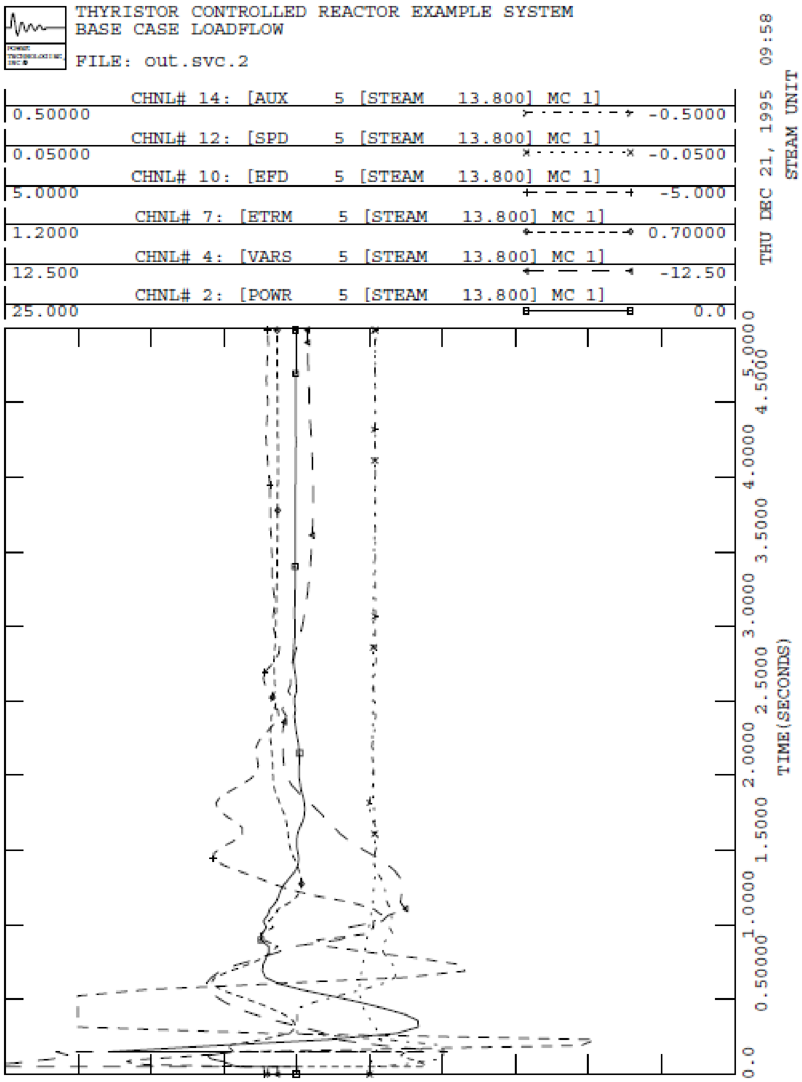


Figure 16.24. L-G Fault, Supplementary Control, Steam Unit

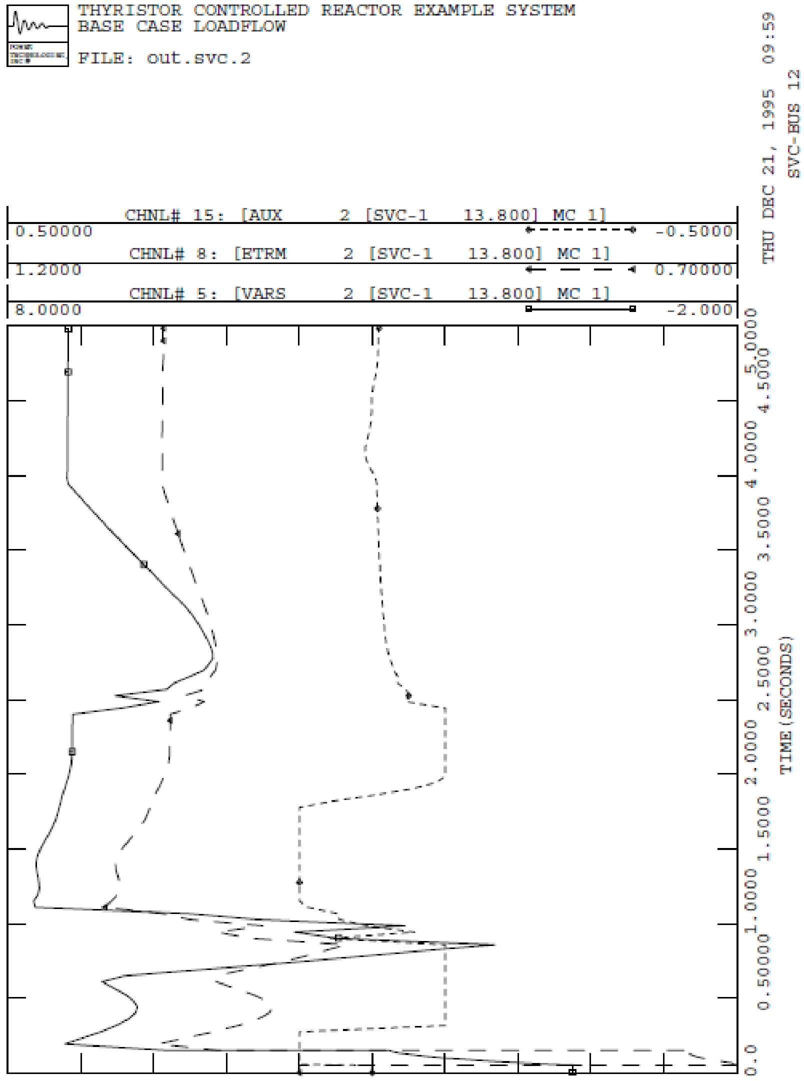


Figure 16.25. L-G Fault, Supplementary Control, Steam Unit

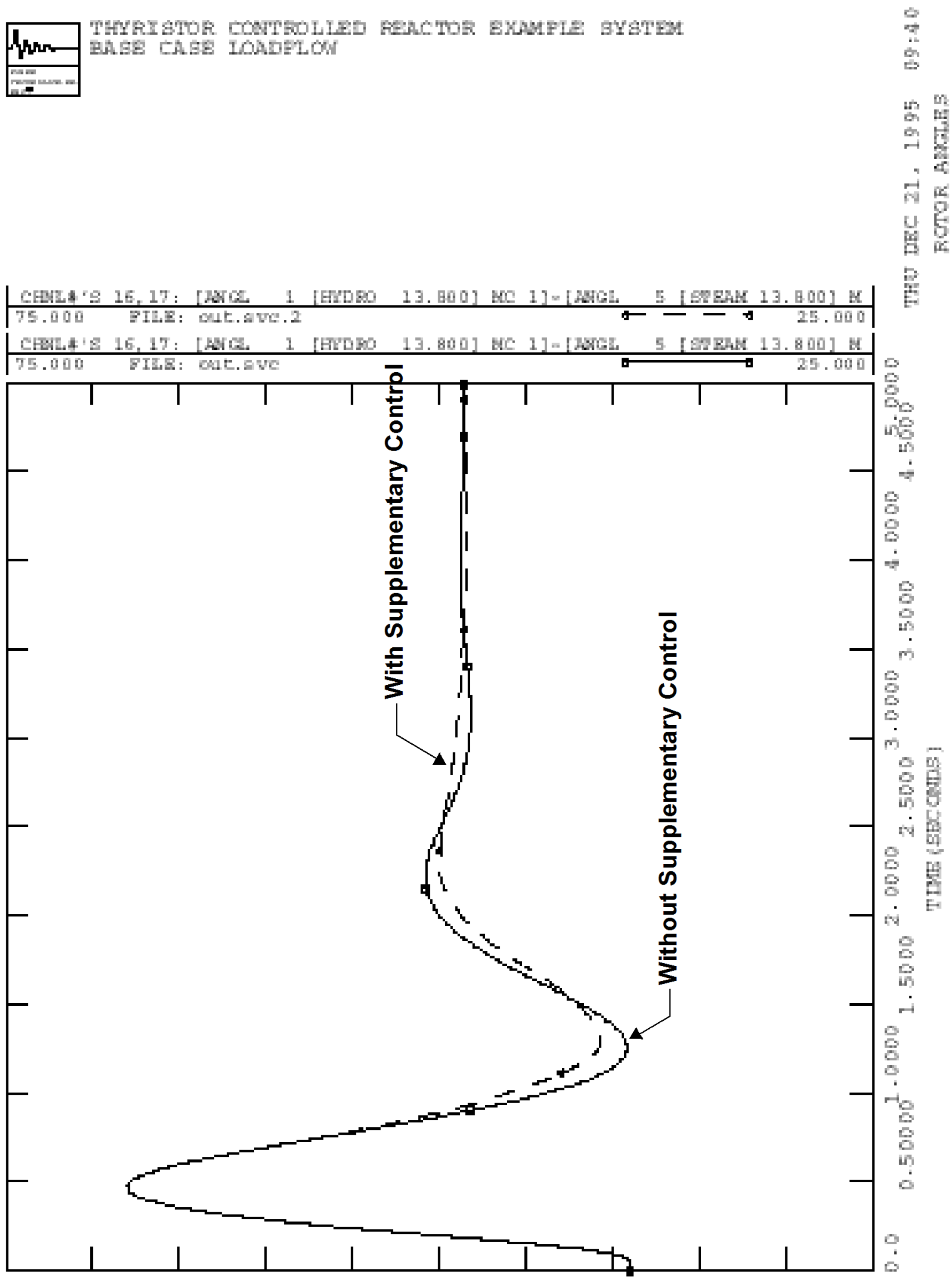


Figure 16.26. Rotor Angle Difference for the Two Runs

CSVGN1

Static Shunt Compensator

This device is located at system bus	#______	IBUS,	
machine	#______	I,	
This model uses CONs starting with	#______	J,	
and STATEs starting with	#______	K,	
and VAR	#______	L,	
and ICON	#______	M.	
The reactor Mvar base = ____________ MBASE.			

CONs	#	Value	Description
J			K
J+1			T_1
J+2			T_2
J+3			T_3 (>0)
J+4			T_4
J+5			T_5
J+6			R_{MIN} (reactor minimum Mvar)
J+7			V_{MAX}
J+8			V_{MIN}
J+9			C_{BASE} (capacitor Mvar)

STATEs	#	Description
K		First regulator
K+1		Second regulator
K+2		Thyristor

VARs	#	Description
L		Y (model output)

ICON	#	Description
M		Memory

IBUS, 'CSVGN1', I, K, T_1, T_2, T_3, T_4, T_5, R_{MIN}, V_{MAX}, V_{MIN}, C_{BASE}/

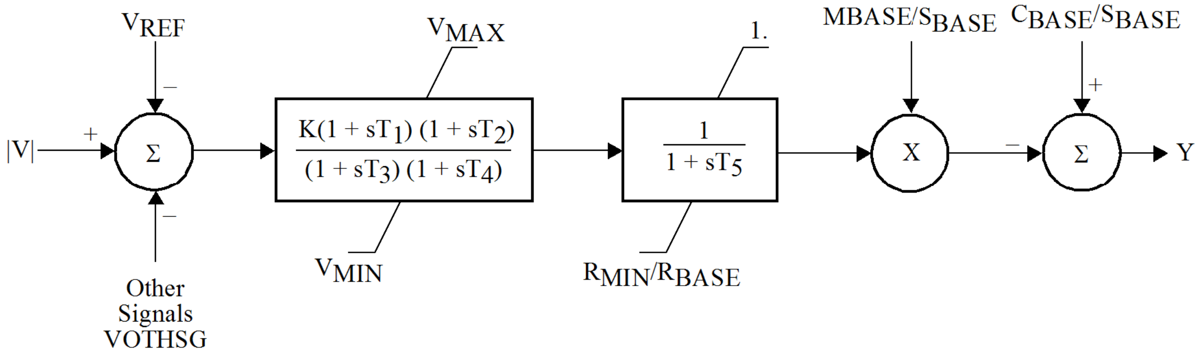


Figure 16.27. PSS®E Model of CSVGN1

16.5. Control Tuning of an SVG

For this example, assume that the SVG is as shown in Figure 16.2, "Static var Source Application", a controlled reactor in parallel with a fixed capacitor bank. The SVG control function is shown in Figure 16.27, "PSS®E Model of CSVGN1". The approach used to tune the SVS is, after it is understood, quite simple and straightforward.

1. First, determine the change in voltage for a change in SVG admittance (de/dy) for the weakest system configuration that is likely to occur, as this will present the severest control problem. The weakest system results in the greatest change (highest de/dy). Represent generators as in the dynamic runs, and solve the power flow with and without an admittance. For example, assume a 100-Mvar reactor causes a voltage change of about 5.6% or de/dy = 0.056 on 100-MVA base.
2. Choose the SVG controller steady-state gain, which will normally be in the range of 100 to 200. Use a gain of 150, which means a 0.66% error in voltage will drive the SVS to ceiling.
3. Assume the SVG time constant of 0.03 sec. Modern SVG controls are very fast and this small time constant should be realizable by standard equipment.
4. Although the SVG block diagram shows a double lead-lag, which can be used to reduce the high steady-state gain to get stable operation at the crossover frequency, use only one of the lags (T_3). The Bode plot of the controller is shown in Figure 16.28, "Bode Plot of Simplified SVG Controller".

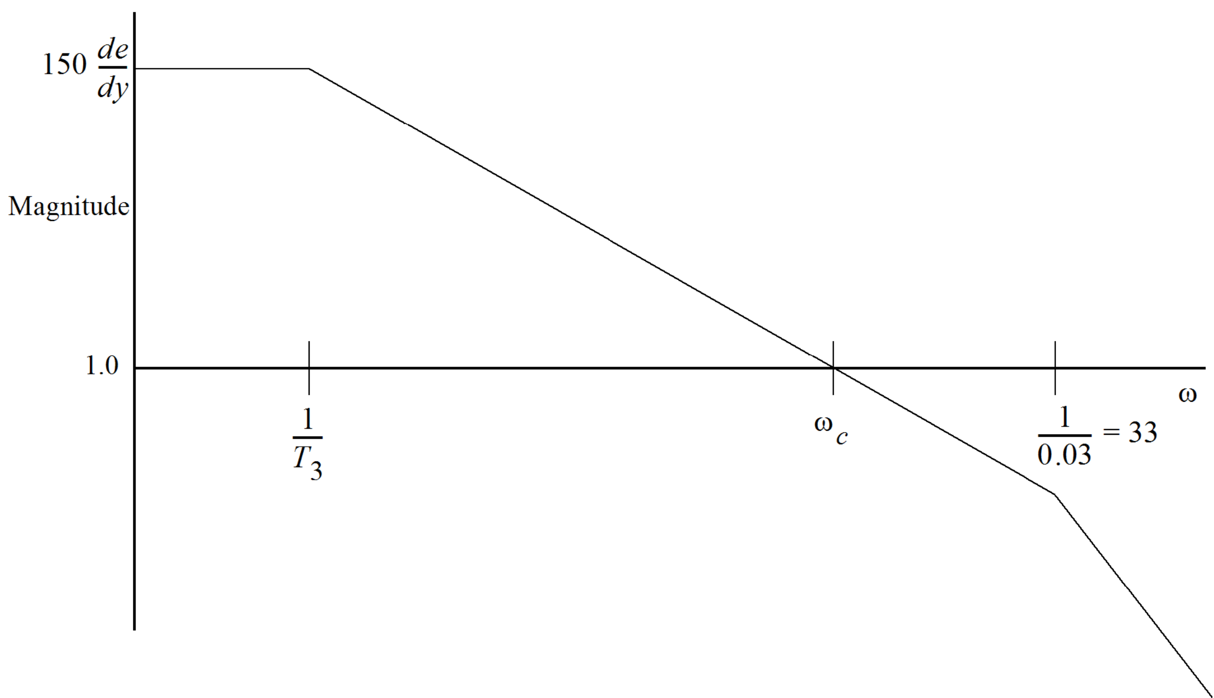


Figure 16.28. Bode Plot of Simplified SVG Controller

The total gain for the controller and process combination is 150 de/dy. The crossover frequency (ω_c) is chosen to be safely away from the second break at 33 rad/sec (e.g., 14 rad/sec). The phase angle at crossover is approximately:

$\phi_c = 90 + \tan^{-1}(0.03)(14) = 90 + 23 = 113°$

This would result in an acceptable response, exhibiting reasonably fast control with a small overshoot. The phase angle at crossover should normally be less than 120°. Phase angles much less than 110° would mean response is more sluggish than necessary. The magnitude at crossover determines T_3.

$$\text{Magnitude} = \frac{150\frac{de}{dy}}{T_3(14)} = 1.0$$

Therefore,

$$T_3 = \frac{150\frac{de}{dy}}{14} \quad \text{sec}$$

where

$$\frac{de}{dy}$$

is on an SVS base.

For a 100-Mvar SVS,

$$\frac{de}{dy} = 0.056$$

on an SVS base, and $T_3 = 0.6$ sec.

For a 150-Mvar SVS,

$$\frac{de}{dy} = 0.084$$

on an SVS base, and $T_3 = 0.9$ sec.

For a 200-Mvar SVS,

$$\frac{de}{dy} = 0.112$$

on an SVS base, $T_3 = 1.2$ sec.

Chapter 17
Excitation System and Controller Models

17.1. Overview

The basic approaches to the excitation of large generators are shown schematically in Figure 17.1, “Excitation Power Source Alternatives”.The excitation system in all cases consists of a high power source of direct current, an intermediate power level controlling circuit, and an instrument power level voltage regulator. The voltage regulator determines the manipulation of the exciter, but its dynamics are often less influential than the nonlinear characteristics of the excitation power source in determining overall dynamic behavior of the system. The proper representation of excitation systems, therefore, requires careful consideration of both the gains and time constants assigned to the voltage regulators and of the characteristics of the excitation power components.

17.2. The dc Exciters

The common excitation system arrangement on older large generators uses a shaft-driven dc generator as the exciter. The dc exciter may be either separately excited, as shown in Figure 17.2, "Separately and Shunt Excited Arrangements for Main Exciters"a, or shunt excited as in Figure 17.2, "Separately and Shunt Excited Arrangements for Main Exciters"b. In either case, the IEEE- recommended excitation system models represent the exciter by the block diagram and nonlinear function, S_e, defined in Figure 17.3, "Nonlinear Transfer Function Model for Rotating Exciter".

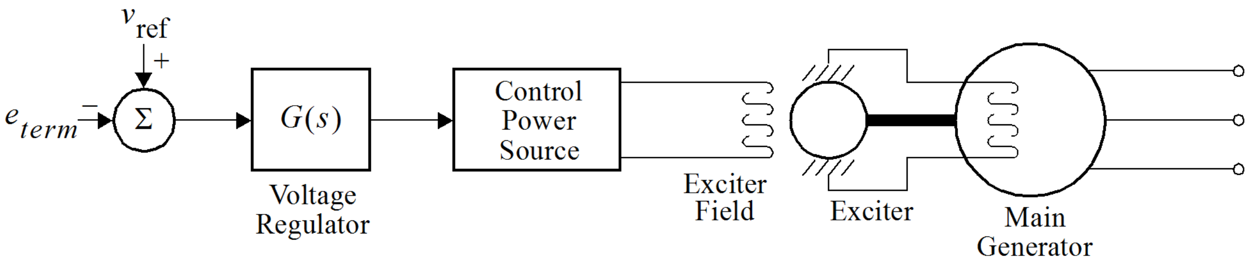
The saturation function, S_e, is a design characteristic of the exciter and is specified to the computer program by the two values $S_e(E_1)$ and $S_e(E_2)$. The curve of S_e versus E_{fd} is assumed by the present PSS®E models to have the form:

$$S_e = \frac{B(E_{fd} - A)^2}{E_{fd}}$$

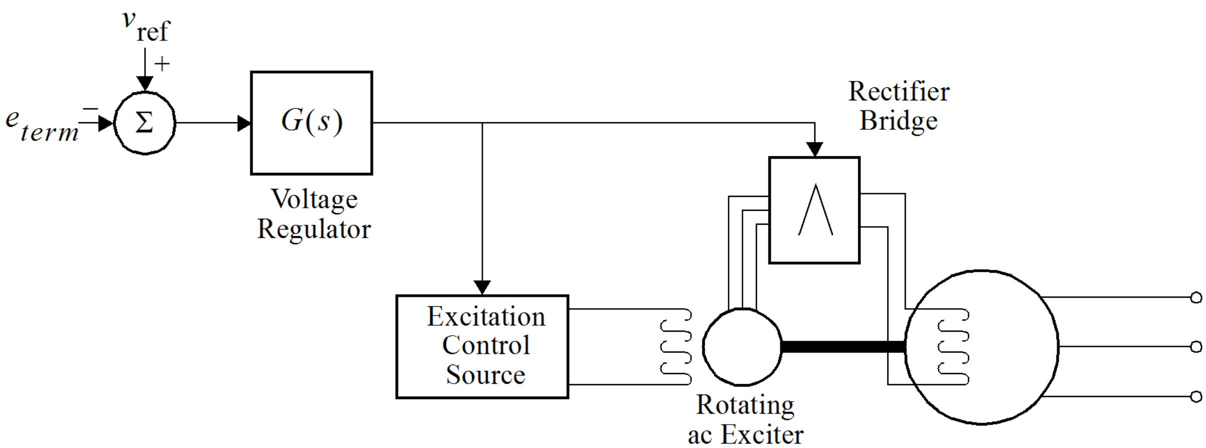
and to pass through the two points defined in Figure 17.3, "Nonlinear Transfer Function Model for Rotating Exciter". The field voltage values, E_1 and E_2, for which the saturation function is specified, should normally be chosen near the knee of the exciter's magnetization curve and near the excitation ceiling, respectively.

Because the saturation curve is a design characteristic of the exciter, the parameters $S_e(E_1)$ and $S_e(E_2)$ are constants. The exciter parameters, T_e and K_e, are not necessarily constant, however.

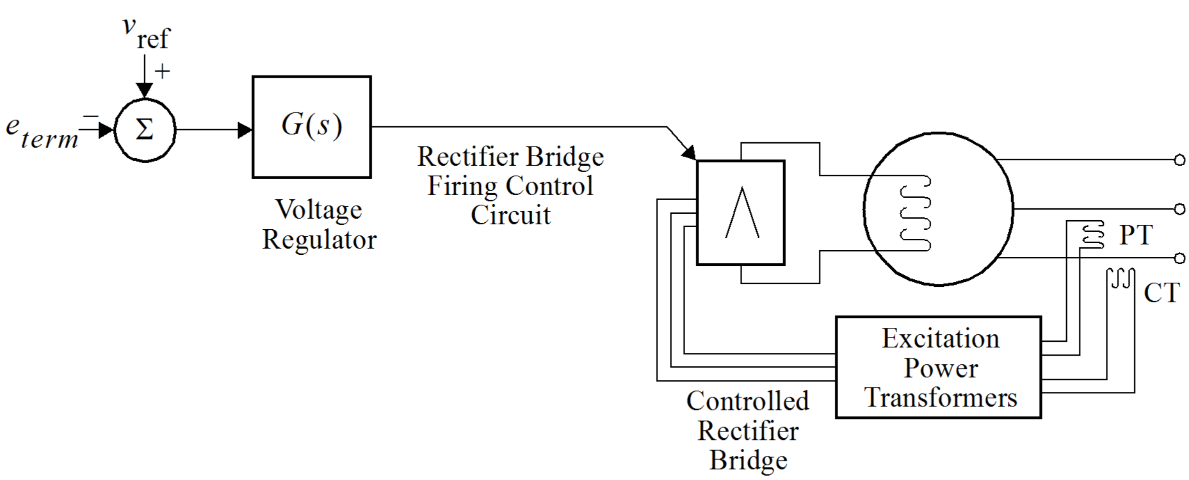
In the case of shunt excited exciters, these parameters may have to be adjusted in accordance with the initial conditions of each simulation run, as outlined in Section 17.2.1, "Separately Excited Exciter".



a. Rotating dc Exciter

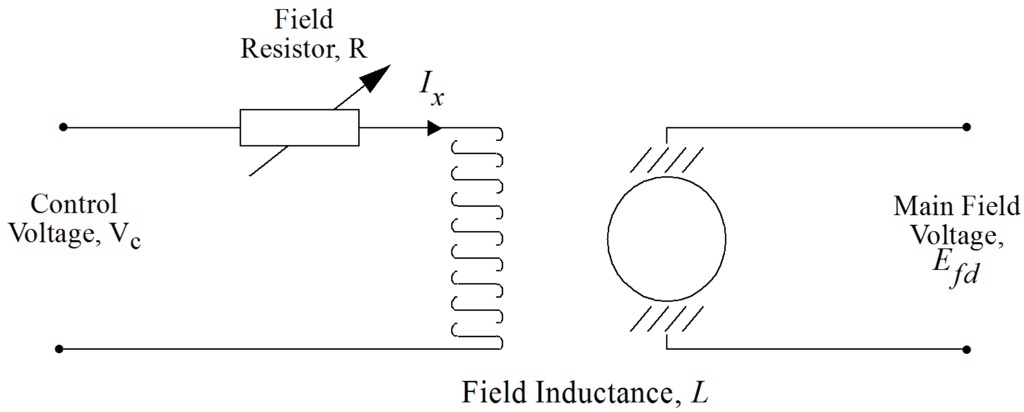


b. Rotating ac

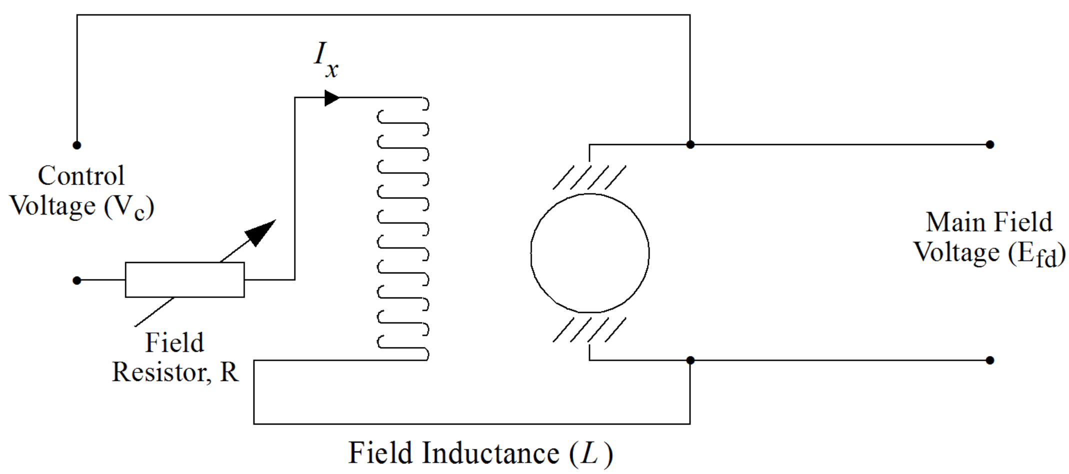


c. Excitation Power Fed from Generator Terminals

Figure 17.1. Excitation Power Source Alternatives

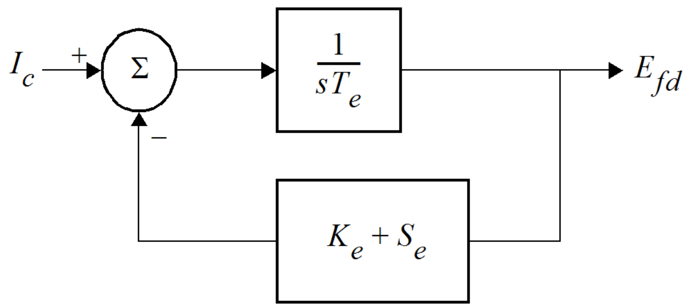


a. Separately Excited Exciter

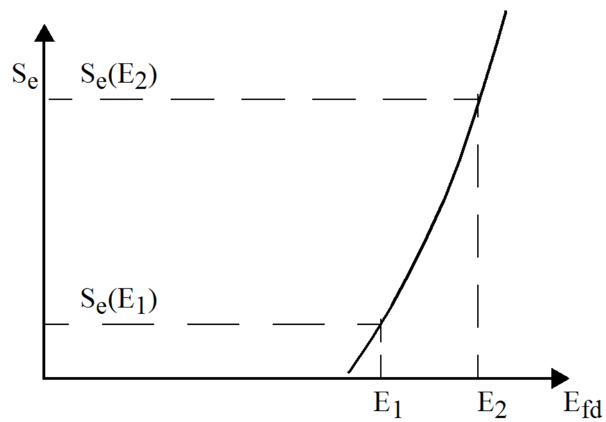


b. Shunt-Excited Exciter

Figure 17.2. Separately and Shunt Excited Arrangements for Main Exciters



a. Rotating Exciter Block



b. Saturation Factor, S_e

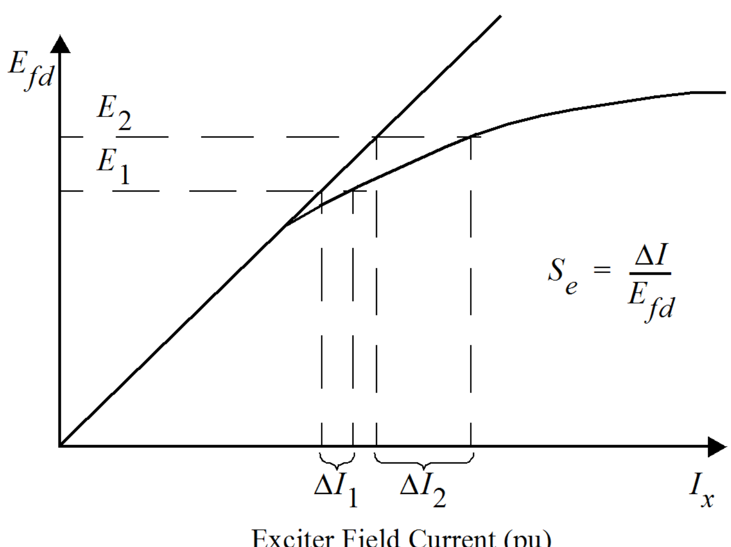


Figure 17.3. Nonlinear Transfer Function Model for Rotating Exciter

c. Relation of Saturation Factor to Exciter Magnetization Curve

17.2.1. Separately Excited Exciter

The separately excited exciter, shown in Figure 17.2, "Separately and Shunt Excited Arrangements for Main Exciters"a, uses per unit characterization of variables; therefore, the output voltage, E_{fd}, is related to exciter field current, I_x, by the open-circuit characteristic shown in Figure 17.3, "Nonlinear Transfer Function Model for Rotating Exciter"c. This characterization may be expressed by:

$$E_{fd} = (I_x - \Delta I) \tag{17.1}$$

and,

$$\frac{\Delta I}{E_{fd}} = S_e \tag{17.2}$$

so that,

$$E_{fd}(1 + S_e) = I_x \tag{17.3}$$

The exciter field current and the output, v_c, of the control source are related by:

$$RI_x + L'\frac{dI_x}{dt} = v_c \tag{17.4}$$

where L ′ is the saturated value of the exciter field inductance. This inductance, L ′ , may be taken for practical purposes as:

$$L' = \frac{L}{1 + S_e} \tag{17.5}$$

where L is the unsaturated inductance of the exciter field. Combining Equation 17.3 through Equation 17.5 gives:

$$RE_{fd}(1 + S_e) + L\frac{dE_{fd}}{dt} = v_c \tag{17.6}$$

Rearranging gives:

$$\frac{L}{R}\frac{dE_{fd}}{dt} = \frac{v_c}{R} - E_{fd} - S_e E_{fd} \tag{17.7}$$

This equation is represented by the block diagram of Figure 17.3, "Nonlinear Transfer Function Model for Rotating Exciter" if the exciter field resistance, R, is constant. In this case, the quantity (v_c/R) can be replaced by a newly normalized variable, I_c, and the transfer function may be fitted to the equation by the following settings:

$$T_e = L / R \qquad (17.8)$$

$$K_e = 1$$

17.2.2. Shunt Excited Exciter

Equations Equation 17.1, Equation 17.2 and Equation 17.3 apply to shunt excited exciters in the same way as they do separately excited units. Figure 17.2, “Separately and Shunt Excited Arrangements for Main Exciters”shows, though, that the control voltage, v_c, is now applied to the field winding in addition to the output voltage of the exciter itself. Equation Equation 17.4 must, therefore, be replaced by:

$$RI_x + L' \frac{dI_x}{dt} = E_{fd} + v_c \qquad (17.9)$$

The exciter field inductance continues to be characterized by equation Equation 17.5. Combining Equation 17.3, Equation 17.5, and Equation 17.9 gives:

$$\frac{L}{R}\frac{dE_{fd}}{dt} = \frac{1}{R}v_c - \left(1 - \frac{1}{R}\right)E_{fd} - S_e E_{fd} \qquad (17.10)$$

This suggests that the block diagram of Figure 17.3, “Nonlinear Transfer Function Model for Rotating Exciter”a can be fitted to the shunt excited exciter by setting:

$$T_e = L / R \qquad (17.11)$$

$$K_e = (1 - 1 / R) \qquad (17.12)$$

$$(v_c / R) = I_c \qquad (17.13)$$

17.2.3. Exciter Operating Practice

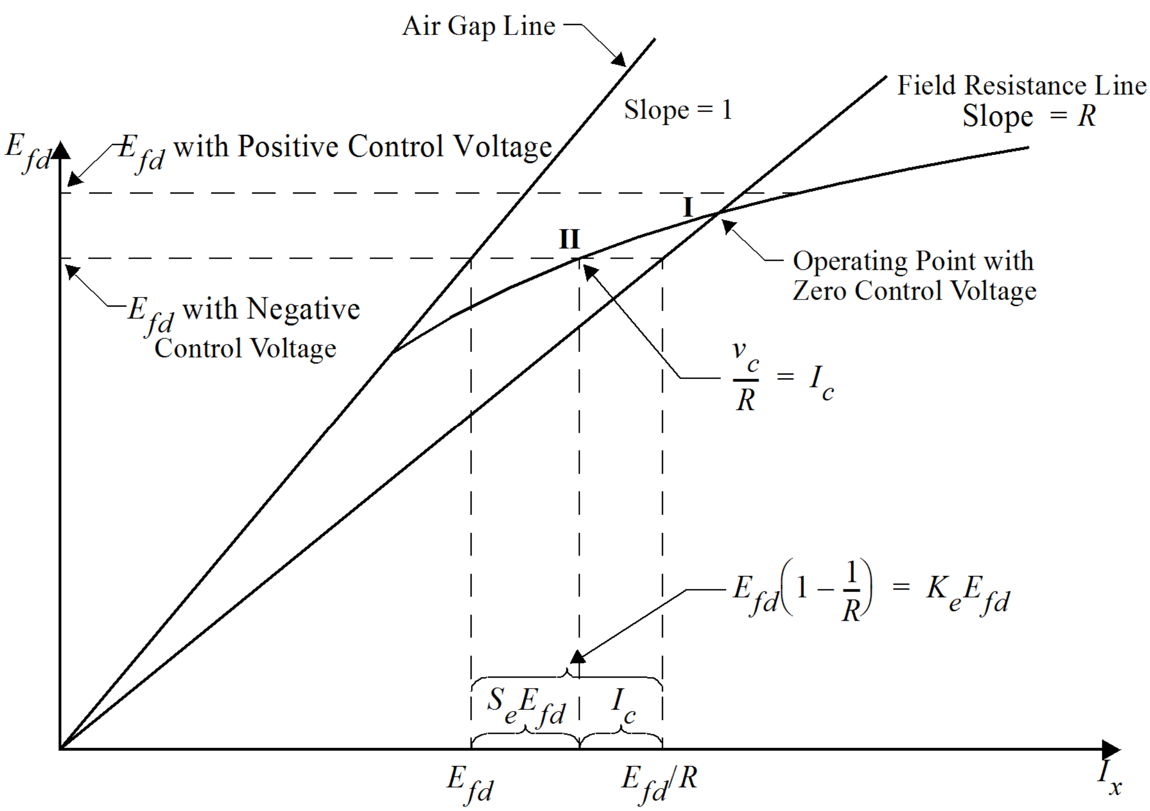
The specification of the constants, K_e and T_e, must be handled with care because the exciter field resistance is often an adjustable quantity rather than a design constant. It is common practice, particularly with shunt exciters, to adjust the exciter field resistance, R, so that the control source voltage, v_c, is nearly zero in steady-state operating conditions. The steady-state solution of Equation 17.10 is:

$$\frac{v_c}{R} = E_{fd} - \frac{E_{fd}}{R} + S_e E_{fd} \qquad (17.14)$$

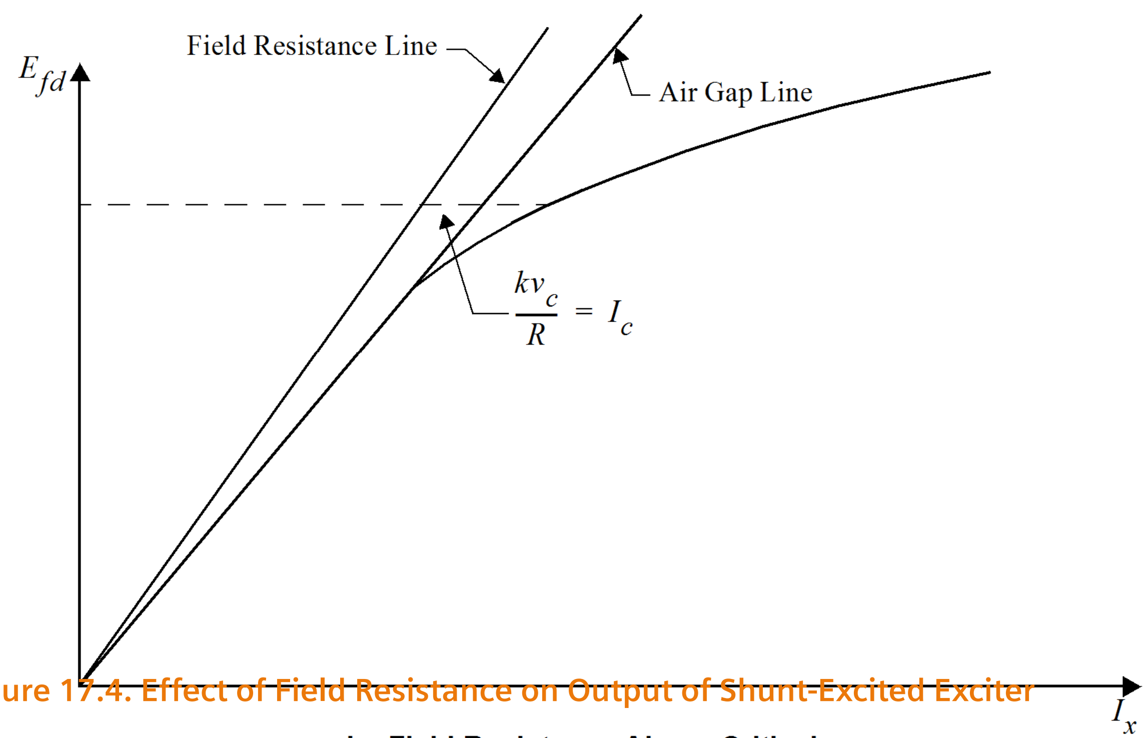
Commonly, the per unit exciter field resistance is adjustable around a nominal value that is close to unity.

Figure 17.4, “Effect of Field Resistance on Output of Shunt-Excited Exciter”a illustrates the solution of Equation 17.14 when the per unit value of R is less than unity. At operating point I the exciter maintains its own field current requirement exactly and operate in steady state with zero output from the excitation control source. At operating point II, the control source must maintain a continuous output, v_c, to trim the exciter’s field current by the amount, I_c.

Changing the exciter’s field resistance to a per-unit value greater than unity produces the situation shown in Figure 17.4, “Effect of Field Resistance on Output of Shunt-Excited Exciter”b where the control source must have a nonzero output at all operating points to make up part of the exciter’s field current requirement that it does not produce for itself.



a. Field Resistance Below Critical Value



b. Field Resistance Above Critical

Figure 17.4. Effect of Field Resistance on Output of Shunt-Excited Exciter

Several widely used excitation systems take advantage of the ability of the shunt exciter field to produce its own full current requirement with little or no output from the control source. These systems provide slow automatic or manual adjustment of the field resistance to bring the operating point close to point *I*, (Figure 17.4, "Effect of Field Resistance on Output of Shunt-Excited Exciter"a) during normal steady operation so the full positive or negative drive capability of the control source will give rapid dynamic adjustment of exciter output during transients. In these systems, the exciter resistance, R, may be assumed to vary little during the few seconds considered in the simulation, but it must be assumed that this resistance has been adjusted slowly to a new value for each new pre-event steady-state condition.

The result of this practice is the recognition that the parameters, K_e and T_e, may be treated as constants in simulation activity RUN, but should be recalculated by activity STRT for each new initial condition to satisfy Equation 17.11 and Equation 17.12 and the renormalization of the control voltage signal in accordance with Equation 17.13. In practice, the value of R is usually quite close to unity. As a result, K_e is strongly sensitive to small changes in R, but T_e and the normalization factor 1/R in Equation 17.13 may reasonably be taken as constants. For most practical purposes, K_e must be readjusted at each new simulation initial condition, but T_e and the control source normalization may be kept constant after proper normal values have been determined.

17.2.4. Automatic Calculation of dc Exciter Parameters in PSS®E Models

Several of the PSS®E excitation system models, as indicated in Table 17.1, "Excitation System Models With Automatic Calculation of dc Exciter Parameters in PSS®E Models", allow two options:

1. Specify K_e and control source range as constants as appropriate for exciters without adjustable field resistance. (This option is usually applicable to excitation systems built by Westinghouse.)

2. Allow K_e and control source range to be calculated by activity STRT to recognize slow reset adjustment of exciter field resistance. (This option is usually required to represent GE-built dc exciter systems using an amplidyne as the control source.)

Table 17.1. Excitation System Models With Automatic Calculation of dc Exciter Parameters in PSS®E Models

PSS®E Model [a]	Exciter Type Normally Represented	Parameters Calculated on Basis of Assumed Design and Operating Practice by Activities STRT and ESTR
IEEET1, IEET1B, IEEEX1, EXDC2 ESDC1A, ESDC2A IEEET4, IEEEX4 IEEET5, IEEET5A	dc exciter	K_e V_{RMAX} V_{RMIN}
IEEET2, IEEEX2 IEEX2A,ESAC5A	ac exciter	K_e V_{RMAX} V_{RMIN}

[a] IEEEXn models comply with IEEE recommendation of 1979. IEEET1 through IEEET4 models comply with IEEE recommendation of 1969. IEEET5 and IEET5A models are variations of IEEET4. EXDC2 model complies with IEEE recommendation of 1981. ESDC1A and ESDC2A models comply with IEEE Std. 421.5 - 1992.

The optional calculation of these parameters is selected by specifying a zero value for K_e and/or V_{RMAX}, (the normalized control source maximum output), in the model's CON data. The models then calculate these parameters in activities STRT and ESTR as follows:

1. If the CON specifying V_{RMAX} is zero, the model will compute V_{RMAX} and set the CON to this value. V_{RMAX} is set as follows:

When the CON containing K_e is zero or negative, V_{RMAX} will just allow the exciter to reach an output voltage of E_2 when K_e is zero, i.e.,

$V_{RMAX} = S_E(E_2) \times E_2$

When the CON containing K_e is positive, V_{RMAX} will just allow the exciter to reach an output voltage of E_2 with the specified value of K_e, i.e.,

$V_{RMAX} = (S_E(E_2) + K_e) \times E_2$

In either case above, V_{RMIN} is then set to $-V_{RMAX}$.

2. If the CON specifying K_e is zero, the model will compute K_e but will not set the CON to this value.

   K_e is set to the value that will require a voltage regulator output of (V_{RMAX}/10) to maintain the present value of excitation voltage, E_{fd}, i.e.,

   $K_e E_{fd} = V_{RMAX}/10 - S_E(E_{fd}) \times E_{fd}$

   $K_e = V_{RMAX}/(10 \times E_{fd}) - [S_E(E_{fd})]$

   The following should be noted:

- V_{RMAX} may usually be treated as a constant for a given machine after it is determined for one typical loading condition because it is only sightly affected by normal adjustment of exciter field resistance.
- K_e is a variable depending upon the initial condition value of E_{fd} and hence upon the generator loading condition.
- The value for V_{RMAX} estimated by the above logic will not necessarily produce the required excitation system response ratio. It may have to be adjusted following the use of the excitation system data verification activities ESTR and ERUN to produce a required response ratio.

The recommended applications of these automatic parameter estimation options:

- Use automatic determination of V_{RMAX} only once in activity STRT, before executing ESTR and ERUN, to obtain an initial estimate of V_{RMAX}. This value should be refined and saved during the excitation system verification process.
- The value of the CON specifying V_{RMAX} should, therefore, be nonzero after completion of exciter data verification as outlined in Chapter 15, *Generator Modeling*.
- Use automatic determination of K_e in all normal initialization of dynamic cases.

17.3. The ac Excitation Systems

17.3.1. Components

Virtually all modern excitation systems use an ac source of excitation power and a rectifier bridge in place of a dc machine. The ac power source may be either a shaft-driven alternator, a transformer connected at the terminals of the main generator, or auxiliary windings in the main generator. The rectifier bridge may be either uncontrolled (diodes) or controlled, using SCRs.

These components are combined in a wide variety of ways by the different manufacturers. The ac excitation system models covered by the IEEE recommendations and standard range from the simple to the elaborate and reflect the breadth of opinion among manufacturers on the modeling of their equipment. The following sections cover the main compound models combined in the various excitation system models of PSS®E.

17.3.2. The ac Exciters

Normally, ac exciters are separately excited and, because their only load is a rectifier, their magnetic behavior can often be represented to acceptable accuracy by the same block diagram and characteristic curve as used for dc exciters (Figure 17.3, "Nonlinear Transfer Function Model for Rotating Exciter"). The values of K_e and T_e in Figure 17.3, "Nonlinear Transfer Function Model for Rotating Exciter" may normally be taken as constants, independent of operating conditions, when modeling ac exciters.

The block diagram of Figure 17.3, "Nonlinear Transfer Function Model for Rotating Exciter" models exciter output voltage as independent of the load current (i.e., main generator field current) on the exciter. While this is quite reasonable in the case of dc exciters, which are normally current-compounded, it is less accurate in the case of ac exciters which, like all alternators, have a substantial synchronous reactance and hence a substantial drop in terminal voltage as load current is increased. The IEEE excitation system modeling recommendations of 1969 neglect this armature reaction within the ac exciter. Newer IEEE recommendations on excitation system modeling presented do recognize this effect, however, as do the new IEEE recommendations (1981) on data exchange and Std. 421.5 - 1992. The ac exciter armature reaction is recognized by the additional block diagram path shown in Figure 17.5, "Transfer Function for ac Exciter Recognizing Demagnetizing Effect of Its Load Current", where the parameter, K_D, is related to the exciter's synchronous reactance.

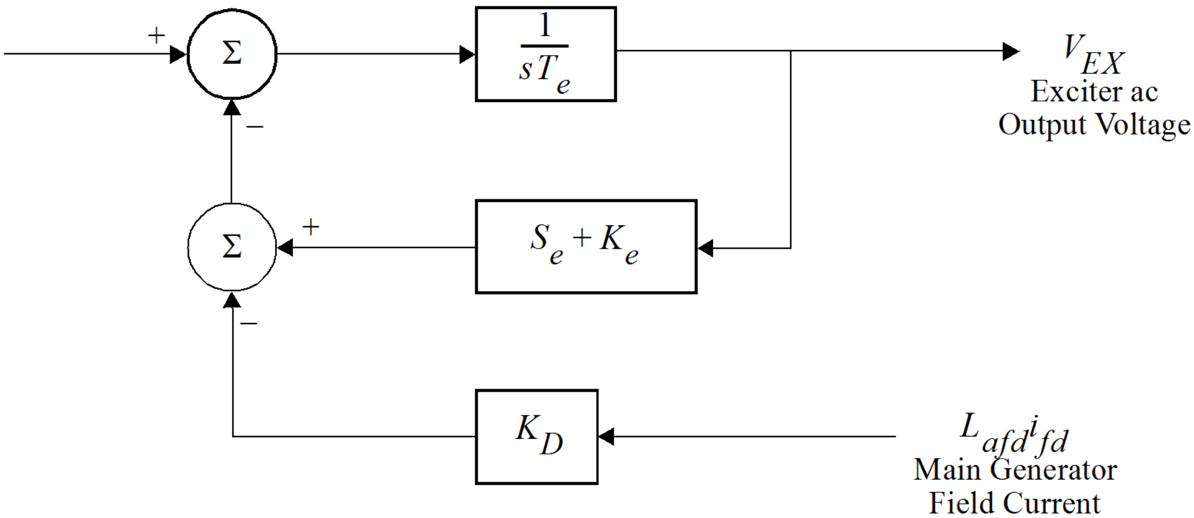


Figure 17.5. Transfer Function for ac Exciter Recognizing Demagnetizing Effect of Its Load Current

The excitation system models corresponding to 1969 recommendations do not represent exciter armature reaction. These models have, however, been widely used to represent excitation systems with ac exciters. Table 17.2, "PSS®E Excitation Systems Representing Armature Reaction" lists models that represent ac exciter armature reaction as shown in Figure 17.5, "Transfer Function for ac Exciter Recognizing Demagnetizing Effect of Its Load Current".

Table 17.2. PSS®E Excitation Systems Representing Armature Reaction

EXAC1 EXAC1A EXAC2 EXAC3 ESAC2A ESAC3A EXBAS	ac excitation power source

17.3.3. Compounded Shunt ac Excitation

The alternative to a rotating ac exciter is a transformer connected at the terminals of the main generator. This alternative may be a simple power transformer or an elaborate current-compounding transformer in which the secondary voltage is dependent on both the current and the terminal voltage of the main generator. The current-compounding transformer is shown in Figure 17.6, "Current-Compounded Excitation Transformer Arrangement".

The conventional primary winding, which is connected in shunt fashion between phases of the main generator, is augmented by a winding connected in series with the main generator stator leads. It is common to place a linear reactor in series with the voltage winding to limit its current and hence to adjust its mmf in proportion to that of the current winding.

The total primary magnetomotive force on the core of this transformer is given by:

$$\mathrm{MMF} = k_I\, i_{gen} \pm j\,\frac{e_{term}}{x}$$

where x is the total reactance in the voltage circuit due to the transformer magnetizing reactance and the linear reactor. (The sign can be made plus or minus by reversing the direction of the winding.) The transformer flux, and hence the secondary voltage, are proportional to this MMF (assuming a constant and minimal degree of saturation), giving:

$$V_{EX} = K_p\, e_{term} + jK_I\, i_{gen} \tag{17.15}$$

where V_{EX} is the transformer secondary voltage, and K_p and K_I are constants depending on turns ratios and linear reactor impedance. The excitation required by the loaded main generator is given approximately by:

$$E_{fd} = e_{term} + jx_q\, i_{gen}$$

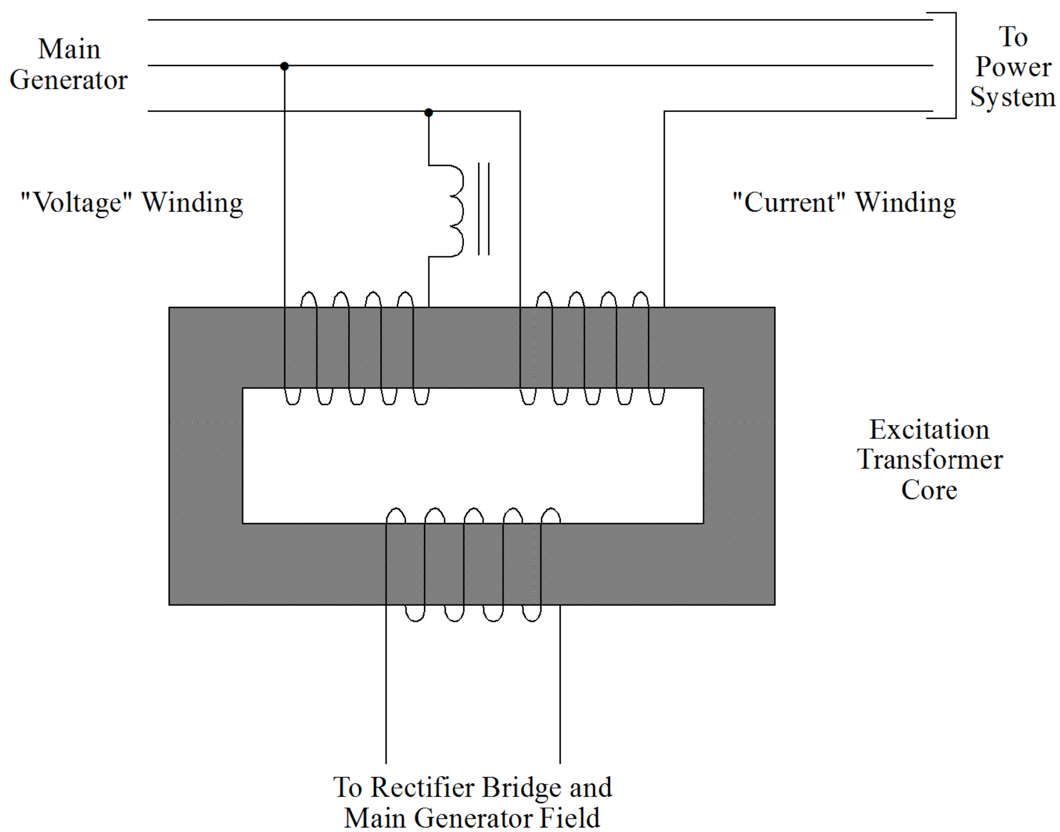


Figure 17.6. Current-Compounded Excitation Transformer Arrangement

Setting the values of K_p and K_I approximately to:

$K_p = 1.0$

$K_I = x_q$

makes the output of the compounded transformer approximately proportional to the excitation voltage that is needed by the main generator. Usually, K_p is set to a value slightly above unity to account for saturation. The approximation Equation 17.15 does not recognize saturation of the main generator exactly or commutation voltage drop of the rectifier, so the excitation must be adjusted by some feedback means. This feedback may be applied by controlled saturation of a compounded transformer that feeds an uncontrolled rectifier, or by the use of a controlled rectifier bridge receiving the output of an unmodulated transformer.

The use of current compounding has the advantage that the excitation source voltage, V_{EX}, can be strong during transmission faults because low terminal voltage is associated with high current. Its use is not universal, however, and many excitation systems use simple transformers and rectifier bridges with sufficiently high capability to produce adequate excitation even when main generator terminal voltage is depressed by faults.

17.3.4. Field Current Rectifiers

The output of a shaft-driven alternator or transformer excitation power source is fed directly to a rectifier bridge to provide the required dc field current for the main generator. The rectifier bridge in many systems is a rotating assembly mounted on the exciter shaft, because this avoids the need for slip rings with high current carrying capacity. When mounted on the shaft, the rectifier bridge is uncontrolled. Its output then depends upon the ac voltage provided by the exciter and on its own commutating voltage drop. This voltage drop can be significant and is represented in several excitation system models.

The curve of F_{EX} versus i_n has been approximated in different ways in different IEEE modeling recommendations over the years. Table 17.3, "PSS®E Models with Rectifier Commulation Drop" lists the PSS®E models that model the commutation drop.

Table 17.3. PSS®E Models with Rectifier Commulation Drop

IEEET3 IEEEX3	EXAC1 EXAC2 EXAC3 EXAC1A ESAC2A ESAC3A ESAC6A	EXST2 EXST2A EXST3 ESST2A ESST3A ESST4B EXPIC1 EXBAS

This model of the commutating drop applies for the broad range of load current on the rectifier. It is considered to be necessary in modeling uncontrolled rectifiers. The commutating process has the effect of reducing the dc output by a factor dependent upon the dc output current and the level of the exciter-alternator ac voltage as shown by the block diagram in Figure 17.7, "Characterization of Excitation Rectifier Commutation Voltage Drop".

Most controlled rectifier bridges, however, operate only with currents in the lower range covered by Figure 17.7, "Characterization of Excitation Rectifier Commutation Voltage Drop" and can often be modeled by a linear relationship rather than by the full curve. The rectifier commutation drop model (Figure 17.7, "Characterization of Excitation Rectifier Commutation Voltage Drop") is combined with the alternator-exciter model of Figure 17.5, "Transfer Function for ac Exciter Recognizing Demagnetizing Effect of Its Load Current" and the compounded transformer model to produce the alternator-rectifier model shown in Figure 17.8, "Combined Alternator-Rectifier Model for Representation of ac Exciter with Uncontrolled Rectifier Bridge at Output" and the transformer-rectifier model shown in Figure 17.9, "Combined Compounding Transformer-Rectifier Model for Representation of ac Excitation System". The parameters T_e, K_e, $S_e(E_1)$, $S_e(E_2)$, K_D, and K_c in Figure 17.8, "Combined Alternator-Rectifier Model for Representation of ac Exciter with Uncontrolled Rectifier Bridge at Output" are determined by inherent machine design characteristics and do not change with plant operating conditions. This model composite alternator-rectifier is incorporated in models such as EXAC1, EXAC2, and EXAC3.

The parameter, K_c, of Figure 17.9, "Combined Compounding Transformer-Rectifier Model for Representation of ac Excitation System" is an equipment design parameter, independent of generator operating conditions. The parameters, K_p and K_I, while not strictly constant in some excitation systems that depend upon controlled saturation of the excitation transformer, are usually treated as constants for each individual generating unit and initial operating condition. Variations of this model are incorporated in model IEEEX3 and in models such as EXST2, EXST3 and ESST4B, which correspond to IEEE recommended model types ST2, ST3 and ST4B.

The excitation rectifier regulation model shown in Figure 17.7, "Characterization of Excitation Rectifier Commutation Voltage Drop" through Figure 17.9, "Combined Compounding Transformer-Rectifier Model for Representation of ac Excitation System" uses the per-unit measure, $L_{afd}i_{fd}$, to characterize the main generator field current. This quantity is equal to E_{fd} in the steady state, but not during transients when the field winding inductance contributes to its back-emf. The quantity, $L_{afd}\ i_{fd}$, is equal to unity when a generator is at rated voltage in the steady state on open-circuit if saturation is neglected.

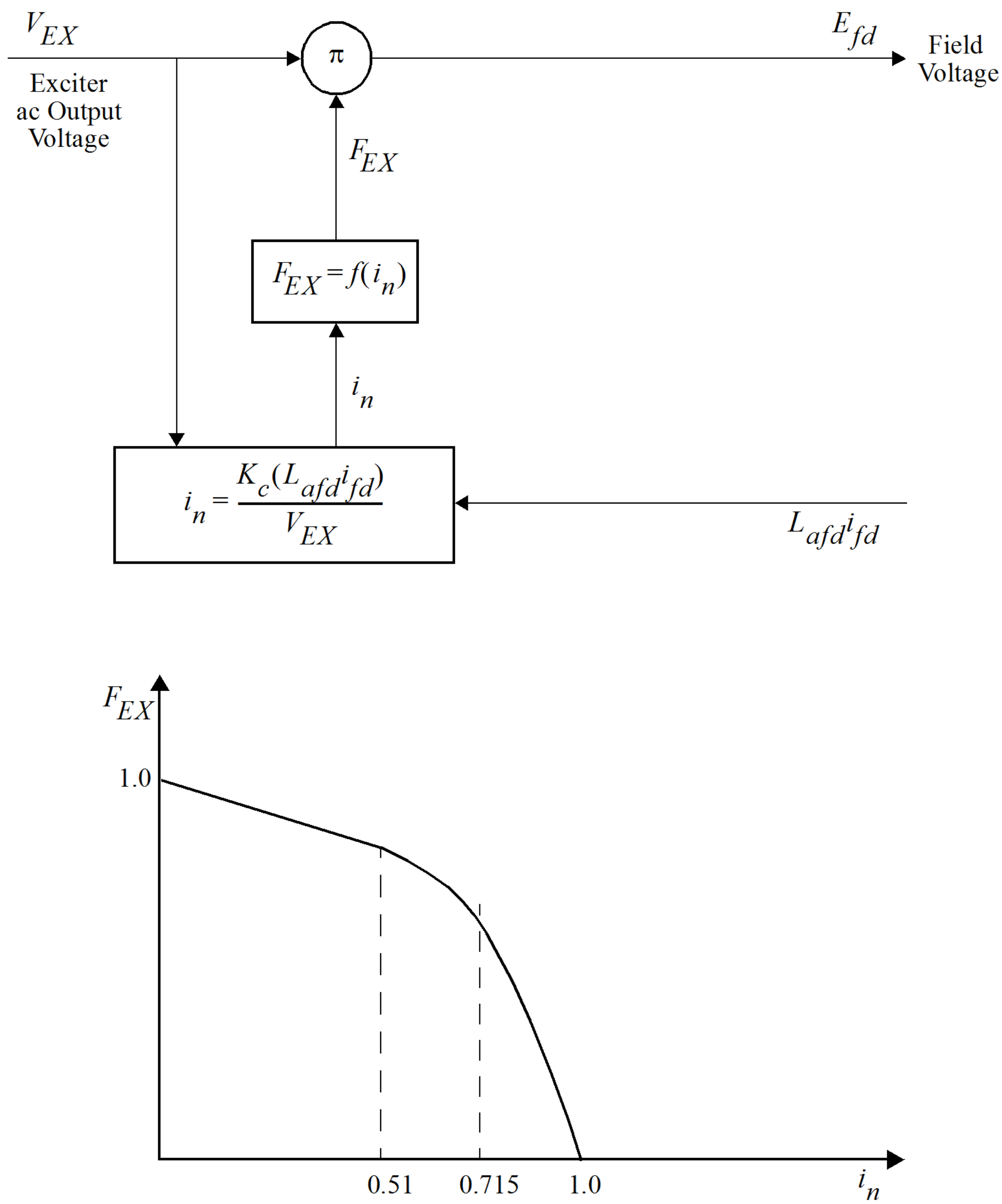


Figure 17.7. Characterization of Excitation Rectifier Commutation Voltage Drop

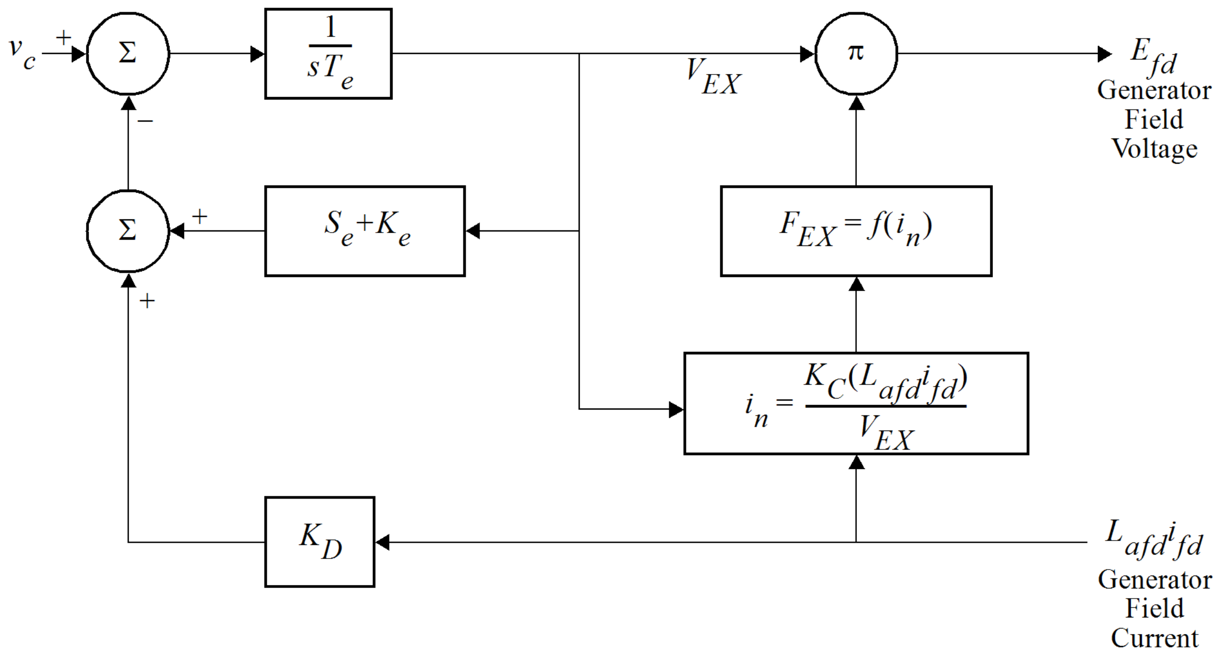


Figure 17.8. Combined Alternator-Rectifier Model for Representation of ac Exciter with Uncontrolled Rectifier Bridge at Output

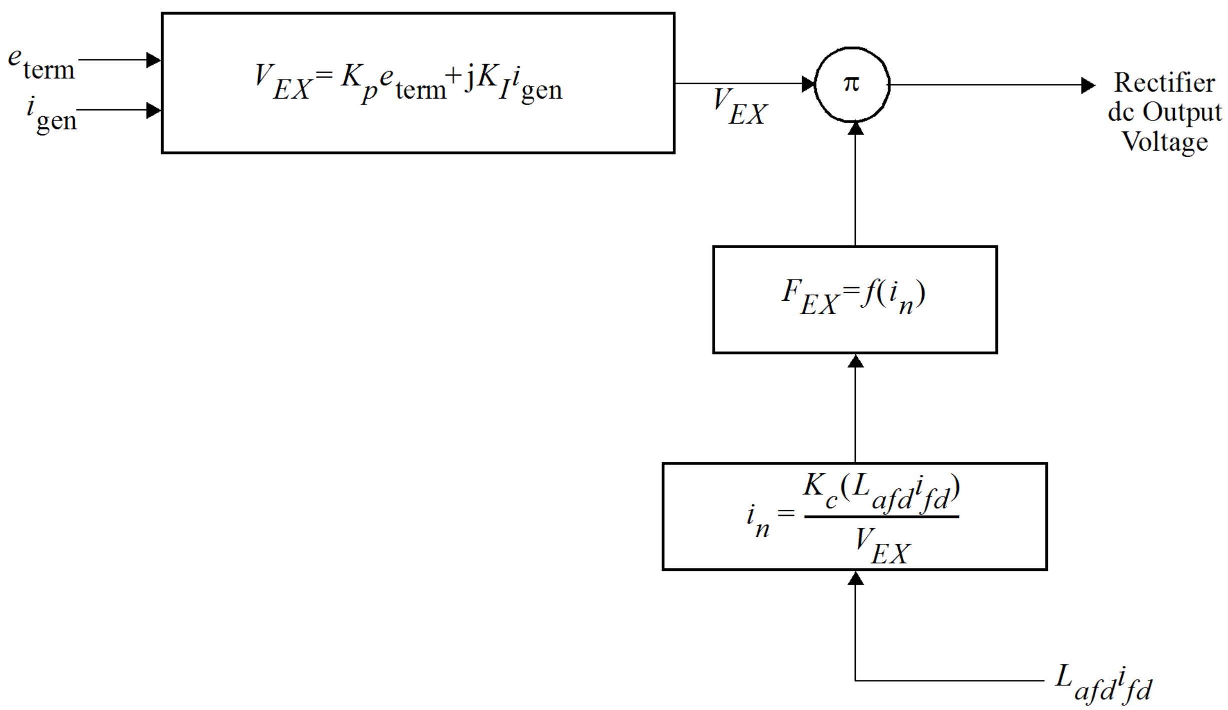


Figure 17.9. Combined Compounding Transformer-Rectifier Model for Representation of ac Excitation System

However, it is equal to S(1.0) in steady-state, rated voltage, open-circuit, operation when saturation is present (see Figure 14-6). All PSS®E generator models provide the excitation system models with the instantaneous value of L_{afd} i_{fd} via the array XADIFD. The quantity, L_{afd} i_{fd}, as shown in Figure 17.7, "Characterization of Excitation Rectifier Commutation Voltage Drop" through Figure 17.10, "Excitation System Overall General Format", is identified in Section 14.2, "Basic Setup Example" as I_{FD}. This terminology is somewhat confusing and can lead to ambiguity in the definition of the parameter K_C of Figure 17.7, "Characterization of Excitation Rectifier Commutation Voltage Drop". The key point, on which proposed values of K_C can be tested for reasonableness, is that the signal characterizing generator field current (whether designated L_{afd} i_{fd} or I_{FD}) should be equal to unity for steady-state, open-circuit, rated voltage operation, in the absence of saturation.

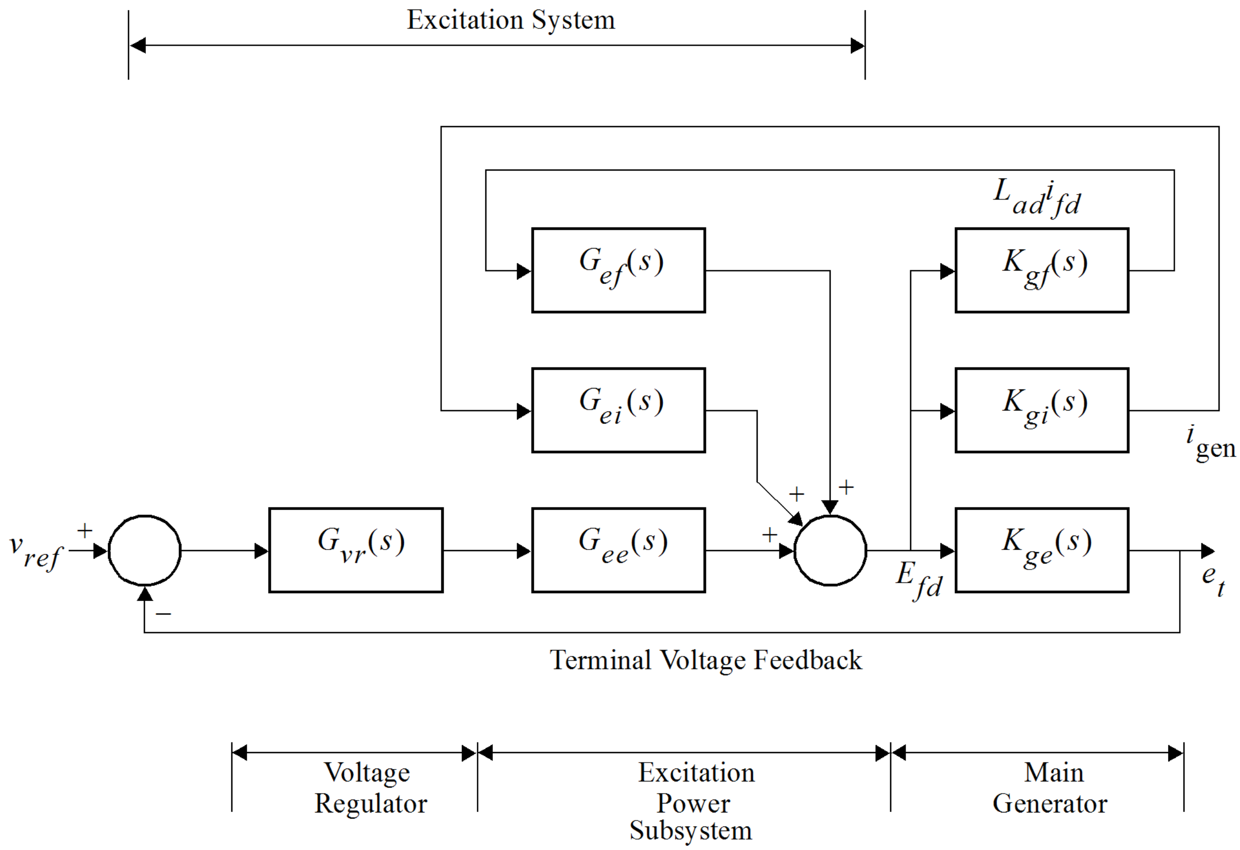


Figure 17.10. Excitation System Overall General Format

17.4. System Voltage Regulators and Control Elements

17.4.1. Transfer Functions

The excitation power elements covered in Section 17.2, “The dc Exciters” and Section 17.3, “The ac Excitation Systems” are controlled by a voltage regulator to form a feedback loop around the main generator. The voltage regulator is normally implemented with low power level components; these are usually electromechanical or magnetic amplifier devices in older systems, and are purely electronic in most more modern systems. Voltage regulator components respond to error in terminal voltage as shown in Figure 17.10, “Excitation System Overall General Format”.

The excitation system’s overall transfer function includes both the dynamic characteristics of the exciter elements and the transfer function of the voltage regulator. The elements $G_{ee}(s)$, $G_{ei}(s)$, and $G_{ef}(s)$ depend upon the details of the excitation power source as shown, for example, in Figure 17.5, “Transfer Function for ac Exciter Recognizing Demagnetizing Effect of Its Load Current”, Figure 17.8, “Combined Alternator-Rectifier Model for Representation of ac Exciter with Uncontrolled Rectifier Bridge at Output”, and Figure 17.9, “Combined Compounding Transformer-Rectifier Model for Representation of ac Excitation System”. (These transfer functions could be derived readily by algebraic manipulations of the figures.) The generator transfer functions vary widely with loading conditions and system impedances. For example, $K_{ge}(s)$ is the simple, time constant function $1/(1 + T_{do}s)$ when the generator is being synchronized and a high-order transfer function with complex poles when it is synchronized and loaded.

The steady-state gain of the voltage regulator should be high to keep the voltage error as small as possible in the steady state. High values of gain in $G_{vr}(s)$ are not tolerable with respect to dynamic behavior, though, because the generator’s field time constant ensures the presence of sufficient phase lag to produce oscillatory behavior of the main feedback loop. It is, therefore, common practice to design the voltage regulator to have a high steady-state gain and a relatively low gain under transient conditions. The desired voltage regulator characteristic is shown, in Bode plot terms, in Figure 17.11, “General Required Form of Voltage Regulator Transfer Function”.

The gain reduction is achieved in a number of different ways in different types and vintages of excitation system. Many of the more modern controlled rectifier systems handle the shaping of their transfer function entirely within the voltage regulator by giving it a transfer function of the form

$$G_{rr}(s) = \frac{A\,(1 + T_1 s)}{(1 + T_2 s)} \tag{17.16}$$

This gives a steady-state gain of A and a gain at high perturbation frequencies of $A(T_1/T_2)$. Older systems and those where the voltage regulator elements are magnetic, rather than electronic, usually achieve their transient gain reduction by a rate feedback arrangement, using rate of change of field voltage, or some closely related signal, as shown in Figure 17.12, “Use of Rate Feedback to Produce Transient Gain Reduction in Excitation System”. The newer systems using the gain reduction transfer function $(1 + T_1 s)/(1 + T_2 s)$ are, typically, set up with T_1 and T_2 equal to about 1 and 10, respectively. This usually allows the steady-state gain, A, to be in the range 100 to 400, with a corresponding high-frequency gain in the region of 10 to 40.

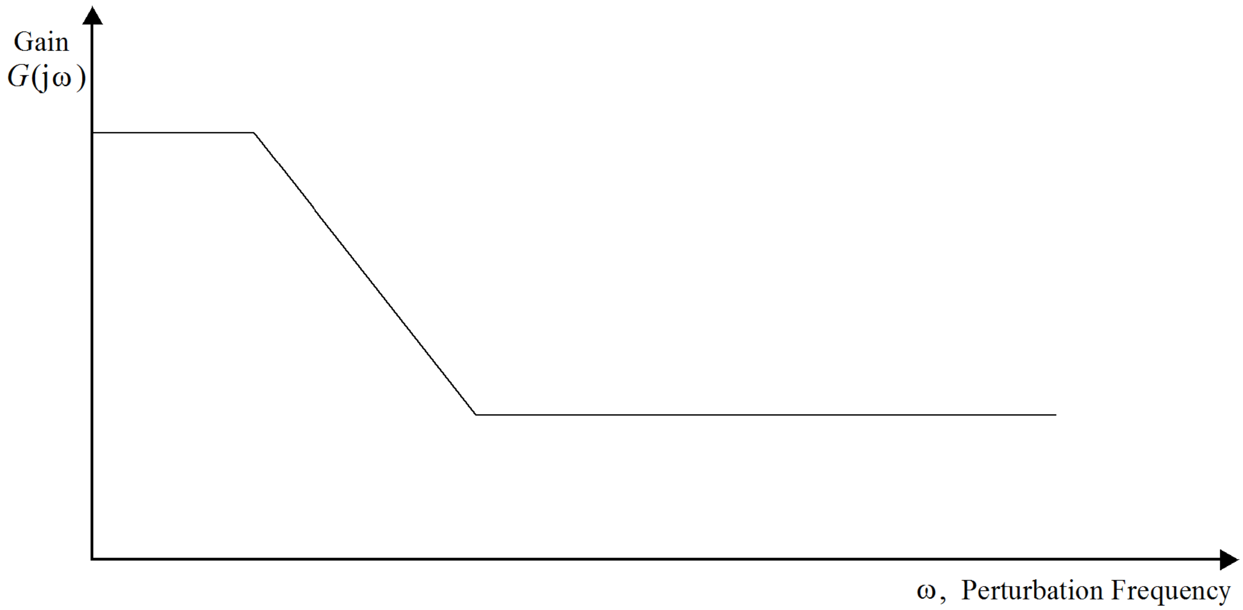


Figure 17.11. General Required Form of Voltage Regulator Transfer Function

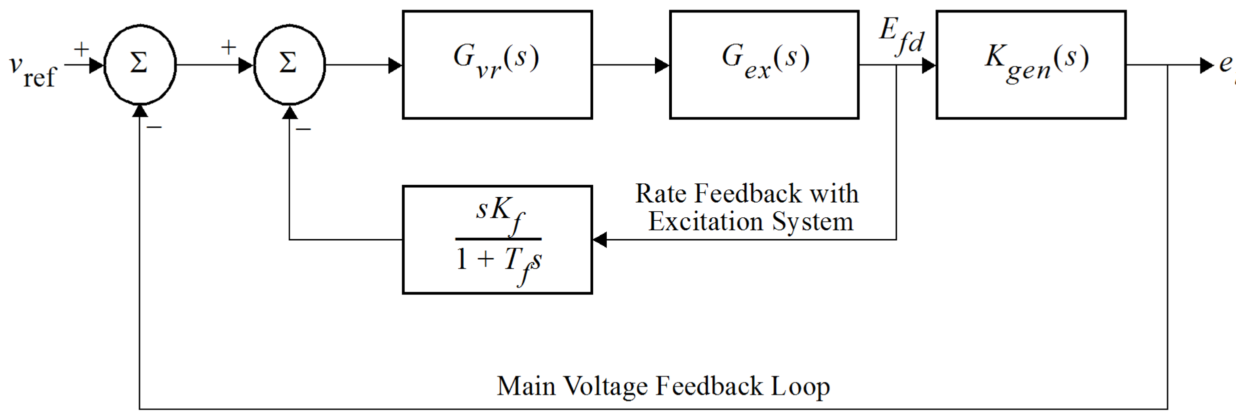


Figure 17.12. Use of Rate Feedback to Produce Transient Gain Reduction in Excitation System

The tuning of older systems is best illustrated by considering the somewhat simplified excitation system form shown in Figure 17.13, "Simplified Excitation System With Rate Feedback". The excitation system time constant is normally much less than 1 sec; it is usually practical to set the rate feedback time constant to 1 or 2 sec and have it significantly greater than T_{EX}.

When T_f is greater than T_{EX}, the transfer function of Figure 17.13, "Simplified Excitation System With Rate Feedback" may be approximated by:

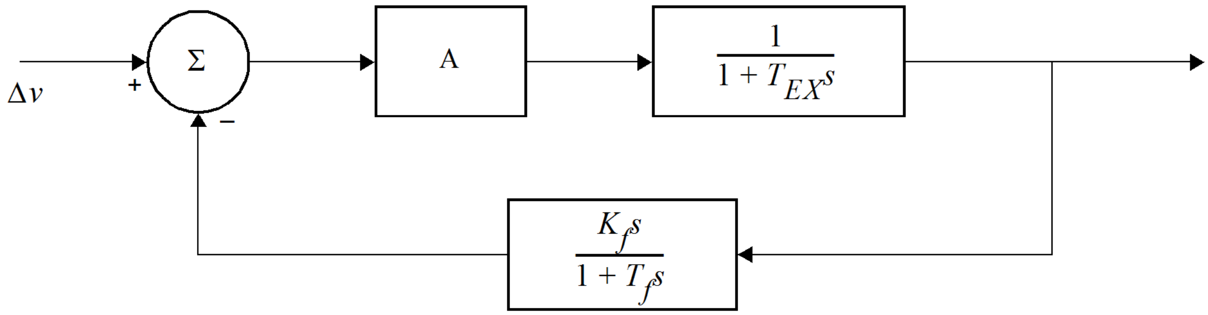
$$\frac{A(1 + T_f s)}{1 + (T_f + AK_f)\, s}$$

A typical situation might call for a steady-state gain of 200, T_f equal to 2 sec, and a high-frequency gain of 20. For this situation:

$$\frac{T_f}{T_f + AK_f} = 0.1$$

$$\frac{2}{2 + 200K_f} = 0.1$$

$K_f = 0.09$



$$\frac{E_{fd}(s)}{\Delta v(s)} = \frac{A(1 + T_f s)}{T_{EX}T_f s^2 + (T_{EX} + T_f + AK_f)s + 1}$$

Figure 17.13. Simplified Excitation System With Rate Feedback

17.4.2. Voltage Regulator Limits

The modeling of the voltage regulator must cover both its linear transfer function, $G_{vr}(s)$, and any limits that may affect its output. Systems using purely electronic methods to derive a firing delay for SCR bridges may usually be assumed to have a large dynamic range and no significant signal limits on the voltage regulator section. Older systems, however, frequently have a limited dynamic range and may involve significant limits.

One of the most significant voltage regulator limits occurs in the case of dc generator type exciters where the final stage of the voltage regulator, the control element of Section 17.2.1, “Separately Excited Exciter” and Section 17.2.2, “Shunt Excited Exciter”, applies current to the exciter’s field. This final stage is often an amplidyne for which the rating and maximum output, rather than the voltage regulator gain, are the principal factors determining the transient behavior of the exciter. In this case, the amplidyne limits are represented by the parameters VRMAX and VRMIN in the IEEE type 1 model and these should be specified or determined automatically in accordance with Section 17.2.4, “Automatic Calculation of dc Exciter Parameters in PSS®E Models”.

17.5. Specific Excitation System Models

17.5.1. Models IEEET1, IEET1A, IEEEX1, ESDC1A

Models IEEET1, IEET1A, IEEEX1, and ESDC1A are widely used to represent systems with shunt dc exciters as well as systems with alternator exciters and uncontrolled shaft-mounted rectifier bridges. When used to represent dc exciter systems, the constants K_e, V_{RMAX}, and V_{RMIN}, should be entered as zero so that PSS®E will determine their values in accordance with Section 17.2.4, "Automatic Calculation of dc Exciter Parameters in PSS®E Models". When used to represent alternator-rectifier systems, the constant, K_e, should be set to unity, and V_{RMAX}, V_{RMIN} should be set to zero so that their values will be assigned by PSS®E during the response ratio test option of activity ESTR. This option automatically initializes each generator to its rated operating condition.

17.5.2. Models IEEET2, IEEEX2, IEEX2A

These models differ from IEEET1, etc., only in the source used for the excitation system stabilizing feedback. IEEET2 and IEEEX2 take this signal as proportional to the control element output, while IEEX2A takes this signal to be proportional to exciter field current. (For comparison, IEEET1, etc., takes a stabilization signal proportional to the output, E_{fd}, of the exciter.) Normally these models represent alternator-uncontrolled rectifier excitation systems. Accordingly, K_e should normally be set to unity and V_{RMAX}, V_{RMIN} should be set by PSS®E using the response ratio test option of activity ESTR .

17.5.3. Models IEEET3, IEEEX3

Models IEEET3 and IEEEX3 differ only in the placement of the limit, V_{BMAX}. Both are intended to represent SCPT excitation systems manufactured by General Electric. These SCPT systems obtain excitation power from a compounding transformer of the general form shown in Figure 17.6, "Current-Compounded Excitation Transformer Arrangement". They achieve control of the field voltage by a control winding on this transformer that is able to saturate its core and effectively use it as a large magnetic amplifier. The rectifier bridge is uncontrolled.

The key parameter of these models is the current compounding gain, K_I, which specifies the relative strength of the voltage and current inputs to the excitation power source. Normal design practice adjusts the gains, K_p and K_I, roughly in proportion to unity and the quadrature synchronous reactance of the generator, respectively. Refinement of such values is necessary, though, to account for rectifier commutation drop and saturation of the generator. Refined estimates of K_p and K_I can be obtained on the assumption that the compounding excitation transformer is sized to provide rated excitation voltage with essentially idle output, V_R, from the voltage regulator. An infinite range of values of K_p and K_I will achieve this. PSS®E requires the user to specify K_p and then, if a zero CON value is specified for K_I, PSS®E computes K_I so as to have an idle value of the voltage regulator output. A reasonable basis for K_p is to set it to a value slightly greater than the per unit field current of the main generator during unity voltage open-circuit operation. As a result, the generator provides its own excitation naturally, with idle voltage regulator output both at zero current output and at full load. The typical generator magnetization curves of Figure 14-5 suggest 1.1 to 1.2 as the reasonable range for K_p.

The automatic determination of K_I is best handled using the response ratio test option of activity ESTR, which always initializes each machine to rated conditions. In most cases, it is then advisable to review the value of K_I determined by PSS®E (in VAR(L)) and transfer it to CON(J+9) so that it is, henceforth, a constant, not adjusted as the generator operating point is varied.

17.5.4. Models IEEET4, IEEEX4, IEEET5, IEET5A

Models IEEET4, IEEEX4, IEEET5, and IEET5A represent older excitation systems where the exciter is a dc machine and the voltage regulator is one of a wide variety of electromechanical devices. All four models use the same exciter representation and all will calculate the field resistance parameter, K_e, (see Section 17.2.4, "Automatic Calculation of dc Exciter Parameters in PSS®E Models") if its value is specified as zero in the CON array. The model block diagrams show variations of voltage regulator logic. None is a purely continuous acting regulator. IEEET4 models a slow reset controller with a deadband, K_R, and a parallel quick-action controller where the deadband, K_V, should be larger than K_R. IEEEX5 models a similar system but with different normalization of the reset rate. IEEET5 is similar again, but has no deadband in its slow reset path.

17.5.5. Models SEXS and REXSYS

Models SEXS and REXSYS represents no specific type of excitation system, but rather the general characteristics of a wide variety of properly tuned excitation systems. Model SEXS is particularly useful in cases where an excitation system must be represented and its detailed design is not known. The gain, K, time constant, T_E, and limits E_{MAX}, E_{MIN}, are a basic representation of the excitation power source. Time constants T_A and T_B provide the transient gain reduction needed to allow satisfactory dynamic behavior with high steady-state gain. Typical parameters for the SEXS model, to represent an unknown but presumably well-tuned excitation system are:

T_A = 1 sec

T_B = 10 sec

K = 200 to 400

T_E = 0.05 sec

E_{MIN} = 0

E_{MAX} = 2.5 to 6, depending upon equipment rating

By proper selection of data REXSYS can be used to represent many different excitation systems where the power source is either an ac or dc generator. Because it can represent many exciters, typical data cannot be supplied. This model is not currently available in the extended term dynamics.

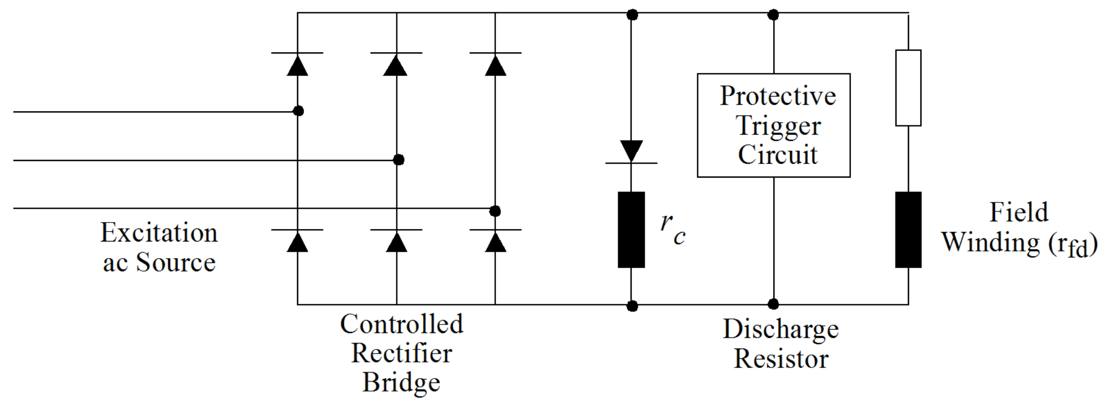
17.5.6. Model SCRX

Like SEXS, SCRX is also a general model, not tailored to the representation of any specific excitation system. SCRX represents the general characteristics of excitation systems shown schematically in Figure 17.14, "Controlled Rectifier Excitation System". These systems are frequently built with rectifier bridges for which current, in relation to the applied voltage, results in a relatively small commutation drop, hence, allowing field voltage to be represented as independent of field current. SCRX can represent a rectifier bridge system fed either from an independent source, such as an externally supplied plant auxiliary bus, or from a transformer connected directly at the generator terminals. SCRX distinguishes between excitation rectifier systems having bidirectional current capability and those that can carry current only in the positive (normal) direction. The first six parameters of SCRX have the same meaning and typical values as those of SEXS; CON(J+6), CSWITCH, distinguishes between systems (bus fed) where ac supply is proportional to generator terminal bus voltage and those (solid fed) where supply is independent of generator terminal voltage.

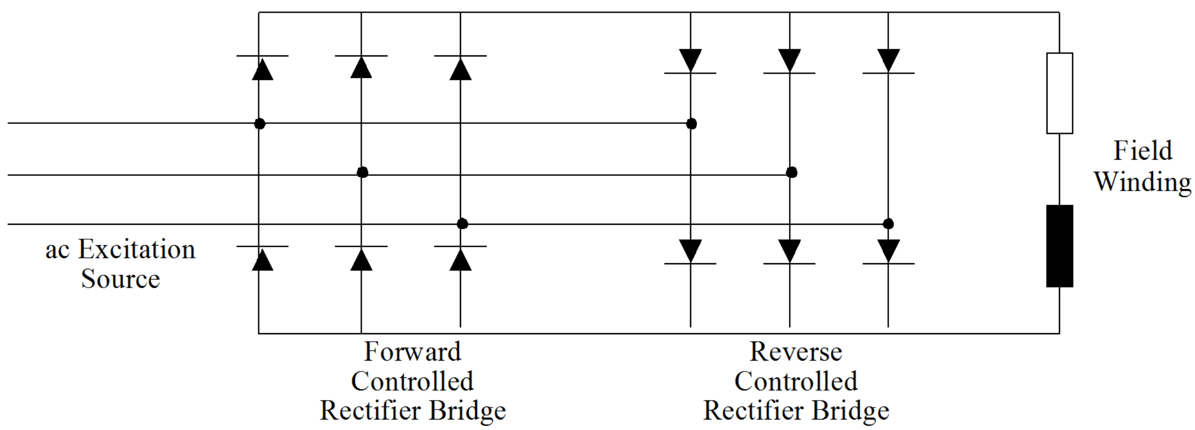
CON(J+7), r_c/r_{fd}, distinguishes between bidirectional and unidirectional excitation systems (Figure 17.14, "Controlled Rectifier Excitation System"). Normal construction is unidirectional as shown in Figure 17.14, "Controlled Rectifier Excitation System"a, with a single rectifier bridge. The thyristors of this bridge are normally fed firing pulses in rectifier mode to provide positive field voltage and carry positive current. During transients, when generator terminal voltage is high, the thyristor firing pulses may shift to the inverter regime to provide a negative field voltage, E_{fd}, while the bridge continues to carry positive current. This negative forcing of the field can reduce field current rapidly but cannot allow negative field current. Accordingly, the bridge is often protected by a reverse bypassing thyristor that can be fired by a crowbar circuit whenever a negative field current, attempting to flow into the diodes, produces a high positive back emf across the bridge. The bypassing thyristor has a series resistor, r_c, to limit its current. A typical value of r_c is about ten times the field resistance, r_{fd}, in order to provide a time constant of field winding discharge approximately 1/10 the natural time constant, T_{do} " on open circuit of the field winding.

Note that the use of the reverse bypassing diode is not universal and that some controlled rectifier excitation systems are designed to withstand any high back emf that is produced by simply blocking reverse field current. These should be modeled by specifying a high value of r_c. Figure 17.14, "Controlled Rectifier Excitation System"b shows an excitation system layout in which two rectifier bridges are connected in reverse polarity to allow field current to flow in either direction. Only one of the two bridges receives firing pulses at a time, and the timing of these allows the field voltage to be either positive or negative, regardless of the direction of field current. This arrangement, while more expensive and less common than the single bridge, is used on hydro generators that feed radial transmission and that are susceptible to magnetic self-excitation when the transmission is opened at the receiving end. SCRX assumes the excitation system has the configuration of Figure 17.14, "Controlled Rectifier Excitation System"b if the parameter, r_c/r_{fd}, in CON(J+7) is specified as zero.

The use of a nonzero value of r_c/r_{fd} to represent an unidirectional system leads to a small time constant in the excitation feedback loop when field current attempts to reverse. The effective value of this time constant is not T_{do} " /(r_c/r_{fd}), as might at first be expected. It is often closer to T_d " /(r_c/r_{fd}) and may become small enough to produce numerical instability of the simulation calculation with the time step of 0.00833 sec that is normally used in PSS®E. Hence, because negative field current is a fairly uncommon occurrence except in radial load rejection situations, it is recommended that the r_c/r_{fd} parameter, CON(J+7), normally be set to zero. Negative field current can then be detected readily by plotting if it is suspected, and the excitation system data can be refined, with due care, when necessary.



a. Unidirectional Excitation Rectifier



b. Controlled Rectifier Excitation

Figure 17.14. Controlled Rectifier Excitation System

17.5.7. Models EXDC2 and ESDC2A

Models EXDC2 and ESDC2A differ from IEEET1, etc. in only one aspect: the voltage regulator's source of supply is the generator or auxiliary bus voltage. As a result, the regulator output limits are proportional to V_T.

17.5.8. Models EXAC1 and ESAC1A

Models EXAC1 and ESAC1A emulate a field-controlled alternator rectifier excitation system consisting of an alternator main exciter with noncontrolled rectifiers. The exciter does not employ self-excitation and the voltage regulator power is taken from a source not affected by external transients. The diode characteristic in the exciter output imposes a lower limit of zero on the exciter output voltage. These models are applicable for simulating the performance of Westinghouse brushless excitation systems. The demagnetizing effect of load current, $L_{ad}i_{fd}$, on the dynamics of the exciter alternator output voltage, V_E, is accounted for in the feedback path that includes the constant, K_D. This constant is a function of the exciter alternator synchronous and transient reactances. Exciter output voltage drop, due to rectifier regulation, is simulated by inclusion of the constant, K_C, a function of commutating reactance, and the approximation to the rectifier regulation curve, F_{EX}, as described in Section 17.3.4, “Field Current Rectifiers”.

In the models, a signal, V_{FE}, proportional to exciter field current is derived from the summation of signals from exciter output voltage, V_E (multiplied by the term $K_E + S_E$) and $L_{ad}i_{fd}$ (multiplied by the demagnetization term, K_D). The exciter field current signal, V_{FE}, is used as the input to the excitation system feedback. None of the parameters of these models are calculated by PSS®E.

17.5.9. Models EXAC2 and ESAC2A

Models EXAC2 and ESAC2A emulate a high initial response field controlled alternator-rectifier excitation system in which the alternator main exciter is used with noncontrolled rectifier. The models are similar to that of EXAC1 except for the inclusion of two additional exciter field current feedback loops simulating exciter time constant compensation and exciter field current limiting elements, respectively. These models are applicable for simulating the performance of Westinghouse high initial response brushless excitation systems.

A direct negative feedback, V_H, around the exciter field time constant reduces its effective value and thereby increases the bandwidth of the excitation system small signal response. The time constant is reduced by the gain $(1 + K_B K_H)$ of the compensation loop and is normally more than an order of magnitude lower than the time constant without compensation. To obtain high initial response with this system, a very high forcing voltage, V_{RMAX}, is applied to the exciter field. A limiter sensing exciter field current allows high forcing, but limits the current. By limiting the exciter field current, exciter output voltage, V_E, is limited to a selected value, V_{LR}, which is usually determined by the specified excitation system response ratio. The output signals from the voltage regulator, V_A, and time constant compensation, V_H, elements are compared with the output signal, V_L, from the limiter in control logic circuitry, which functions to provide a sharp transition from regulator control to limiter control of excitation at the limit point. Excitation is controlled by the more negative of the two control signals.

Although the current limit is realized physically as in EXAC2, the time constants associated with the loop can be extremely small. Therefore, the limit can be modeled as a positive limit on exciter voltage back of commutating reactance as done in model ESAC2A.

None of the parameters of these models are calculated.

17.5.10. Models EXAC3 and ESAC3A

Models EXAC3 and ESAC3A emulate a field controlled alternator-rectifier excitation system, which includes an alternator main exciter with noncontrolled rectifiers. The exciter employs self-excitation and the voltage regulator power is derived from the exciter output voltage. Therefore, this system has an additional nonlinearity, simulated by the use of a multiplier for which the inputs are the voltage regulator command signal, V_A, and the exciter output voltage, E_{FD}, times K_R. These models are applicable to systems such as the GE ALTERREX excitation systems employing static voltage regulators.

The demagnetizing effect of load current, $L_{ad}i_{fd}$, on the dynamics of the exciter alternator output voltage, V_E, is accounted for in the feedback path, which includes the constant K_D, which is a function of the exciter alternator synchronous and transient reactances. Exciter output voltage drop due to rectifier regulation is simulated by inclusion of the constant, K_C (which is a function of commutating reactance) and the approximation to the regulation curve, F_{EX}. In the model, a signal proportional to exciter field current, V_{FE}, is derived from the summation of signals from exciter output voltage, V_E (multiplied by the term $K_E + S_E$) and $L_{ad}i_{fd}$ (multiplied by the demagnetization term, K_D). The excitation system stabilizer also has a nonlinear characteristic; the gain is K_F for exciter output voltage less than E_{FDN}. When exciter output exceeds E_{FDN}, the value of this gain becomes K_N. Model ESAC3A represents the effects of the feedback limiter operation by limits on V_E. None of the parameters of EXAC3 and ESAC3A are calculated by PSS®E.

17.5.11. Models EXAC4 and ESAC4A

Models EXAC4 and ESAC4A emulate an alternator-supplied rectifier excitation system. This high initial response excitation system utilizes a full thyristor bridge in the exciter output circuit and the voltage regulator operates directly on these elements. The exciter alternator uses an independent voltage regulator to control its output voltage to a constant value. These effects are not modeled, however, transient loading effects on the exciter alternator are included. Exciter loading effects can be accounted for by using the exciter load current and commutating reactance to modify excitation limits. The excitation system feedback is frequently accomplished in thyristor systems by a series lag-lead network rather than through rate feedback. The time constants, T_B and T_C, would be used to simulate this control function. The overall equivalent gain and the time constant associated with the regulator and/or firing of the thyristors would be simulated by K_A and T_A, respectively. Systems utilizing these simulation models include the General Electric ALTHYREX and rotating thyristor excitation systems. The difference in these two models is in the handling of the exciter limits.

17.5.12. Models EXST1 and ESST1A

Models EXST1 and ESST1A, of a potential source controlled rectifier-exciter excitation system, are intended to represent systems in which excitation power is supplied through a transformer from the generator terminals (or the unit's auxiliary bus) and is regulated by a controlled rectifier. The maximum exciter voltage available from such systems is directly related to the generator terminal voltage (except as noted below).

In this type of system, the inherent exciter time constants are very small and exciter stabilization as such is normally not required. On the other hand, it may be desirable to reduce the transient gain of such systems for other reasons. The model shown is sufficiently versatile to represent transient gain reduction implemented either in the forward path via time constants, T_B and T_C (in which case K_F would normally be set to zero), or in the feedback path by suitable choice of rate feedback parameters, K_F and T_F. Voltage regulator gain and any inherent exciter time constants are represented by K_A and T_A.

In many cases, the internal limiter following the summing junction can be neglected, but the field voltage limits, which are functions of both terminal voltage (except when the exciter is supplied from an auxiliary bus, which in turn is not supplied from the generator terminals) and generator field current, must be modeled. The representation of the field voltage limits as linear functions of generator field current is possible. In addition, for most transformer fed systems, K_C is quite small, permitting the term to be neglected for many studies.

While the majority of these excitation systems employ a fully controlled bridge, the model is also applicable to semicontrolled systems. In this case, the negative ceiling is set to zero. Examples of type ST1 excitation systems are:

- Canadian General Electric silcomatic excitation systems.
- Westinghouse Canada solid-state thyristor excitation system.
- Westinghouse type PS static excitation system with type WTA, WHS, WTA-300, or type TWGR regulators.

- ASEA static excitation system.
- Brown Boveri static excitation system.
- Rayrolle-Parsons static excitation system.
- GEC-Eliott static excitation system.
- Toshiba static excitation system.
- Mitsubishi static excitation system.
- General Electric potential source static excitation system.
- Hitachi static excitation system.
- Basler model SSE excitation system.

For most of these systems, the cosine characteristic relating thyristor firing angle to bridge output is compensated for by an inverse-cosine function between regulator output and firing angle. In such systems the gain, K_A, is a constant and is independent of exciter supply voltage. In a few systems, this inverse-cosine compensation is not employed, and K_A becomes a cosine function, dependent on supply voltage. This model can be used to approximate these systems for some types of studies, but more accurate representation may be required for others. Model ESST1A models a field current limiter to protect the generator rotor and exciter, which sometimes results from the very high forcing capability of these systems. The gain of this limit is represented by K_{LR} and a start setting of I_{LR}.

17.5.13. Models EXST2, EXST2A and ESST2A

Some static systems utilize both current and voltage sources derived from the generator terminal quantities as components of the power source. These compound source rectifier excitation systems are modeled by these ST2 models. It is necessary to form the exciter power source from a phasor combination of terminal voltage, V_T, and terminal current, I_T. Rectifier loading and commutation effects are accounted for (see Section 17.3.4, “Field Current Rectifiers”). The regulator controls the exciter output through controlled saturation of the power transformer components. T_E represents the integration rate associated with the inductance of the control windings, and the EFD_{MAX} limit represents the limit on the exciter voltage due to saturation of the magnetic components. If the K_I CON value is specified as zero, the model calculates the proper value of K_I using the same assumptions as used for IEEET3 and IEEEX3. One example of such a systems is the GE static excitation system, frequently referred to as the SCT-PPT or SCPT system.

EXST2A is identical to EXST2 except that in the EXST2A model the regulator output is multiplied rather than added to the compounded transformer output. This modification was made to more accurately model test results.

ESST2A is identical to EXST2A except for under-excitation limit input.

17.5.14. Models EXST3 and ESST3A

Some static systems utilize internal quantities within the generator, which may be expressed as phasor combinations of generator terminal voltage and current, to form the source of excitation power. Such compound source-controlled rectifier-excitation systems employing controlled rectifiers in the exciter output circuit are represented by these models. The excitation system stabilizer for these systems is provided by a series lag-lead element, represented by the time constants, T_B and T_C. An inner loop field-voltage regulator is characterized by of the gains, K_A and K_G, and the time constants, T_A. Rectifier loading and commutation effects are accounted for (see Section 17.3.4, "Field Current Rectifiers"). The EFD_{MAX} limit is established by the saturation level of power components. Systems of this type include the General Electric GENERREX and shunt-thyristor excitation systems.

Location of limits differentiate ESST3A from EXST3. Note that ESST3A is from the IEEE standard.

17.5.15. Model ESAC5A

ESAC5A is a simplified model for a brushless excitation system where the regulator is supplied from a source such as a permanent magnet generator, which is not affected by system disturbances. The model can be used to represent small excitation systems such as those produced by Basler and Electric Machinery.

As for the dc exciters, this model uses loaded rather than open circuit exciter saturation data.

17.5.16. Model IEET1B

Model IEET1B is included to provide the modeling of exciters developed for Consolidated Edison Company units; Ravenswood 1, 2, and 3; Poletti; and Arthur Kill.

17.5.17. Model EXPIC1

EXPIC1 is recommended to be used for excitation systems where voltage regulator control element is a proportional plus integral type (PI). A specific excitation system was not used as a starting point. Judicious choice of constants can allow this model to be used to model a variety of manufacturers implementation of a PI type exciter. The model has been used in PTI studies of several COGEN facilities, for exciters manufactured or supplied by the Fuji Electric Co., Ltd., GE Canada, and the new GE EX2000 digital-based excitation systems.

17.5.18. Type ESAC6A Excitation System

Type ESAC6A excitation system model is used to represent field-controlled alternator-rectifier excitation systems with system-supplied electronic voltage regulators. The maximum output of the regulator, VR, is a function of terminal voltage, VT, and the model includes an exciter field current limiter. It is particularly suitable for representation of stationary diode systems such as those produced by C.A. Parsons.

17.5.19. Model EXBAS

Model EXBAS is used to represent Basler static voltage regulators where output provides the entire field current of a shaft-mounted dc or ac exciter. The model should be used mainly for separately excited exciters where the regulator is the sole source of dc excitation to the excitation field, which may be either shaft mounted dc or ac. Therefore, the user should typically enter a value of Ke near unity. The regulator power supply of this model is auxiliary bus fed independently from the generator or is a shaft-driven permanent magnet generator, which gives essentially constant ac voltage.

17.5.20. Model ESAC8B

Model ESAC8B represents the Basler digital excitation control system voltage regulator as applied to a brushless exciter. The automatic voltage regulator consists of a PID controller implemented in a microprocessor. Because it uses a high processor rate, the design is done as if the controller were continuous even through it is digital.

17.5.21. Model EXELI

Model EXELI is used to represent an all-static PI transformer fed excitation system. This model combines a stabilizer and an exciter unit.

A PI voltage controller establishes a desired field current setpoint for a proportional current controller. The integrator of the PI controller has a follow-up input to match its signal to the present field current.

The stabilizer section can be nullified by a proper selection of the associated constants, which can make the stabilizer signal equal to zero. The regulation of the transformer/rectifier unit is represented by X_e and it can be zero or positive. The controller reset time constant, T_{nu}, cannot be zero.

17.5.22. Model ESST4B

Model ESST4B is used to represent static systems with both potential and compound source rectifier excitation. This model represents the following types of equipment:

- GE EX2000 Bus Fed Potential Source
- GE EX2000 Static Compound Systems
- GE Ex2000 Generrex - PPSor - CPS

Rather than the lead-lag regulation as used by the ESST3B, this model has a non windup lead-lag regulator. Maximum excitation input for this model is into a low value gate downstream from the proportional and integral blocks. Minimum excitation is summed at the reference.

17.5.23. Models REXSYS and REXSY1

Models REXSYS and REXSY1, available for state space simulation only, were added to match a general type of exciter available in an alternate stability program and used frequently. A quick review of the data shows that many different systems can be modeled with these exciters by the proper selection of constants.

17.6. Alternate Voltage Regulator Inputs

17.6.1. Principle

Generator voltage regulators may be used to control either generator terminal voltage, a current compensated terminal voltage, or a remote bus voltage. Current compensation is achieved by using a compensated voltage:

$$v_c = e_{term} + Z_c\, i_{gen} \tag{17.17}$$

in place of generator terminal voltage, v_t, as the voltage feedback input signal to the voltage regulator. Remote bus voltage regulation is achieved by using a sensed voltage in place of the terminal voltage. All PSS®E voltage regulator models use a voltage signal from the array ECOMP as the input. If the user has called no specific model, ECOMP is set equal to ETERM, causing the excitation system to regulate terminal voltage. The voltage regulator on a given generator regulates an alternate voltage by applying model IEEEVC, COMP, or REMCMP to that machine. These models replace the terminal voltage in the ECOMP array with the compensated voltage or the alternate bus voltage, and feed this signal to the voltage regulator.

17.6.2. Model IEEEVC

IEEEVC compensates the terminal voltage according to Equation 17.17. Polarity is critical. The current, i_{gen}, is positive when leaving the generator. Accordingly, positive values of R_c and X_c in $Z_c = (R_c + jX_c)$ cause the compensated voltage to appear to be the voltage at a point inside the generator. If IEEEVC is used, the generator's actual terminal voltage continues to be accessible in array ETERM while its compensated terminal voltage is available in array ECOMP. Both ETERM and ECOMP values may be assigned to output channels.

17.6.3. Model COMP

Model COMP compensates generator terminal voltage in general accordance with Equation 17.17, but with a reversal of presumed polarity and with only a reactive component in the compensating impedance. A positive value of X_e, CON(J) causes the compensated voltage to correspond to that at a point outside the generator. COMP places the compensated voltage in array ECOMP and leaves terminal voltage in array ETERM. Both may be assigned to output channels.

17.6.4. Model REMCMP

Model REMCMP places the voltage of the bus specified by ICON(I) in the ECOMP array. If the remote bus is not found in the network or if the bus specified is out-of-service, an appropriate message is printed and terminal voltage is fed to the regulator. If during a simulation the remote bus is disconnected, a large discontinuity may be fed to the regulator due to this switch. If REMCMP is used, the generator's actual terminal voltage continues to be accessible in array ETERM while the remote bus voltage is available in array ECOMP. Both ETERM and ECOMP values may be assigned to channels.

17.6.5. Model COMPCC

Model COMPCC compensates terminal voltage in accordance with equations:

$$E_{COMP1} = V_T - \left(\frac{I_{T1} + I_{T2}}{2}\right)(R_1 + jX_1) + I_{T1}(R_2 + jX_2)$$

$$E_{COMP2} = V_T - \left(\frac{I_{T1} + I_{T2}}{2}\right)(R_1 + jX_1) + I_{T2}(R_2 + jX_2)$$

This scheme is used to equalize division of reactive MVA and to prevent circulating reactive current between two ac machines with individual regulators operating in parallel. Cross-compound units are the most likely candidates to share one transformer and use this scheme. This model assumes both units on the same bus and, therefore, the output ETERM will be the same for both units. The E_{COMP} value for each unit will be different depending on impedance input and generator currents.

17.7. Supplementary Excitation Controller Models

17.7.1. General Principles

Excitation systems with high transient gain and small time constants tend to reduce the damping of generator rotor angle oscillations. This negative damping effect can be counteracted by making the excitation system respond to rotor angle motion as well as deviations of terminal voltage under transient conditions, while being sensitive only to terminal voltage in the steady state. A detailed discussion of the destabilizing effect and its counteraction by recognition of rotor angle motion is presented in "Concepts of Synchronous Machine Stability as Affected by Excitation Control," F.P. de Mello, C. Concordia, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-88, pp. 316-329, 1969.

The application of supplementary stabilizing signals is illustrated by Figure 17.15, “Overall Synchronous Machine Block Diagram”>. The normal excitation system path is represented here by the transfer function, E(s). The normal reference signal of the voltage regulator, v_{ref}, is modified by the addition of a supplementary signal, Δv_s, that is derived from a suitable measurement related to shaft motion via a transfer function, G(s). All PSS®E excitation system models assume that the supplementary signal may be present and calculate the error signal for the voltage regulator as:

$$\Delta e = \Delta v_{ref} + \Delta v_s - \Delta e_t$$

PSS®E always uses compensated terminal voltage in place of actual terminal voltage. The reference signal is present in array VREF, the compensated voltage is taken from array, ECOMP, and the supplementary signal is taken from array VOTHSG. Accordingly, the voltage regulator error calculation in terms of PSS®E arrays is:

$$\Delta e = VREF(I) + VOTHSG(I) - ECOMP(I)$$

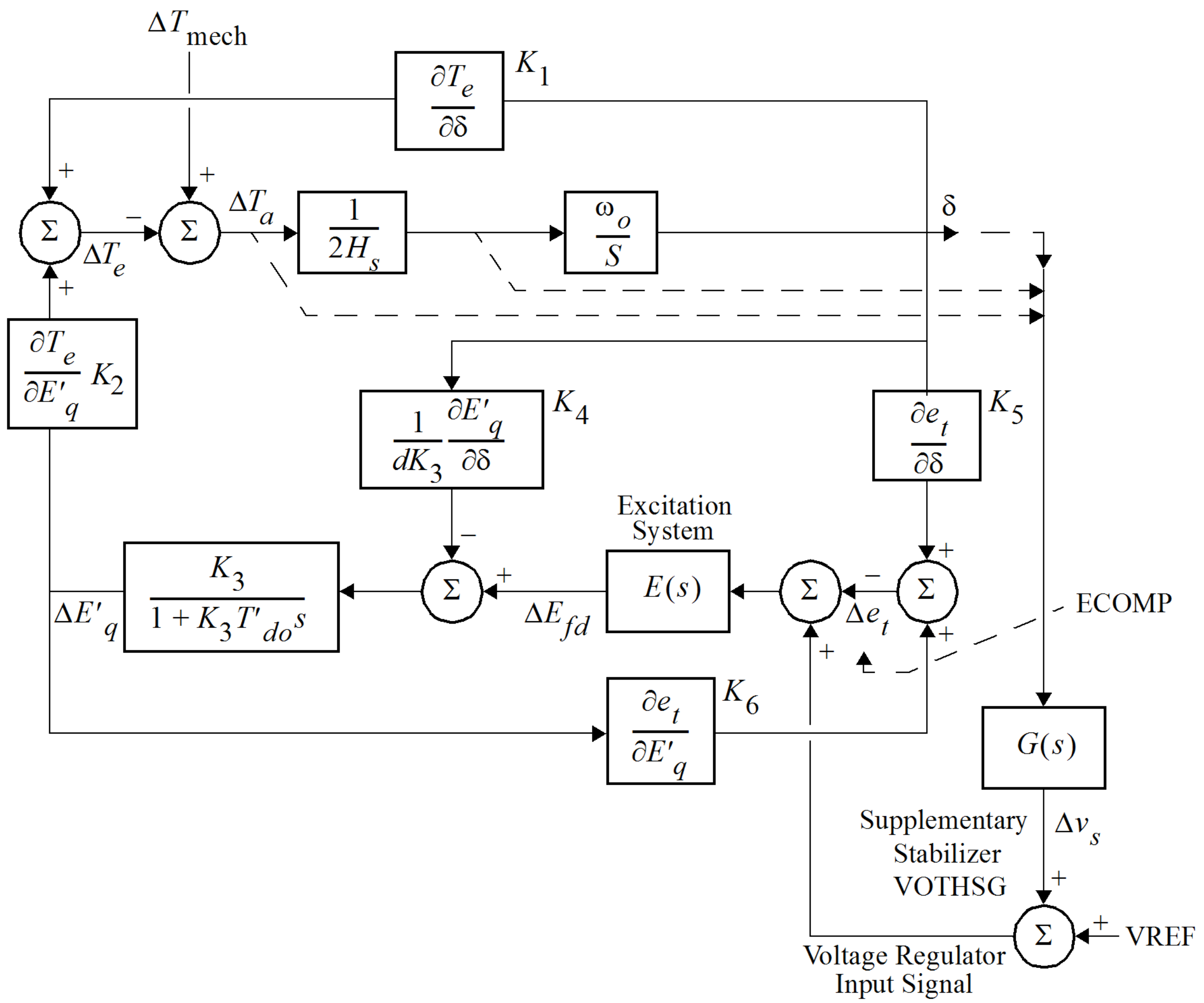


Figure 17.15. Overall Synchronous Machine Block Diagram

The three signals in ECOMP, VREF, and VOTHSG are per unit and all calculations of supplementary stabilizing signals must reduce the value to per unit in terms of generator voltage before placing it in the VOTHSG array. The gain values used in supplementary stabilizer models must be specified accordingly. The user may use any meaningful logic in computing the instantaneous value of VOTHSG(I). The usual approach is to call a PSS®E library model, such as IEEEST, and implement an appropriate stabilizer transfer function, G(s), to determine the supplementary signal. The model call or other calculation determining the supplementary signal must be made prior to the call of the excitation system model that must respond to this signal.

17.7.2. Model IEEEST

Model IEEEST implements the general-purpose supplementary stabilizer representation given in the 1979 IEEE modeling recommendations (see Section 14.2, “Basic Setup Example”). IEEEST is able to pick up a variety of different input signals, all of which may be presumed to be related to shaft motion under certain circumstances. The G(s) transfer function implemented by IEEEST is quite general; it includes a notch filter, two lead-lag blocks to introduce phase lead into the supplementary signal, and a washout block to ensure that the supplementary signal is zero in the steady state.

The ICONs of IEEEST specify the source of the signal inferring shaft motion. A value of 1, 3, or 4 for ICON(IC) indicates that the signal is to be a quantity defined by the machine identified by the arguments IBUS and IM; the value of ICON(IC+1) is ignored in these cases. When the value of ICON(IC) is 2, 5, or 6, the signal is defined by the electric network and can be measured at a point other than the machine where the supplementary signal is applied. In this case, a zero value of ICON(IC+1) indicates that the signal is to be measured at the machine terminals and a nonzero value indicates that the signal is to be measured at a point remote from the generator terminals, namely the bus for which the number is given.

The basic function of IEEEST is to make the phase of the supplementary signal lead that of the input signal. This function is handled by the two lead-lag blocks and is specified by the time constants T_1, T_2, T_3, and T_4. The required gain setting and steady-state washout function are provided by the constants K_3, T_5, and T_6. These seven constants, except T_6, may be set to zero to bypass an unneeded block. Setting $T_1 = T_2 = 0$ bypasses one lead-lag block if its phase lead is not needed. If no washout action is needed, i.e., if the input is accelerating power, the effect of the washout block may be cancelled by setting $T_5 = T_6 = 20$.

The filter block of IEEEST may be used to represent the filtration that is built into some supplementary stabilizers. This filtration usually takes the form of a notch or band-stop filter designed to block a troublesome oscillation not related to the one that the stabilizer is intended to act upon. This may, for example, be a torsional oscillation of the turbine generator shaft or an oscillation between two closely coupled machines that is observable in the input signal but not related to an oscillation of the machine against other remote machines. The filter block may be bypassed by setting the CONs A_1 through A_6 to zero. Nonzero values of numerator coefficients must be associated with nonzero denominator coefficients. The values of A_1 through A_6 in any specific stabilizer will depend, in large measure, on its designer's views and preferences.

The limits L_{SMAX} and L_{SMIN} provide simple clipping of the supplementary signal; typical limit values are ±0.1 pu to ensure that the supplementary signal does not overwhelm the voltage regulation function during major system disturbances. The limits V_{CU} and V_{CL} allow the supplementary signal to be blocked completely when the generator's compensated terminal voltage (designated as V_{CT} on the IEEEST data sheet) falls outside the band from V_{CU} to V_{CL}. These two CONs, V_{CU} and V_{CL}, may be set to zero to bypass this blocking function.

17.7.3. Model STAB1

Model STAB1 is a subset of IEEEST responding to the shaft speed of its designated generator as its only input. It's action is the same as IEEEST when all A constants and blocking CONs of IEEEST are set to zero.

17.7.4. Models STAB2A, STAB3, and STAB4

Models STAB2A, STAB3, and STAB4 are special representations of specific types of supplementary stabilizing units. Both produce a supplementary signal by introducing phase-lead into a signal proportional to electrical power output measured at the generator terminals.

17.7.5. Model IEE2ST

Model IEE2ST is a derivative of IEEEST. It allows two input signals to be summed to create the signal for processing by the phase-lead blocks. Each signal is selected by ICON values as described in Section 17.7.2, "Model IEEEST". Either input may be blocked by setting the corresponding ICON to zero. IEE2ST does not model the notch filter of IEEEST but includes the same limiting and blocking of the output signal.

17.7.6. Model ST2CUT

Model ST2CUT is identical to IEE2ST except in the way in which blocking the output is achieved. ST2CUT assumes the stabilizer is either directly wired to the exciter setpoint or that an operator adjusts the input voltage setpoint signal to the stabilizer. Output of the stabilizer is cut off when terminal voltage differs from the initial voltage by the user-specified values of V_{CU} and V_{CL}. V_{CL} is normally input as a negative value.

17.7.7. Model PTIST1

PTIST1 models the microprocessor-based power system stabilizer as built by PTI. It models the inputs as derived from potential and current transformers. The algorithms convert these sampled values into a stabilizing signal.

17.7.8. Model PTIST3

PTIST3 is an extension of the PTIST1 model for the PTI microprocessor-based stabilizer. The updated model includes:

- Third lead-lag function.
- Two-stage torsional filter.
- *Tap-averaging* feature.
- *Time-at-a-limit* function.
- Analog output option.
- Additional signal limiters.

Each of these model additions is discussed below.

Third Lead-Lag

Two CONs and one VAR (for the STATE or STORE) have been added to accommodate this feature. If the user wishes to disable the third lead-lag, then CON(J+13), T_6 must be set identically to zero.

Torsional Filter

The torsional filter includes two second-order stages. Six CONs and two VARs (storage locations) have been added to accommodate each stage. If the user wishes to disable the torsional filter, then CON(J+19), B_2, must be set identically to zero. In this event both stages are bypassed. If B_2 is equal to zero, then values specified for any of the other torsional filter CONs do not matter. However, if the filter is enabled, then both stages are active and CON(J+25), B_5, must also be greater than zero to avoid a divide-by-zero problem.

The actual stabilizer controlling software, except for the torsional filter, has been designed to mimic an analog controller. The torsional filter has been implemented directly in the digital domain (z-plane discrete time filter) via a first direct digital structure. Therefore the torsional filter has been coded into the model using z-form for state-space dynamics as well as extended term.

Tap-Averaging

The tap averaging function keeps a running average of the last ICON(M+1), NAV, control outputs (clicks) up to a maximum of 16. This feature can be disabled by setting ICON(M+1) equal to 1 (i.e., average 1 output).

The last ICON(M+1) outputs are stored in the output averaging table, VAR(L+22) through VAR(L+37). The sum of the last ICON(M+1) outputs is stored in the output accumulator VAR(L+38). The averaging feature was added to reduce tap chattering under steady-state conditions.

If the control output at any given click exceeds the threshold specified in CON(J+26), A_{thres}, the averaging function will be automatically bypassed, and that output signal will be passed directly to the limit function. This feature has been added such that under transient conditions the stabilizer reverts to normal operation.

When the absolute value of output signal is beyond the threshold, the output averaging table entries and accumulator are zeroed out. When the signal falls below the threshold, the table is rebuilt starting with the first signal within the threshold. If the output averaging is enabled, then the threshold value would probably be specified in the range from 0.002 to 0.02.

Time-at-a-Limit

The time-at-a-limit function performs two options:

1. Counts the number of clicks (control outputs) that the output signal continuously exceeds a user-defined threshold as set in CON(J+29), L_{thres}.
2. After the output signal has continuously exceeded the threshold for a number of user-defined counts as specified by ICON(M+2), NCL, the function ramps the tap position to nominal or the analog output to zero over a user-specified number of counts as defined in ICON(M+3), NCR.

This feature is designed to prevent the stabilizer from remaining at its extreme tap position for a prolonged period of time. The minimum control output value (absolute) that drives the autotransformer to its maximum tap position is 0.1.

The user should be aware that the model counts the number of clicks (or control outputs) such that if the user-defined simulation time step is greater than the physical sampling rate (0.025 sec), the model may produce timing errors. However, it is expected that the time-at-a-limit function would only play a role during local disturbances when the user should be in small time step mode.

Analog Output Option

ICON(M), ISW, controls the output option in force. If ICON(M) is set equal to zero, the stabilizer will operate in normal mode, where the output control signal is used to select an autotransformer tap position, which, in turn, modulates the feedback terminal voltage (digital output option). If ICON(M) is set equal to one, the stabilizer will operate in analog mode, where the output control signal is fed into the exciter as a supplementary control signal.

Additional Signal Limiters

CON(J+30), P_{min}, can be specified such that if the machine power drops below this value the stabilizer will instantaneously move to nominal tap or zero analog output and remain there until the condition clears. CON(J+27) is the digital signal limiter such that the control output may be clipped to the value specified for D_L prior to selecting a tap position.

CON(J+28), AL, is the corresponding output signal limiter for the analog output option.

17.7.9. Model STBSVC

Model STBSVC provides a supplementary signal for the WSCC static var compensation model CSVGN5. STBSVC receives one or two signals as input and its output, from the model's transfer function, is placed in the array VOTHSG, which is used by the static var models. The first signal is required and for this signal the user may choose electrical power, bus frequency, or accelerating power. The signal of electrical power is the per unit flow of a branch or the total flow of parallel branches. The signal of accelerating power is obtained from a remote machine. An optional second signal is derived from a remote bus voltage, vars from the SVC into the system, the SVC current into the system; vars can be obtained from a remote machine or from a branch. The values of these signals are per unit, scaled by the system base quantities.

The choices for the signals are indicated from the values assigned to the ICONs in the model. A value in ICON(IC) selects the quantity for the first signal as noted on the data sheet. If there is an error, i.e., ICON(IC) is outside the range as listed on the data sheet, the model will print out an error message and change the value for ICON(IC) to 3 for bus frequency. A value in ICON(IC+1) selects the quantity for the second signal. By setting ICON(IC+1) to 0 no signal will be obtained and the model will derive its stabilizing signal output from just the first input signal. If the value entered for ICON(IC+1) is outside the range as listed on the data sheet, then the model will print out an error message and set ICON(IC+1) to 0 for no signal.

The other four ICONs indicate the source of the signals. ICON(IC+2), ICON(IC+3), and ICON(IC+4) indicate the equipment source of the first input signal. For accelerating power and bus frequency deviation, the remote bus number is stored in ICON(IC+2). The remote machine ID number is stored in ICON(IC+4). For power flow between for a branch, ICON(IC+2) is the from bus number; ICON(IC+3) is the to bus number; and ICON(IC+4) is the circuit number. If set to –1, power flow is the total of the parallel branches. A value stored in ICON(IC+5) is the remote bus number providing the bus voltage is obtained. By setting ICON(IC+5) to 0, the bus voltage will produce an error message.

17.7.10. PSS2A

Model PSS2A, like IEE2ST, is a dual-input stabilizer. This model can represent a variety of stabilizers with inputs of power, speed, or frequency.

For each of the two inputs, two washouts can be represented along with a transducer time constant. The indices N and M allow a ramp-tracking or simpler filter characteristic to be represented. Phase compensation is provided by the two lead-lag or lag-lead blocks.

17.8. Models MNLEX1, MNLEX2 and MNLEX3

Minimum excitation limiters or under-excitation volt-ampere limiters are provided in excitation systems to increase E_{FD} during high voltage to maintain steady-state stability. The models listed in Table 17.4, " Models Developed for Consolidated Edison Company of New York" were developed under contract for the Consolidated Edison Company of New York. These different minimum excitation system characteristics are represented and can be combined with excitation systems IEET1B. Care should be taken when using these models to assure coordination between normal excitation control through the voltage comparator and excitation control by the proper minimum excitation limiter. Coordination is normally achieved by these methods, but currently only with excitation system model IEET1B:

- Summing the output of the minimum excitation limiter with the output of a voltage error function that is limited. Either the voltage comparator or the minimum excitation limiter will then normally be on its limit.
- Feeding voltage comparator and minimum excitation limiter outputs into a high value gate.

The output of these limiters is placed in the VOEL array.

Table 17.4. Models Developed for Consolidated Edison Company of New York

Model	Units	MEL Manufacturer
MNLEX1	Ravenswood 3	Allis Chalmers
MNLEX2	Poletti	Westinghouse
MNLEX3	Ravenswood 1 and 2 Arthur Kill	General Electric

Chapter 18
Speed Governor System Modeling

18.1. Overview

The turbine-governor models are designed to give representations of the effects of power plants on power system stability. They are not, however, intended to be used in studies of the detailed behavior of individual plants. A functional diagram of the representation used and its relationship to the generator is shown in Figure 18.1, "Speed Governor and Turbine in Relationship to Generator".

Because of the wide variety in the details of individual turbine controls, the PSS®E models do not attempt to give a high degree of exactness for any given plant; rather they represent the principal effects inherent in conventional steam turbine, gas turbine, nuclear, and hydro plants.

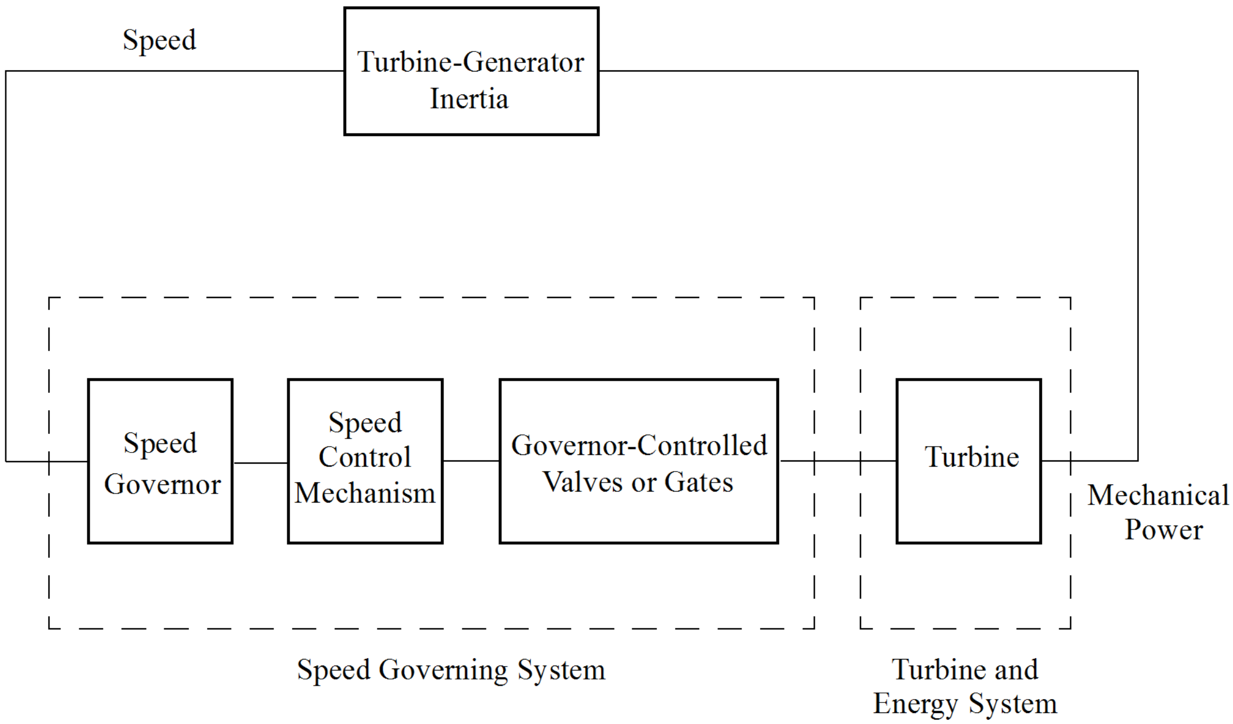


Figure 18.1. Speed Governor and Turbine in Relationship to Generator

18.2. Turbine-Governor Data

The turbine-governor status is determined, as for generators, by the following criteria:

- Online when the terminal bus type is 2 and the machine status is 1.
- Off-line when the terminal bus type is 1 or 4 or machine status is 0.

All turbine-governor data should be specified on the same base used for the generator. Hence, if all machine data is entered on each machine's individual base, the governor permanent droop, *R*, of all units should be set equal to ensure equal load sharing on all units.

The turbine damping factor, D_{turb}, is equal to $\partial P_{turbine} / \partial_{speed,}$ in per unit, on a base equal to unit rating. For steam, nuclear, and gas turbines, D_{turb} can normally be taken as zero; for hydro turbines its value normally lies between 0 and 0.5 pu.

18.3. Model TGOV1

TGOV1 is a simple model representing governor action and the reheater time constant effect for a steam turbine. The ratio, T_2/T_3, equals the fraction of turbine power that is developed by the high-pressure turbine. T_3 is the reheater time constant, and T_1 is the governor time constant. Representative values for typical units are:

R = 0.05 pu

T_1 = 0.50 sec

T_2/T_3 = 0.3

T_3 = 5 to 9 sec

18.4. Gas Turbine-Governors

The general subject of gas turbine modeling for power system transient stability analysis is described in a paper by W.I. Rowen, "Simplified Mathematical Representations of Heavy-Duty Gas Turbines," ASME 83-GT-63, Engineering for Power, October 1983, pp. 865.

18.4.1. Model GAST

GAST represents the principal dynamic characteristics of industrial gas turbines driving generators connected to electric power systems. Speed variations from nominal are expected to be small (approximately ±5%). The model consists of a forward path with governor time constant, T_1, and a combustion chamber time constant, T_2, together with a load-limiting feedback path. The load limit is sensitive to turbine exhaust temperature, and T_3 represents the time constant of the exhaust gas measuring system.

The ambient temperature load limit [CON(J+4)] should be set to unity, when the turbine is operating at design ambient temperature. At a higher ambient temperature, it should be set to a lower value, as prescribed by manufacturer's data. Hence, the dynamic behavior of the turbine changes with ambient temperature. The constant, K_T, is used to adjust the gain of the load-limited feedback path.

The load reference, [VAR(L)], is set equal to shaft power PMECH, when the model is initialized during activity STRT. The load-limited feedback path only controls fuel flow to the gas turbine through the low valve gate, when its output is lower than the original load reference (decremented by the droop signal, $1/R$). The damping coefficient, D_{turb}, is used to represent speed damping introduced by the gas turbine rotor.

A distinction exists between the maximum fuel valve opening, VMAX[CON(J+6)], and the ambient temperature load limit. The maximum fuel valve opening is an operational control and may be adjusted by the operator to allocate load within a plant. The ambient temperature load limit is a turbine design parameter, and load-limiting feedback serves a protective function. Representative data for a typical gas turbine generator unit are listed here:

R = 0.05 pu

T_1 = 0.4 sec

T_2 = 0.1 sec

T_3 = 3.0 sec

VMAX = 1.0 pu

VMIN = – 0.05 pu

Ambient temperature load limit = 1.0 at 80°F (rated); 0.9 at 105°F

K_T = 2.0

D_{turb} = 0.0

18.4.2. Model GAST2A

GAST2A has a more detailed representation of gas turbine dynamics than GAST. As with GAST, it is intended for operation near rated speed. The speed governor can be configured for droop or isochronous modes of operation by selecting 1 or 0 for CON(J+3). The temperature controller assumes control of turbine power when exhaust gas temperature exceeds its rated value. The reference cited in Section 18.4, "Gas Turbine-Governors" can be used for obtaining estimates of model constants if actual data is not available.

18.4.3. Model GASTWD

GASTWD has the same detail representation of gas turbine dynamics as GAST2A. The governor system for this model is based on a Woodward governor consisting of an electric speed sensor with proportion, integral, and derivative control.

18.4.4. Model WESGOV

WESGOV may be used to model the Westinghouse 501 combination turbine-governor. This gas turbine model has discrete cycle sampling times, Δ TP and Δ TC. T_1 and T_2 represent the valve, piping, and combustion time constants. T_{pe} is the electric power measurement time constant.

18.5. Hydro Governor Models

Several models are available for hydro electric plant simulation. Although they have similar governor models, they differ in hydraulic system representation:

- Linear models (IEEEG2, IEEEG3, IEESGO, WPIDHY, and HYGOV2).
- Nonlinear models (HYGOV, HYGOVM, WEHGOV).

18.5.1. Linear Models

Linear models assume the following penstock/turbine transfer function:

$$\frac{p}{g} = \frac{1 - T_W \times s}{1 + T_W \times s/2}$$

where *p* and *g* are per unit mechanical power and gate position, respectively.

The water column constant, T_W, is given, approximately, by:

$$T_W = \frac{L \times Q}{g_v \times A \times H}$$

where:

Q = Flow at initial loading level.

H = Head at initial loading level.

L = Centerline length of penstock plus scroll case plus draft tube.

g_v = Gravitational acceleration.

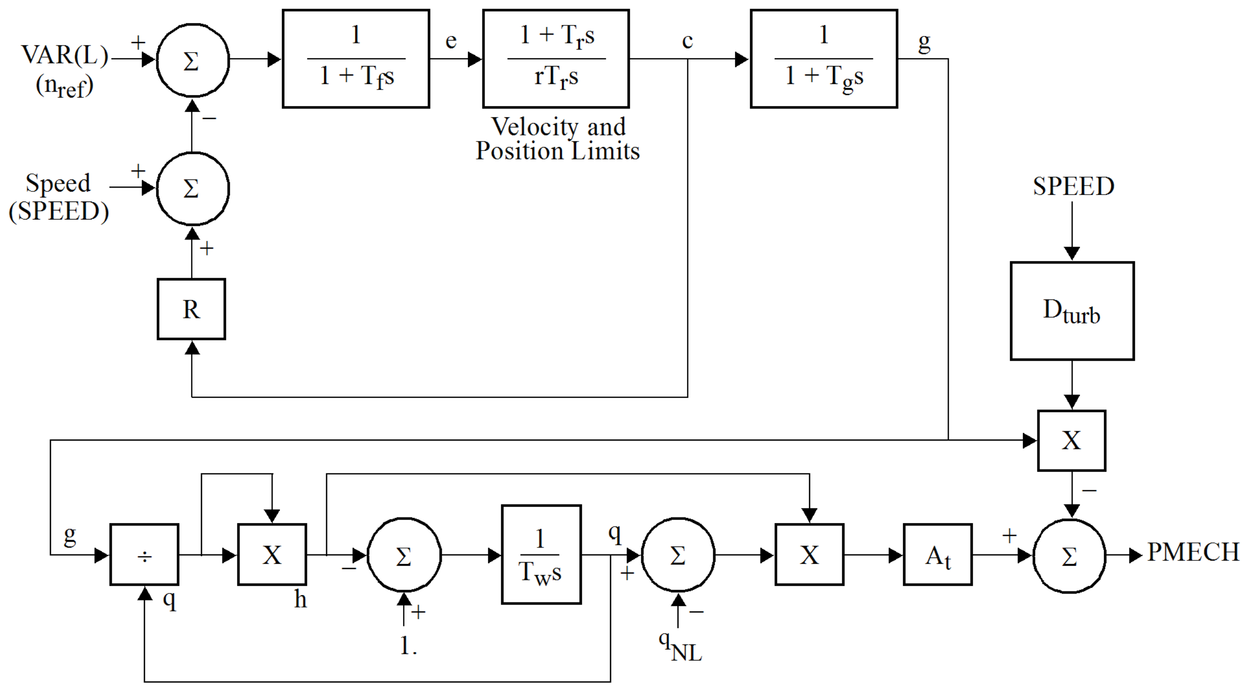
A = Penstock cross-sectional area.

Because *Q* at half load is about half its full load value, while H remains fairly constant, T_W varies significantly with loading level.

These models are valid only for the small deviations of frequency and gate position that are typical in large power systems. They also require that the user recalculate the value of T_W for each new initial loading level.

18.5.2. Model HYGOV

HYGOV represents a straightforward hydro electric plant governor, with a simple hydraulic representation of the penstock with unrestricted head race and tail race, and no surge tank. The hydraulic and governor models are shown in Figure 18.2, “Hydraulic and Governor Models”.



R=Permanent droop	f=Per unit flow
r=Temporary droop	h=Per unit Head
T_r=Governor time constant	q_{NL}=No power flow
t_f=Filter time constant	A_t=Turbine gain
T_g=Servo time constant	D_{turb}=Turbine damping
g=Per unit gate opening	

Figure 18.2. Hydraulic and Governor Models

Linearization of the penstock/turbine transfer function for small perturbations around a Q_0, H_0 operating point results in:

$$\frac{p}{g} = \frac{1 - T_W \times s}{1 + T_W \times s/2}$$

where:

$$T_W = T_W \times \frac{Q_0}{H_0}$$

T_W is calculated as in (16.2) but uses per unit base flows and heads that are independent of initial loading level. Base flow is turbine flow when gates are fully open (g = 1 pu). Base head is head on turbine when the flow is base flow. Q_0 and H_0 are per unit of the base flow and head, respectively. By multiplying the water time constant by Q_0 and $1/H_0$, the model automatically accounts for dynamic changes in its effective value. The penstock/turbine model is valid for the full range of hydro turbine operation from speed no load to maximum gate opening. It is also valid for large speed deviations and can be used to simulate load rejection overspeed conditions if no relief valve or jet deflector action is expected.

The governor model is valid for dashpot-type mechanical governors (e.g., Woodward, English Electric), and for dashpot-equivalent electrohydraulic governors (e.g., ASEA). No acceleration governing (derivative action) term is included because this is used only in specialized situations in most interconnected power systems.

The permanent droop, R, and temporary droop, r, are specified per unit on a base equal to unit rating. The velocity limit, VELM, is the reciprocal of the time taken for the gates to move from fully open to fully closed. The maximum gate limit, GMAX, is equal to the gate limit setting as established by the operator at the governor console; it cannot exceed 1 pu. The minimum gate position is normally zero. The no power flow, q_{NL}, is the flow required to maintain rated speed with the unit off-line; q_{NL} is expressed in per unit of base flow. The turbine gain, A_t, is given by:

$$\frac{1}{g_{FL} - g_{NL}}$$

where:

g_{FL} = Full load gate ($0 < g_{FL} < 1$).

g_{NL} = No load gate ($0 < g_{NL} < 1$).

Representative hydro plant data values are:

R	Permanent droop	0.05 pu
r	Temporary droop	0.1 to 1.0 pu
T_r	Governor time constant	2 to 20 sec
T_f	Filter time constant	0.05 sec
T_g	Gate servo time constant	0.5 sec
VELM	Gate velocity limit	0.167 pu/sec
GMAX	Maximum gate	1.0 pu
GMIN	Minimum gate	0.0 pu
T_W	Water time constant	1.0 to 3.0 sec
A_t	Turbine gain	1.2
D_{turb}	Turbine damping coefficient	1.5 to 2.0 for Pelton (bucket) 0.0 for Kaplan (blade) 0.5 for Francis
q_{NL}	No power flow	0.08 pu

Values of r and T_r should be set to give stable isolated load governing. A guideline for setting r and T_r is:

$$T_r = 4T_W \qquad r = \frac{T_W}{H}$$

These guideline settings should be reviewed for each individual unit.

18.5.3. Model HYGOVM

In hydro plant layouts where a long supply conduit is required, it is fairly common practice to use a surge tank. The purpose of the surge tank is to provide a degree of hydraulic isolation of the turbine from the head deviations generated by transients in the longest portion of the conduit. Many surge tanks also include an orifice where head loss serves to dissipate the energy of hydraulic oscillations and to produce a damping effect. The hydraulic system model in HYGOVM is designed to allow detailed simulation of the representation of the surge chamber system:

- Penstock dynamics.
- Surge chamber dynamics.
- Tunnel dynamics.
- Penstock, tunnel, and surge chamber orifice losses.
- Surge chamber level beyond maximum or minimum alarm.

Penstock dynamics are largely determined by the upper loop in Figure 18.3, "Penstock Dynamics Loop". The loop gain is proportional to the inverse of the square of gate position and thereby increases significantly for small openings. Under load rejection conditions, near total gate closure, the loop effective time constant will tend to zero.

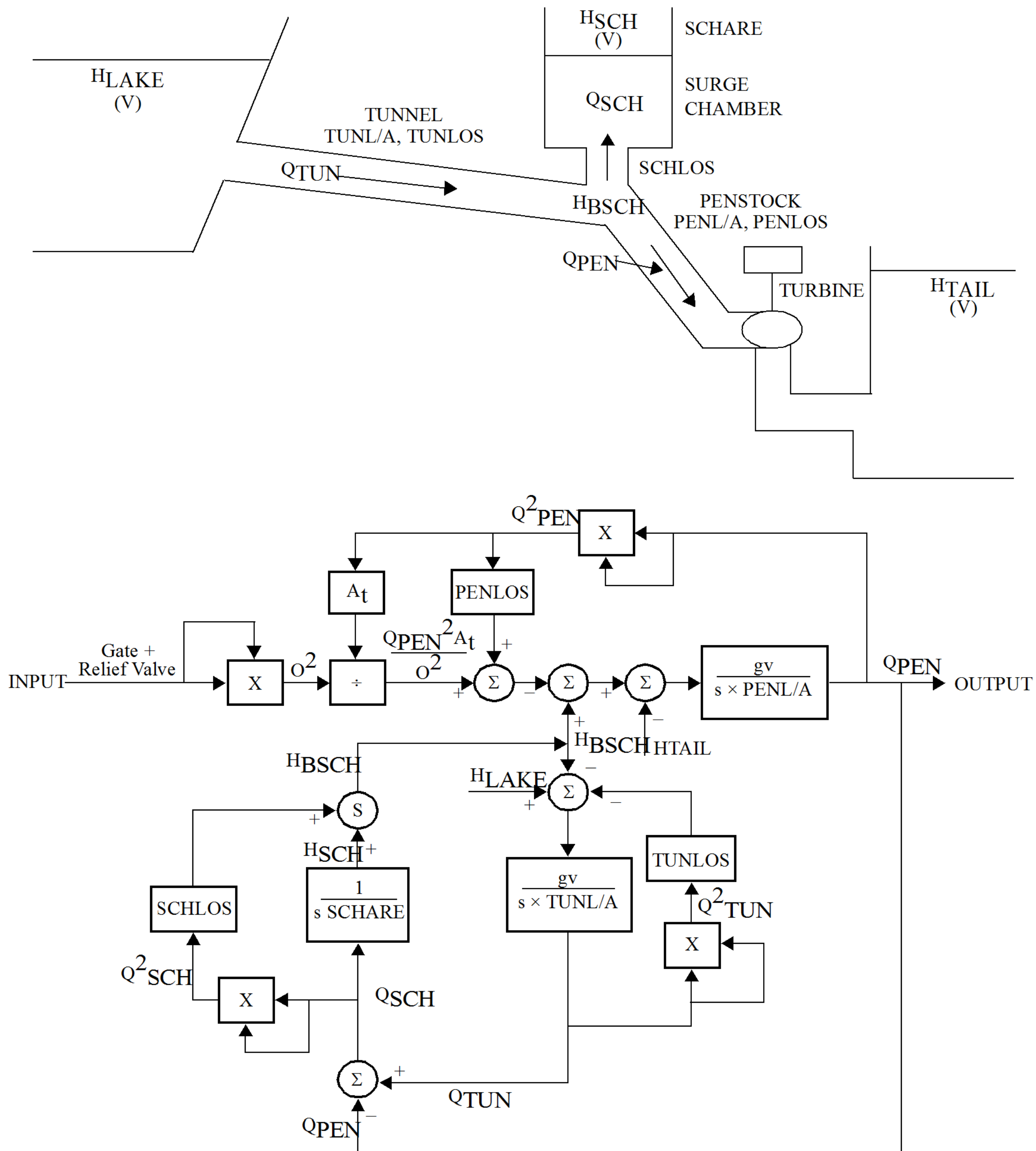
The model cannot handle low time constants without incurring numerical instability. It deals with this problem by assuming an algebraic solution (i.e., an instantaneous response, just before numerical instability would occur). This change in model response can be visualized by an instantaneous drop in turbine head (VAR(L+1)) to values close to the head at the surge chamber base (VAR(L+4)). At the time the algebraic solution is applied, power and flows at the penstock are negligible and will not affect governor or surge chamber studies. The governor system used in the HYGOVM model (Figure 18.4, "HYGOVM Governor System") is based on the HYGOV governor representation, but has these additional features:

- *Separate maximum opening and closing gate rate limits*. The maximum gate closing rate (MXGTCR) is usually a compromise between maximum scroll case head, surge tank overflows, and unit overspeed under load rejection. A representative value is 0.125 pu/sec. The maximum gate opening rate (MXGTOR) determines minimum surge chamber levels when accepting load. A value of +0.1 pu/sec is representative.
- *Buffered opening and closing rates when gate opening is near full closure*. Buffering the gate closure may produce a reduction in overpressures under load rejection. This feature will reduce impact loadings on the gate linkage and limit the magnitude of the pressure pulsations that occur while the gates are fully closed during the decay of load rejection overspeed. A representative value for the maximum buffered closing gate rate (MXBGCR) is –0.05 pu/sec and 0.15 pu for the buffer limit (BUFLIM). The maximum buffered opening rate (MXBGOR) is normally equal to MXGTOR.
- *Pressure regulator (relief valve) simulation*. This regulator is a bypass, generally attached to the turbine casing. It is operated directly from the governor or the gate mechanism of the turbine. The amount of water bypassed is sufficient to keep the total discharge through the penstock fairly constant, hence controlling pressure rise. The maximum relief valve opening (RVLMAX) can be set equal to GMAX. For the water-wasting type, the maximum relief valve closing rate (RVLVCR) should be set to 0. pu/sec; for the water-saving type, a representative value for RVLVCR is –1/70 pu/sec.

- *Jet deflector simulation*. Long penstock impulse turbines are not allowed rapid reductions in water velocity because of the pressure rise that would occur. To minimize the speed rise following a sudden load rejection, a governor-controlled jet deflector is normally placed between the needle nozzle and the runner. The governor moves this deflector rapidly into the jet, cutting off the load. Typical values for maximum jet deflector opening and closing rates (MXJDOR and MXJDCR) are +0.5 and 0.5 pu/sec, respectively.

Turbine characteristics in HYGOVM are defined based on rated conditions:

1. Rated power = CON(J+1).
2. Rated flow = CON(J+2).
3. Rated head = CON(J+3).
4. Gate opening at rated operating point = CON(J+4).
5. No power flow = CON(J+5) × CON(J+2).

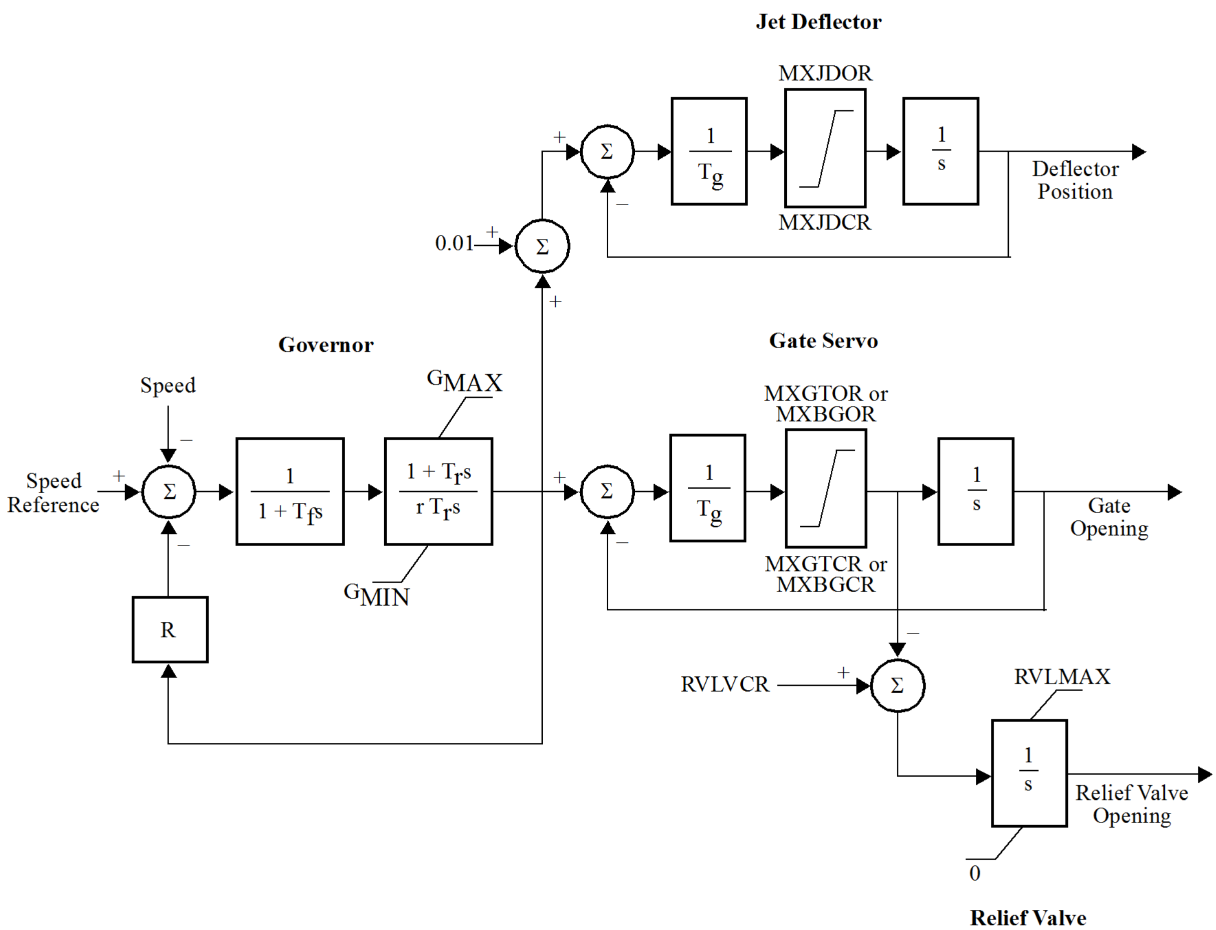


LEGEND:

gv	Gravitational acceleration	At	Turbine flow gain
TUNL/A	Summation of length/cross section of tunnel	O	Gate + relief valve opening
SCHARE	Surge chamber cross section	HSCH	Water level in surge chamber
PENLOS	Penstock head loss coefficient	QPEN	Penstock flow
TUNLOS	Tunnel head loss coefficient	QTUN	Tunnel flow
FSCH	Surge chamber orifice head loss coefficient	QSCH	Surge chamber flow
PENL/A	Summation of length/cross section of penstock, scroll case and draft tube		

Figure 18.3. Penstock Dynamics Loop

Hydro Turbine Governor Lumped Parameter Model



LEGEND:

R	Permanent droop	MXBGCR	Maximum buffered gate closing rate
r	Temporary droop	GMAX	Maximum gate limit
T_r	Governor time constant	GMIN	Minimum gate limit
T_f	Filter time constant	RVLVCR	Relief valve closing rate
T_g	Servo time constant	RVLMAX	Maximum relief valve limit
MXGTOR	Maximum gate opening rate	MXJDOR	Maximum jet deflector opening rate
MXGTCR	Maximum gate closing rate	MXJDCR	Maximum jet deflector closing rate
MXBGOR	Maximum buffered gate opening rate		

Figure 18.4. HYGOVM Governor System

The following parameters are calculated by the model:

$$K_t \text{ (Turbine Power Gain)} = \frac{P_{Rated}}{(Q_{Rated} - Q_{No\ load}) \times H_{Rated} \times MVA_{Base}}$$

$$T_{fg} \text{ (Turbine Flow Gain)} = \frac{Q_{Rated}}{(G_{Rated} \times \sqrt{H_{Rated}})}$$

Turbine power is a function of turbine flow and turbine head, which, in turn, are a function of penstock flow, gate position, and relief valve or jet deflector position. For turbines with a relief valve:

$$\text{Turbine Flow} = \frac{Q_{penstock} \times \text{Gate Opening}}{\text{Gate Opening} + \text{Relief Valve Opening}}$$

$$\text{Turbine Head} = \frac{(Q_{penstock})^2 \times A_t}{(\text{Gate Opening} + \text{Relief Valve Opening})^2}$$

For turbines with a jet deflector:

Turbine Flow = $Q_{penstock}$ × MIN (1., Jet Position/Gate Opening)

$$\text{Turbine Head} = \frac{Q_{penstock}{}^2\, A_t}{(\text{Gate Opening})^2}$$

For turbines with neither relief valve nor jet deflector:

Turbine Flow = $Q_{penstock}$

$$\text{Turbine Head} = \frac{Q_{penstock}{}^2\, A_t}{(\text{Gate Opening})^2}$$

$$\text{Turbine Power} = K_t \times \text{Turbine Head} \times (\text{Turbine Flow} - \text{No Power Flow}) - \text{Damping}$$

$$\text{Damping} = \text{DAMP} \times \text{per unit speed deviation} \times \text{MIN (Jet Position, Gate Position)}$$

where DAMP is DAMP1 for overspeeds under RPM1, DAMP2 for overspeeds above RPM2, and linearly interpolated for overspeeds between RPM1 and RPM2. The HYGOVM model should be used for dynamic analyses of hydro plants when the time range of interest is comparable to the surge tank natural period. For shorter time periods, the simpler HYGOV model can be used, unless relief valve or jet deflector action is expected.

Surge Tank Natural Period =

$$\left(\frac{\text{SCHARE} \times \text{TUNL/A}}{\text{Gravity}}\right)$$

Figure 18.5, "Short-Term versus Midterm GSTR/GRUN Hydro Governor Test" shows the result of simulating a 0.1-pu step load increase on an isolated hydro plant using both HYGOV and HYGOVM. A surge tank natural period is 3 min. For the normal 3- to 5-sec transient stability time frame of interest, simulation results are almost identical. For longer simulation times, surge tank level starts falling, and mechanical power recovery lags behind that of the HYGOV model, which assumes an infinite surge tank. Detailed conversion of the HYGOVM data into HYGOV format follows these steps:

$$\text{Flow Base (STATE(K+3) in HYGOV)} = \sqrt{\frac{(\text{HLAKE} - \text{HTAIL})}{\text{PENLOS} + \text{TUNLOS} + 1/(T_{fg})^2}}$$

$$\text{Head Base (VAR(L+1) in HYGOV)} = \text{HLAKE} - \text{HTAIL} - \text{Flow Base}^2 \times (\text{PENLOS} + \text{TUNLOS})$$

$$T_W\,\text{(CON(J+8) in HYGOV)} = \frac{\text{PENL/A} \times \text{Flow Base}}{\text{Head Base} \times \text{Gravity}}$$

$$A_t\,\text{(CON(J+9) in HYGOV} = \frac{P_{Rated} \times \text{Head Base} \times \text{Flow Base}}{MVA_{Base} \times Q_{Rated} \times H_{Rated} \times (1 - Q_{No\ Load})}$$

Gravity = 9.81 or 32.21, depending on whether metric or English units are used. For longer term analyses, for surge chamber dynamics analyses, and for load rejection analyses involving relief valve or jet deflector action, the HYGOVM or HYGOVT models should be used.

18.5.4. Model WEHGOV

WEHGOV is a model of a Woodward Electronic hydro-governor with proportional, integral, and derivative control. The turbine is represented by a nonlinear model for the penstock dynamics in a similar fashion as HYGOV, but the model includes look-up tables to allow the user to represent nonlinearities in the flow versus gate position and mechanical power versus flow during steady-state operation.

The model allows for the use of three feedback signals for droop:

- Electrical power.
- Gate position.
- PID output.

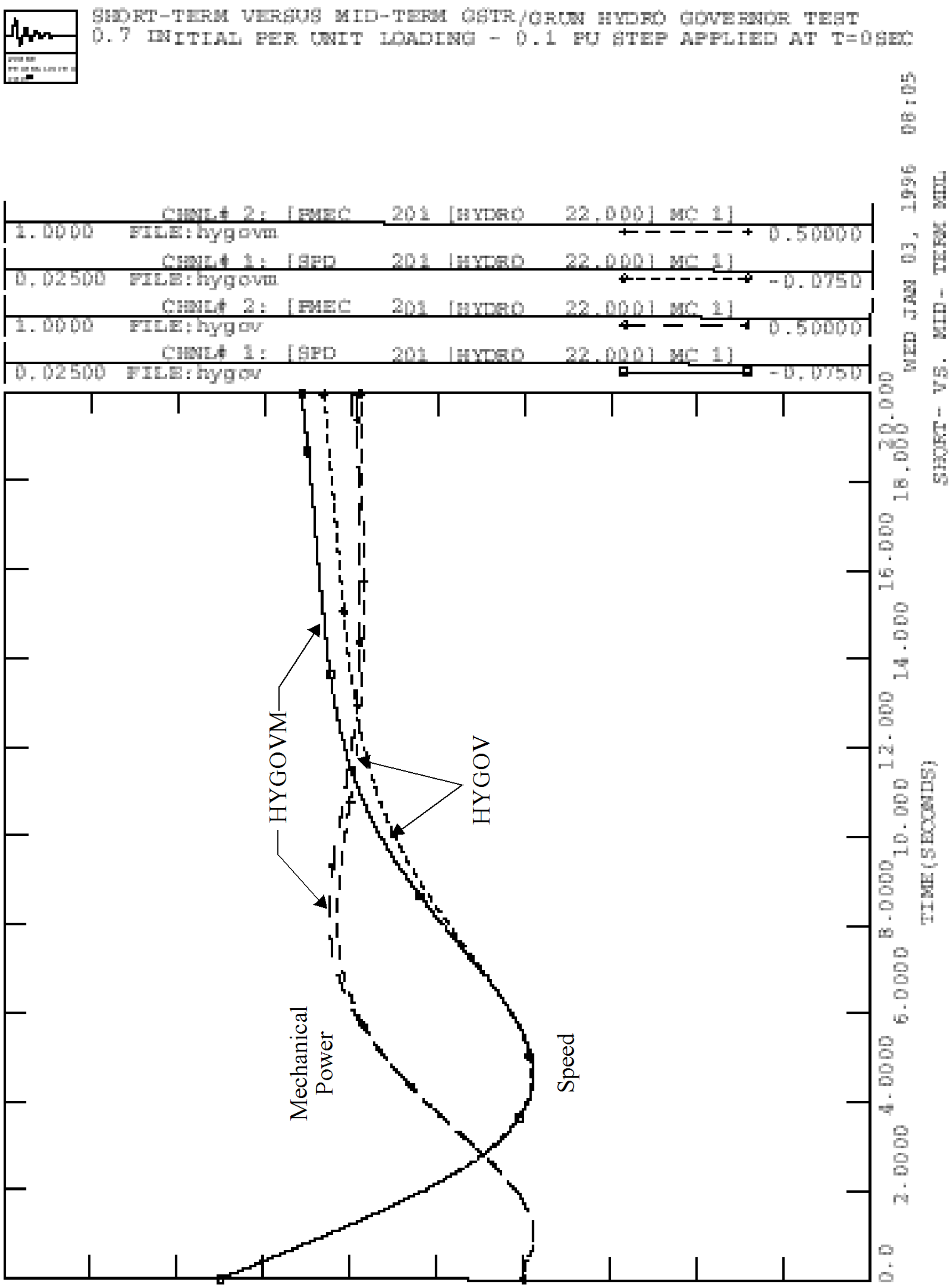


Figure 18.5. Short-Term versus Midterm GSTR/GRUN Hydro Governor Test

To specify which signal will be used, refer to the following:

Feedback Signal	CON(J)	CON(J+1)	ICON(M+)
Electrical power	0	Value for droop	0
Gate position	Value for droop	0	0
PID output	Value for droop	0	1

PID Controller

The derivative controller has a time constant to limit the derivative characteristic beyond a breakdown frequency to avoid amplication of high-frequency noise. This time constant is labeled T_D (i.e., CON(J+6)), and its value is typically 0.10 sec.

The PID controller also has a limiter on the integral control to prevent windup when the gates are at their limit. The gate position limits are set in GMAX for maximum and GMIN for minimum. For the integral controller there is another variable called DICN, CON(J+18) that allows the integral controller to advance beyond the values for the gate limits. The maximum limit for the integral controller is:

GMAX + DICN

and the minimum limit is:

GMIN – DICN

The value for DICN ranges from 0 to 10% and it is set with the field tuning for the governor.

Pilot Valve

The output signal of the PID controller is fed into the pilot valve. The pilot valve also has a set of limits that are similar to that for the integral controller. The maximum limit for the pilot valve output is:

GMAX + DPV

and the minimum limit is:

GMIN - DPV

The value for DPV, CON(J+17), is typically about 2% to ensure that gate can be fully opened or closed.

Distribution Valve

The output signal of the pilot valve is fed into the distribution valve. The limits of the distribution valve define the maximum rates to open or close the gates. These two rate limits are:

1. GTMXOP (maximum gate opening rate), CON(J+10).

2. GTMXCL (maximum gate closing rate), CON(J+11).

The values for both parameters are in per unit gate position per second. Note that the value for GTMXCL must be less than 0.

Turbine Model

The model for the penstock hydraulics is similar to that for HYGOV. However, the turbine model includes two look-up tables to account for steady-state nonlinearities in the model. The first table is defined by CON(J+19) through CON(J+28). This set of CONS represent the water flow through the turbine as a function of gate position. Increasing values starting with GATE1 and FLOW1 must be entered into this table. The second table is defined by CON(J+29) to CON(J+48) to represent per unit mechanical power on machine MVA rating as a function of flow. Again, increasing values starting with FLOW1 and PMECH1 must be entered.

18.5.5. Model HYGOVT

In this model, a traveling-wave solution is applied to the penstock and tunnel (Figure 18.6, "Traveling-Wave Model HYGOVT").These are divided into 9 to 19 segments, and the characteristics solution method is applied to the resulting time-space lattice. Boundary conditions and head losses are fully recognized. For accurate results, the simulation time step should be no larger than:

PENLGTH/(9 × PENSPD)

where PENLGTH is the penstock length and PENSPD is the penstock wave velocity. Maximum accuracy is attained when simulation time step is equal to, or a submultiple of:

PENLGTH/(19 × PENSPD)

Conduit wave velocity, assuming rigid walls and accounting for water compressibility, alone is 1420 m/sec (4659 ft/sec). This velocity is the maximum that can be physically attained. Actual conduits do not have rigid walls, a representative value for penstock conduits is 1100 m/sec (3609 ft/sec).

For this model, the governor and turbine models are the same as in the HYGOVT model. The decision to use the inelastic (HYGOVM) or elastic (HYGOVT) models relies on the hydraulic system characteristics and the study scope. Because of time-step constraints (16.22), traveling-wave simulation turnover may be penalized by the need to use a smaller time step than would otherwise be required with the inelastic model. However, some error is involved with the use of an inelastic model. This error can be quantified by the difference between the elastic and the inelastic head/flow transfer functions in the frequency domain. This difference, per unit of the elastic case, is approximately:

$$- \frac{T_p^2 \times s^2}{3} \qquad (18.1)$$

where T_p is the penstock wave travel time (PENLGTH/PENSPD), and s is the Laplace operator. T_p is typically 0.5 sec, but can be as high as 1.5 sec for long penstocks. For normal governor action, speed loop crossover, i.e., the dominant mode, occurs at about 1/2 T_W rad/sec. With T_W being typically 1 to 2 sec, s is in the order of 0.25 to 0.5 rad/sec. The difference between elastic and inelastic response will usually be negligible, unless very long penstocks are studied. A critical case run using both model assumptions may prove to be the easiest way to assess this difference.

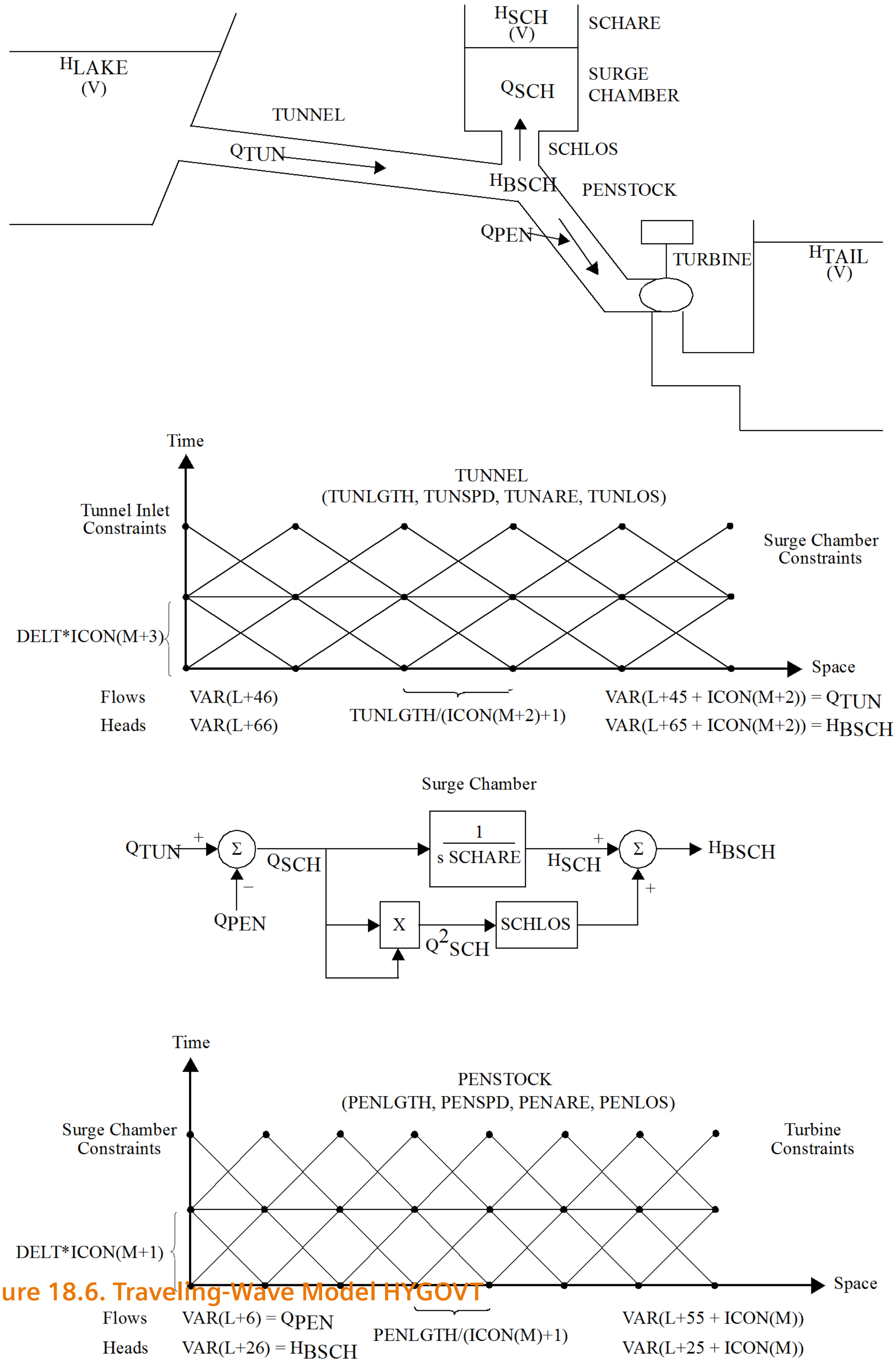


Figure 18.6. Traveling-Wave Model HYGOVT

Figure 18.7, “Elastic versus Inelastic Hydro Governor Models Comparison — Example 1” shows a case where an isolated hydro power plant with a T_W of 1.83 sec and a T_p of 0.42 sec is subject to a 0.2-pu increase in load. Except for some transient, high-frequency effects, the difference between the elastic and inelastic solutions is negligible. There are times, however, when traveling wave analysis is essential. Overpressures due to load rejection are critical just before or at gate closure time, the ensuing pressure pulsations occur after the gate is totally closed. A closed or almost closed gate results in infinitely small penstock time constants, and infinitely large *s* values in Equation 18.1.

Figure 18.8, “Elastic versus Inelastic Hydro Governor Models Comparison — Example 2” shows the simulation of a total gate closure on the same system as in Figure 18.7, “Elastic versus Inelastic Hydro Governor Models Comparison — Example 1”. For gate positions at or near total closure, the inelastic simulations of scroll case head and penstock flows are no longer applicable. Surge chamber levels and tunnel are not affected by these high-frequency effects.

18.5.6. Model PIDGOV

The PIDGOV hydro turbine governor model represents plants with straight forward penstock configurations and three term electro-hydraulic governors (i.e., Woodard electronic). This model uses a simplified turbine-penstock model that does not account for variation of water inertia effect with gate opening. This model can be made to correspond to other models using the classical turbine-penstock model by setting *atw* (factor that multiplies the water inertia time constant) to unity.

The feedback signal used by the governor can either be the gate position or the electrical power, and can be selected by setting the feedback flag to one for gate position or zero for electrical power.

The input to this model is the shaft speed deviation, and the outputs are turbine gate position and mechanical power.

18.6. Model IEESGO

The IEESGO general-purpose turbine-governor model is included for its compatibility with other widely used stability programs. With judicious selection of the time constants and gains, this model gives either a good representation of a reheat steam turbine or an approximate representation of a hydro plant of simple configuration.

18.7. Model HYGOV2

The nonstandard hydro turbine-governor of HYGOV2 includes the same basic permanent and temporary droop elements as the standard PSS®E model, HYGOV, but includes a slightly different representation of the lags within the governor hydraulic servo system and of the speed signal filtering. The penstock turbine model of HYGOV2 is highly simplified and is valid only for small deviations of gate position from their initial conditions. Unlike HYGOV, HYGOV2 requires the user to recalculate the value of the water column time constants for each new initial loading level. The water column time constants, T_5, and T_6, of HYGOV2 are related to the water inertia time constant T_W of Section 18.5, "Hydro Governor Models" by $T_5 = P_o T_W$ and $T_6 = P_o T_W/2$. HYGOV2 was developed for a specific plant and should not be used except in appropriate special situations. In the great majority of situations, HYGOV is to be preferred.

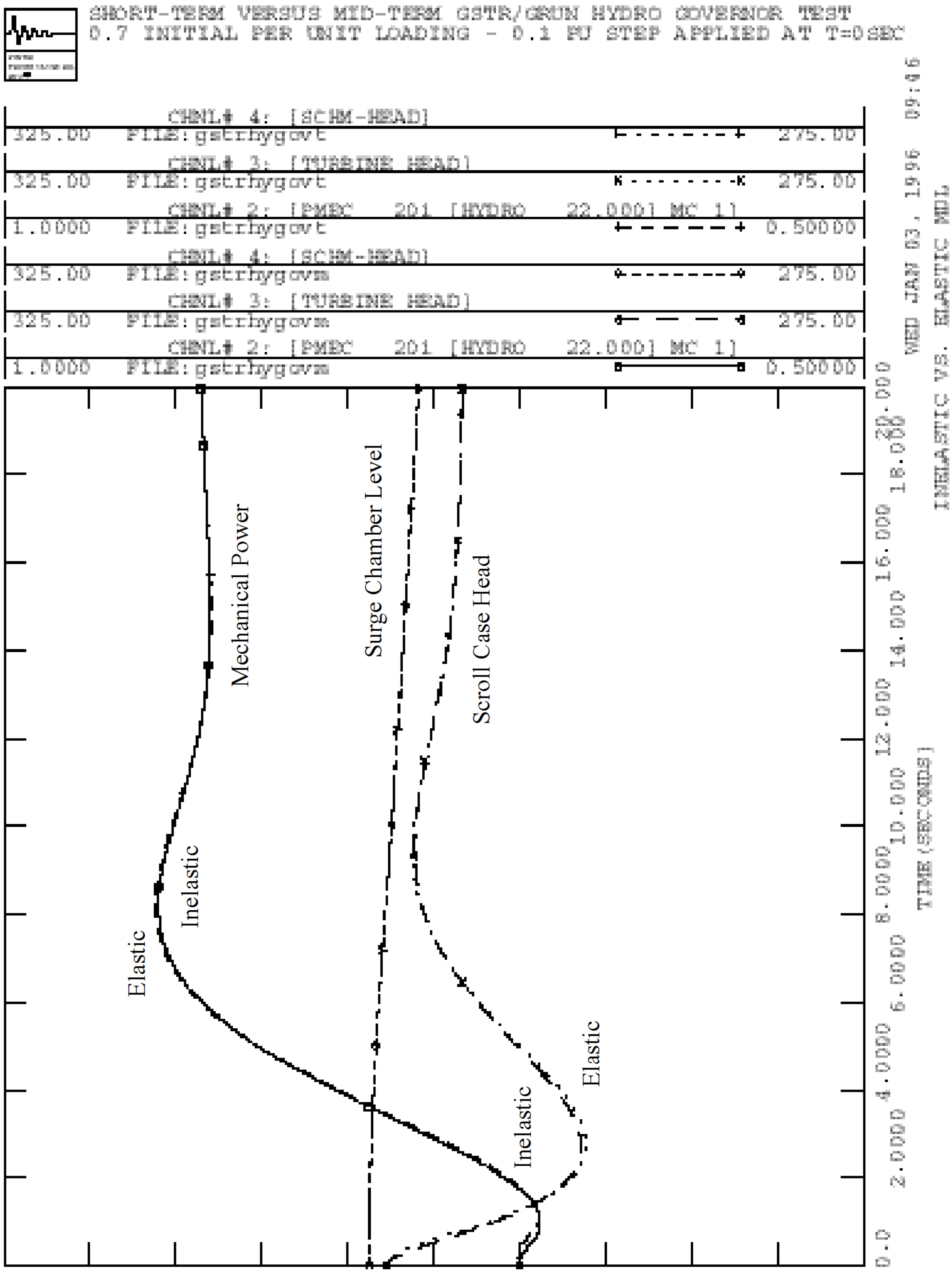


Figure 18.7. Elastic versus Inelastic Hydro Governor Models Comparison — Example 1

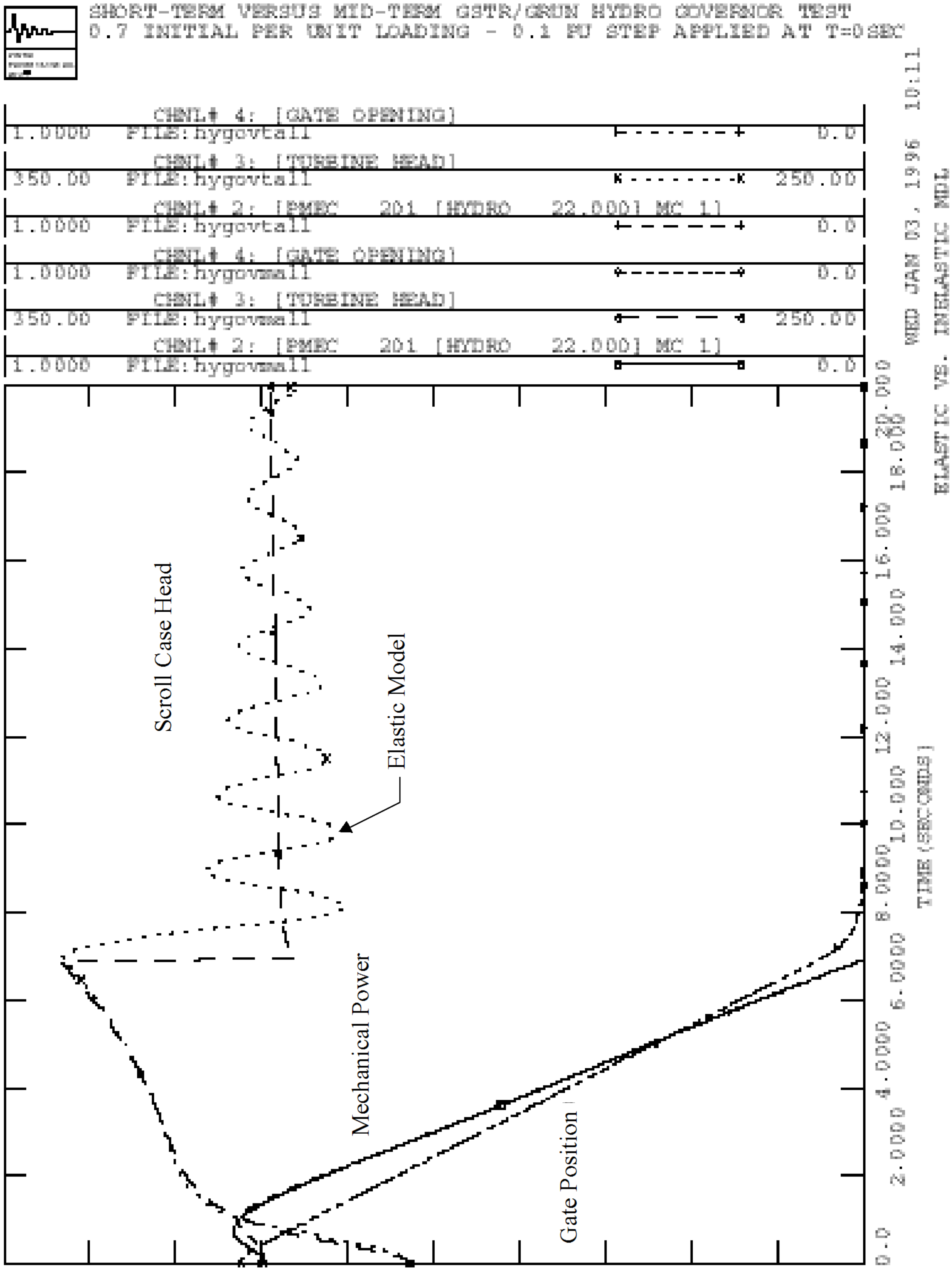


Figure 18.8. Elastic versus Inelastic Hydro Governor Models Comparison — Example 2

18.8. Model TGOV2

TGOV2 is a fast valving model of a steam turbine that represents governor action, a reheat time constant, and the effects of fast valve closing to reduce mechanical power. In this model, T_1 represents the governor time constant, K is equal to the fraction of the turbine power that is developed by the turbine sections not involved in the fast valving, T_3 is the reheater time constant, and T_t represents the time constant with which power falls off after closure of the intercept valve. TGOV2 is unique among PSS®E models in that the user must supply the initiation time for fast valving to begin. This information is supplied in one of two ways. The first method would be by using activity ALTR to change VAR(L+1) to the value of TIME at the instant that the user wants the fast valving to begin. STRT sets VAR(L+1) equal to 9999 so that VAR(L+1) can be changed only after STRT has been run. The second and more common method of initiating fast valving is by user added statements in CONEC. As an example, suppose a user wishes fast valving to begin when the generator speed deviation exceeds 0.01 pu. The user would add the following to CONEC (refer to Accessing Machine and Load Data of the *PSS®E Program Operation Manual*):

```
IF (VAR(720) .LT. 100. .OR. MODE.NE.2) GO TO 500 CALL GENCHK(500,'1',II,'IN
CONEC') IF (SPEED(II) .GT. CON(10000)) VAR(720)=TIME 500 CONTINUE
```

where VAR(720) is VAR(L+1) for machine 1 at bus 500, and CON(10000) is set equal to 0.01. Constants TA, TB, and TC define how long it takes to close the intercept valve, how long it stays closed, and how long it takes to reopen. These three constants use VAR(L+1) as their reference time after fast-valving is initiated. The user should use caution and in most cases should not modify VAR(L+1) after fast valve action has commenced.

18.9. Model IEEEG1

IEEEG1 is the IEEE recommended general model for steam turbine speed governing systems. By the appropriate choice of parameters, this model can be used to represent a variety of steam turbine systems including nonreheat, tandem compound, and cross-compound types. IEEEG1 can also approximate the behavior of hydro turbine-governors. The user should obtain reference b listed in Section 14.2, “Basic Setup Example” of this manual for the explanation of constants. Data for P_{MAX} and P_{MIN} should be specified in per unit on the MBASE of the high-pressure unit in the case of cross-compound sets.

18.10. Models IEEEG2 and IEEEG3

IEEEG2 and IEEEG3 are alternative representations of hydro turbine speed governing systems. In some cases, where data may be more easily obtainable for these representations or because they are more exact, these representations may be preferred over that of IEEEG1. The water time constant, T_W, is generally in the range of 1 to 3 sec. Typical values for IEEEG3 would be:

T_R = 5.0 sec.

T_G = 0.5 sec.

T_p = 0.04 sec.

d = 0.3.

s = 0.05.

18.11. Model TGOV3

TGOV3, a modification of the IEEEG1 model, is now PTI's recommended model for fast valving studies. Data selection should be based on the same definitions used for IEEEG1. Several additional data items are required by this model. The P_{RMAX} CON has been added. This value, which limits the maximum pressure in the reheat stage, is generally about 1.1 pu. The TA, TB, and TC time constants along with the initiating of the fast valving, are identical to those defined for TGOV2. This model does recognize the nonlinearity between flow and valve position as shown on the data sheet.

18.12. Model CRCMGV

CRCMGV models cross-compound units in other widely used stability programs. The constants used are:

T_1 = The control time constant.

T_3 = The servo time constant.

T_4 = The steam boil time constant.

T_5 = The steam reheat time constant.

F = The shaft capacity ahead of the reheater divided by the total shaft capacity.

18.13. Models DEGOV and DEGOV1

DEGOV is a model of an isochronous governor for a diesel engine. DEGOV1 is a model of a governor for a diesel engine where droop control is used with either throttle or electric power feedback. These models are based on a Woodward governor consisting of an electric speed sensor, a hydro-mechanical actuator, and the diesel engine. The output of the actuator is a valve position of the fuel supply. A typical design of a diesel engine would limit the fuel input on a per-cycle basis. The amount of energy developed per cycle is directly proportional to the amount of fuel per cycle. Multiplying energy developed per cycle by the rotational speed of the engine gives the power being supplied by the prime mover to the generator. Therefore, the output of the engine is multiplied by the rotational speed of the generator and the limits for the actuator can be expressed as torque limits.

It should be noted that the DEGOV model represents an isochronous governor and, therefore, use of this model should be restricted to diesel generators operating isolated from other synchronous sources. For a diesel generator online with other synchronous sources the DEGOV1 model should be used.

To determine the engine dead time, use the following formula:

$$DT = \frac{15}{N} + \frac{60}{Nn}$$

where:

DT = The dead time in sec.

N = The engine speed in rpm.

n = The number of cylinders firing per revolution.

18.14. Model SHAF25

SHAF25 is a shaft spring model for up to 25 masses. The array of constants from J to J+102 must be prepared as shown in the model data sheet for SHAF25. Zeros are entered for unused parameters. The first two constants, $X_d - X'_d$ and T'_{do} are used in the calculation of exciter torque. When a shaft torsional system is stimulated by electromagnetic torques in the generator (or motor), this model should be used in conjunction with model GENDCO (see Section 14.4.5.5). The modeled mass-spring system is composed of rotational springs in a radial configuration. Figure 18.9, "Sample Shaft System" shows a sample layout.

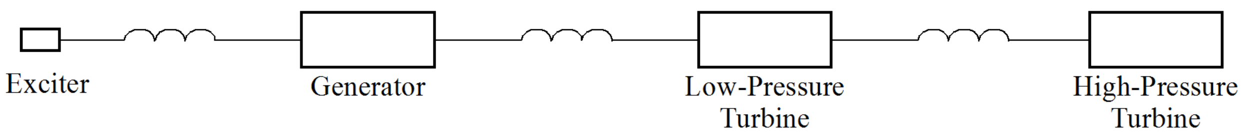


Figure 18.9. Sample Shaft System

18.14.1. Data Preparation for SHAF25

The following steps should be followed to prepare data:

1. Draw a diagram of shaft to be modeled (see Figure 18.10, "Numbered Shaft Layout" with masses circled and shaft sections boxed). Number masses and shaft sections according to the following rules:

Mass 1 must be at one of the ends of the shaft.

The remaining masses are numbered consecutively starting from mass1 and going to the other end of the shaft.

$K_{shaft\ i\text{-}j}$ connects mass i to mass j.

Figure 18.10, "Numbered Shaft Layout" shows numbering for a sample layout. Note masses are circled and shaft sections are boxed.

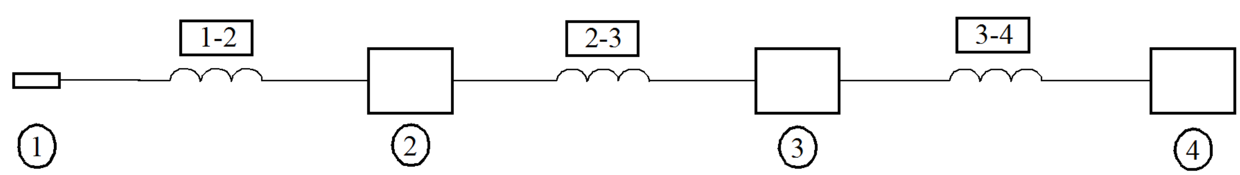


Figure 18.10. Numbered Shaft Layout

18.14.2. Calculation of Inertias for Masses

The mass inertias used for each component are expected to be entered in units of kW-sec/kVA. Data supplied in the English system can be converted using the following formula:

$$H = \frac{0.231\ WR^2\ (rpm)^2\ 10^{-6}}{R}$$

where:

H = Inertia constant in kW-sec/kVA.

WR^2 = Moment of inertia in lb-ft^2 (based on radius).

rpm = Rotational speed of the mass in revolutions per minute.

R = Machine kVA rating.

If given data in the metric system, the formula becomes:

$$H = \frac{1.37\ GD^2\ (rpm)^2\ 10^{-6}}{R}$$

where GD^2 = Moment of inertia in kg-m^2 (based on diameter). Note that $GD^2 = 4I$, where I = mass moment of inertia in kg-m^2. The formula for H given above can also be written in a more common form as given below:

$$H = \frac{1}{2}\frac{I\omega_m^2}{S}$$

where:

S = Machine VA rating.

ω_m = Mechanical angular speed in radians.

18.14.3. Shaft Stiffness Calculation

The values of K_{shaft} should be entered in units of per unit torque per electrical radian on machine MVA base. When the stiffness coefficients of the shafts are expressed in terms of Newton-meter (Nm) per mechanical radian, the following formulas should be used for conversion.

$$T_{base} = \frac{Rating}{\omega_m}$$

$$K_{shaft} = \frac{K}{T_{base}} \times \left(\frac{\omega_m}{\omega_e}\right)$$

where:

Rating = Rating of machine, VA.

ω_m = Angular velocity of the massive mechanical radians per second.

ω_e = Angular velocity of the electrical frequency in electrical radians.

K = Stiffness coefficient in Nm per mechanical radian.

T_{base} = Shaft mechanical torque base, in newton meters.

Because model results are reported per unit, this torque base value will be valuable to get information to match typical shaft degradation curves.

18.14.4. Mass Damping

The values at *D* should be entered as dimensionless damping coefficients, i.e., per unit torque divided by per unit speed. A value of *D* = 0.05 indicates that the reaction torque at the mass damper at rated speed is 0.05 pu.

18.14.5. Data Calculation Check

To check the calculations, check the frequency of one mass and coefficient of stiffness, before conversion, by one of the following:

$$\omega_1 = \sqrt{\frac{K_q}{WR^2}}$$

$$\omega_1 = \sqrt{\frac{4K}{GD^2}}$$

and compare it with after-conversion data using the formula:

$$\omega_2 = \sqrt{\frac{Kshaft}{2H}\omega_0}$$

The results should be identical.

18.14.6. Time Step when Using SHAF25

When using SHAF25, the integration time step should be compatible with the highest shaft natural frequency. As a general guide, the time step should satisfy the following:

$$\Delta T < 0.1 \times \frac{2}{\omega_{smax}} = \frac{0.03}{f_{smax}}$$

where:

ω_{smax} = Maximum shaft natural frequency, rad/sec.

f_{smax} = Maximum shaft natural frequency, Hz.

18.15. Model TGOV4

TGOV4 is a model of a steam turbine and boiler that represents governor action, explicit valve action for both control and intercept valves, main, reheat and low-pressure steam effects, and boiler effects. Also incorporated into the model are a power load unbalance (PLU) relay and an early valve actuation (EVA) relay that, when triggered, will cause fast valving of the control or intercept valves.

18.15.1. Governor Model

Most of the model's time constants are similar to those used in other PSS®E governor models. They are defined according to "Dynamic Models for Steam and Hydro Turbines in Power System Studies," IEEE Committee Report, IEEE PES 1973 Winter Meeting, paper T73 089-0 and listed below:

K = The inverse of the governor speed droop.

T_1, T_2 = The governor controller lag and lead time constants.

T_3 = The valve servomotor time constant for the control valves.

T_4 = The steam bowl time constant.

T_5 = The steam reheat time constant.

T_6 = The crossover time constant.

K_1 = The fraction of the total turbine power developed by the high-pressure turbine.

K_2 = The fraction of the total turbine power developed by the intermediate-pressure turbine.

U_O = The control valve open rate limit.

U_C = The control valve close rate limit.

U_{OIV} = The intercept valve open rate limit.

U_{CIV} = The intercept valve close rate limit.

P_{RMAX} = The maximum pressure limit in the reheater.

T_{IV} = The valve servomotor time constants for the intercept valves.

R = The speed droop for the intercept valve governor.

Offset = The offset applied to the intercept valve speed control to keep the valves wide open and inhibit closing action unless speed exceeds the offset. This value is usually about 3%. PSS®E, however, adds this with speed regulated frequency so a value multi plied by $1/R$ should be entered (e.g., $0.03 \times 20 = 0.6$).

The remainder of the time constants are explained in the following sections. Due to the per unit system employed throughout the model, it is necessary that all machine data be entered on the unit's actual machine base. The logic diagram of the PLU and EVA relays is shown in Figure 18.11, "Model TGOV4 Logic Diagram for PLU and EVA", and the block diagram of the model is given in Figure 18.12, "Model TGOV4 Block Diagram for PLU and EVA".

18.15.2. Boiler Model

A boiler model is included to properly reflect the effects of boiler pressure on turbine power. The boiler constants are:

K_P = Boiler proportional control gain.

K_I = Boiler integral control gain.

T_{Fuel} = Fuel lag time constant.

T_{FD1}, T_{FD2} = Approximation of deadtime due to the fuel supply system.

C_b = Boiler storage constant.

K_b = Friction drop coefficient.

The effects of boiler pressure controls can be neglected by setting K_P are K_I to zero. However, drum pressure will still be affected by changes in main steam flow; C_b cannot be zero.

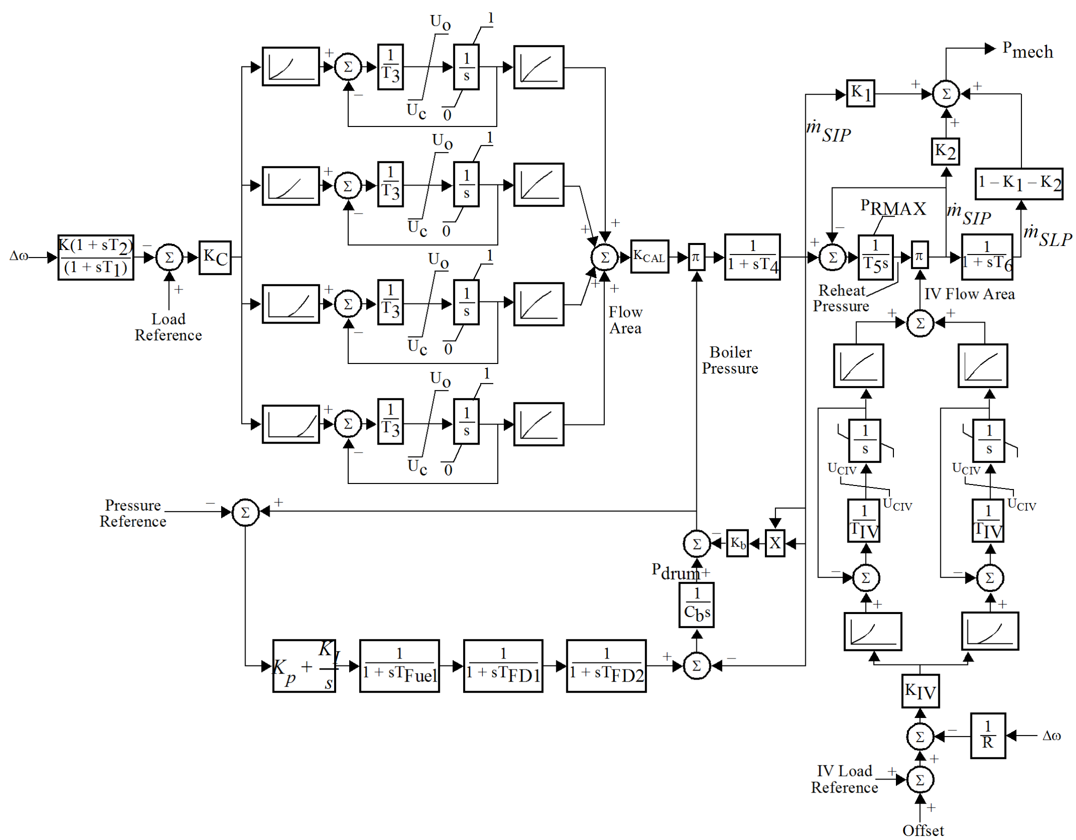


Figure 18.11. Model TGOV4 Logic Diagram for PLU and EVA

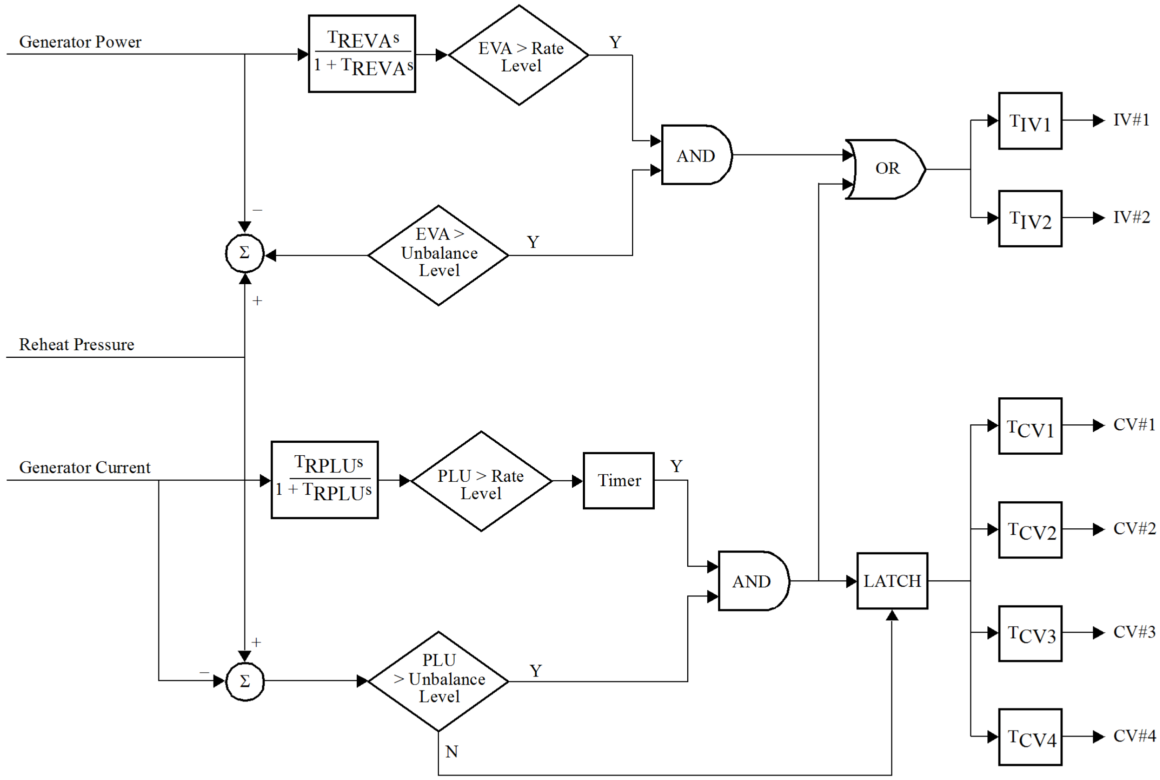


Figure 18.12. Model TGOV4 Block Diagram for PLU and EVA

18.15.3. Valve Model

Up to four control valves and two intercept valves can be modeled as either linear or nonlinear. The characteristics are defined by specification of a data point on the curve. The characteristics are specified separately for the control and intercept valves. The shape of the valve characteristic is defined by specifying the value of the per unit valve position to get a flow area of 80% of the total flow area (0.8 pu). Figure 18.13, "Per Unit Valve Position" shows a plot of flow area versus valve position for several different characteristics. A typical value of valve position at 80% flow area would be 0.3. To specify a linear valve characteristic, a value of 0.8 should be given.The flow area is calculated from the valve position using the equation:

Flow Area = $K(1 - e^{-A(\text{Position})})$

The constants K and A are calculated in activity STRT and stored in VARs. Specification of a valve position at 80% that is less than 0.2 may cause a small error in the calculation of flow area at small values of valve position. Valves that are nearly linear (valve position at 80% very close to 0.8) should be modeled as linear.

The valve position demand may also be modeled as linear or nonlinear. A nonlinear model would be used in cases where nonlinear demand control is used to cancel-out the nonlinear valve characteristics to get a linear steady-state relationship between load reference and flow area. Figure 18.14, "Control Signal" shows a plot of valve position demand versus control signal. The curve is defined by specifying the value of valve position demand corresponding to a control signal of 0.8. Similar to the valve characteristic, specified values less than 0.2 may cause a small amount of error and valve control close to linear should be modeled as linear. The valve position demand is calculated using the equation:

Valve Position Demand =

$$\frac{-\ln\left(\frac{K - \text{Control Signal}}{K}\right)}{A}$$

The constants A and K are calculated in activity STRT. The valve position demand can also be modeled with an offset in control valves 2, 3, and 4 and intercept valve 2. A valve controller with an offset requires a larger value of control signal to get a given amount of position demand. For example, an offset of 0.5 would mean that the valve position demand would be 0 for a control signal less than 0.5, determined by the characteristic between 0.5 and 1.5, and fully open above 1.5. The offsets must be in ascending order. The constants K_{CV} and K_{IV} are calculated in activity STRT to normalize the flow area calculation, accounting for the offsets, so that a one per unit control signal results in a one per unit flow area.

The constant K_{CAL} is used to calibrate the maximum flow area (1.0 pu) to the maximum mechanical power, per unit on the generator MVA base. This constant can be used to account for valves that are oversized or undersized compared to the maximum turbine output. For example, if the fully opened valves result in only a mechanical power of 0.9 pu, K_{CAL} should be 0.9.

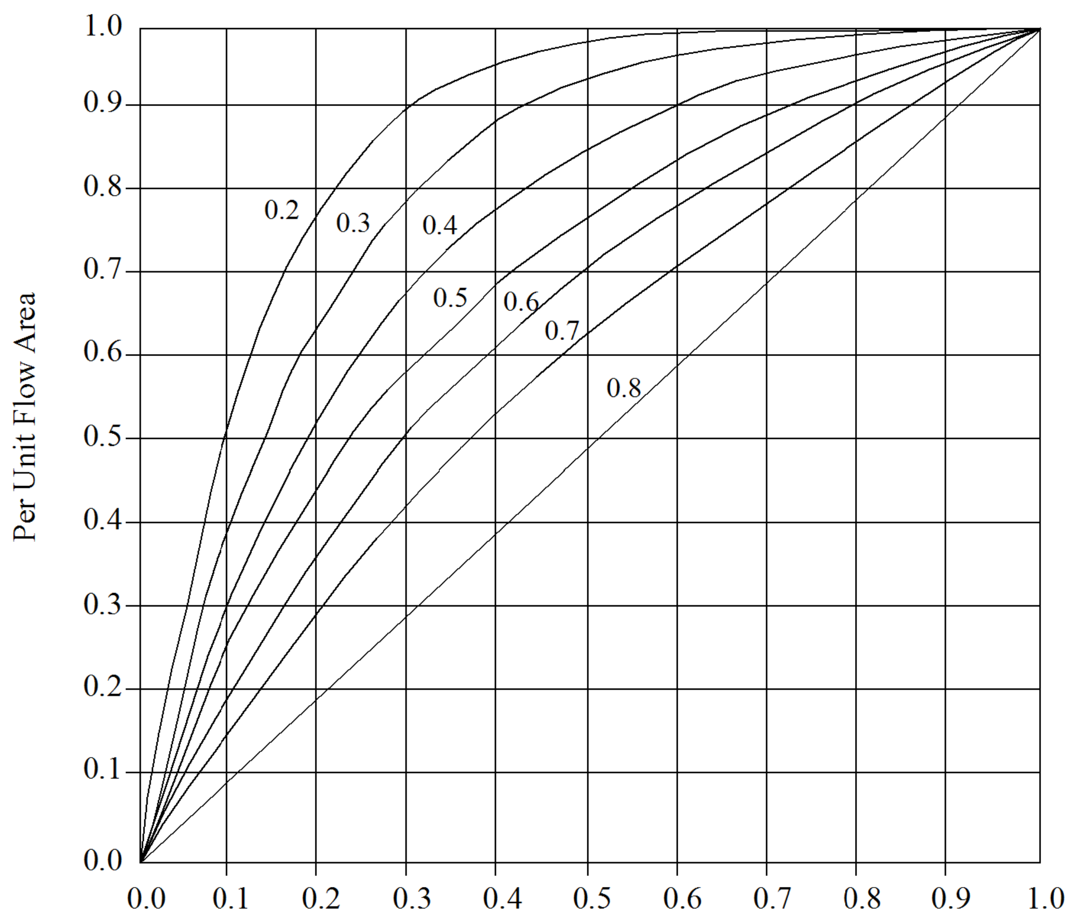


Figure 18.13. Per Unit Valve Position

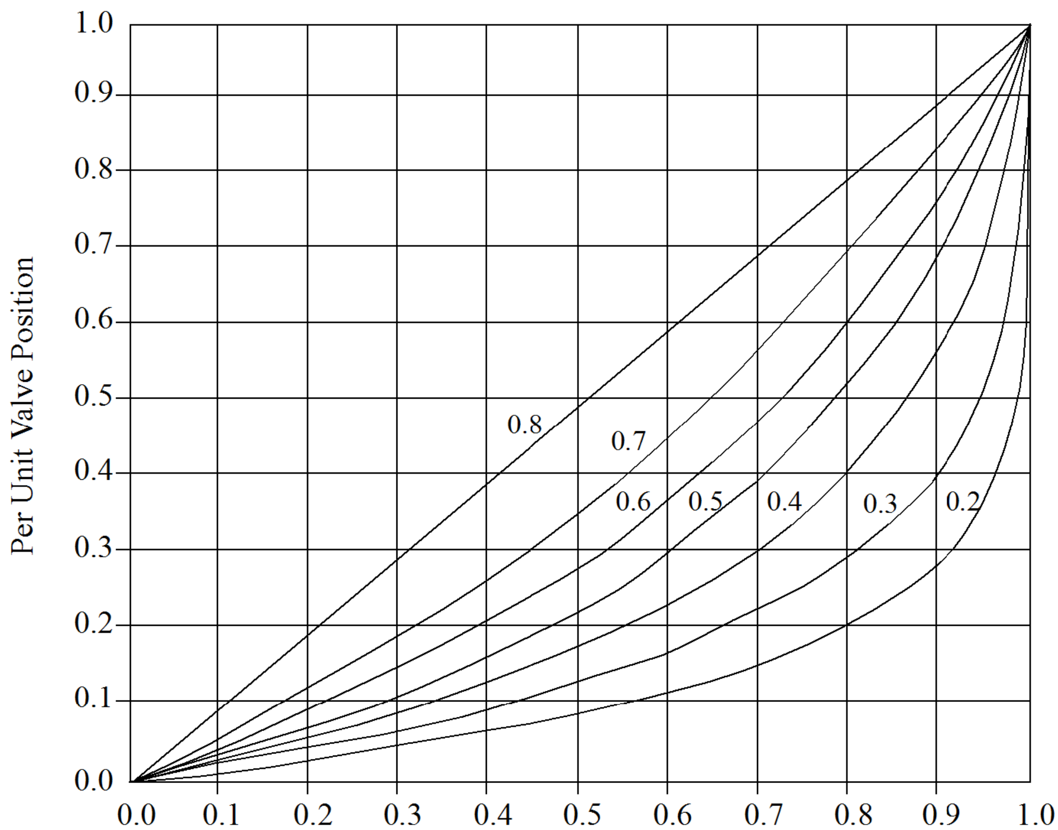


Figure 18.14. Control Signal

18.15.4. Control of Fast Valving

The value of ICON (IC+2) determines the control mode of fast valving:

ICON(IC+2)	Control Mode
0	No PLU or EVA
1	User-controlled PLU/EVA
2	PLU
3	PLU and EVA

In control mode 0, fast valving simply does not occur. Triggering of fast valving in control modes 2 and 3 is explained in the next section. In control mode 2, the user defines what time the control valves and/or the intercept valves are to begin closing. The valves close at their defined closing rate, remain closed for their individually set closure times, and then reopen at their opening rates. The following constants are used in the manual closure of the valves:

CON	Event
J+33	Time for the control valves to start to close
J+34	Control valve closing rate
J+35-J+38	Time closed for control valves 1 to 4

CON	Event
J+39	Time for the intercept valves to start to close
J+40	Intercept valve closing rate
J+41-J+42	Time closed for intercept valves 1 and 2

18.15.5. PLU Relay

The PLU relay consists of two parts; both must be triggered to initiate valve action. The first part consists of a comparison circuit that calculates the per unit difference between reheat pressure (representing mechanical power) and generator current. The second part calculates the rate of change of current. When the rate of change of current is greater than the PLU rate limit, a timer is started. The timer start time is stored in a VAR. If the rate of change of current is still greater than the rate limit when the timer runs out and the difference between reheat pressure and current is greater than the unbalance limit, the PLU relay is triggered and fast valving action is initiated. The time of activation is stored in a VAR for both the control and intercept valves. The control and intercept valves begin closing after their respective time delays. The valves close at the rate specified for the control and intercept valves. The time at which control valve number 1 and intercept valve number 1 close are stored in VARs. Each individual valve stays closed for a time period defined by the user and reopens according to its defined rate.

At the same time the PLU is triggered, the latch is set. The latch is not reset until the difference between reheat pressure and current is less than the unbalance level. While the latch is set, the load references to the control and intercept valves are removed. Also the control valve load reference is ramped down at a user-defined rate, but only down to a minimum load reference. The following constants are used in the PLU circuit:

CON	Event
J+33	Delay between PLU trigger and the control valves starting to close
J+35-J+42	Same as for user control
J+39	Delay between PLU trigger and the intercept valves starting to close
J+43	Time constant for rate of change of current
J+44	Rate level
J+45	Length of timer in seconds
J+46	Unbalance level

18.15.6. EVA Relay

The EVA relay consists of two parts; both must be triggered to initiate valve action. The first part consists of a comparison circuit that calculates the per unit difference between reheat pressure and generator electrical power. The second part calculates the rate of change of electrical power. If the rate of change of electrical power is greater than the EVA rate limit and the difference between reheat pressure and electrical power is greater than the unbalance limit, the EVA relay is triggered and fast valving action is initiated. The time of activation is stored in a VAR for the intercept valves. The intercept valves begin closing after their time delay. The valves close at the rate specified for the intercept valves. The time at which intercept valve 1 closes is stored in a VAR. Each individual valve stays closed for a time period defined by the user and reopens according to its defined rate. The following constants are used in the EVA circuit:

CON	Event
J+35-J+42	Same as for user control

CON	Event
J+39	Delay between EVA trigger and the intercept valves starting to close
J+47	Time constant for rate of change of electrical power
J+48	Rate level
J+49	Unbalance level

18.16. Model WPIDHY

WPIDHY is a model of the Woodward PID hydro governor with proportion, integral and derivative control. This electric governor has advantages over the hydraulic governor with temporary droop in that it can provide a faster response. Care should be used in specifying the derivative gain because studies have shown too much gain will result in excessive oscillations. This model does allow for the nonlinearity between gate position and actual mechanical power.

18.17. WSCC Governor Models

Several new governor models were added to version 10 of the WSCC stability program. Some of these models contain provisions for deadbands, nonlinear gains and governor blocking. This section documents equivalent PSS®E turbine-governor models.

WSIEG1 models the IEEE-recommended general model for steam turbine speed governing systems (IEEEG1) with some nonlinearities.

Models WSHYDD and WSHYGP are special models required for hydro units in WSCC. The WSHYDD is a double derivative hydro governor. The WSHYGP represents the old WSCC GP governor plus turbine model. A proportional, integral derivative controller is modeled in WSHYGP.

18.18. Model GGOV1

The GGOV1 model can be used to represent a variety of prime movers controlled by PID governors. It is suitable, for example, for representation of:

- gas turbine and single shaft combined cycle turbines,
- diesel engines with modern electronic or digital governors,
- steam turbines where steam is supplied from a large boiler drum or a large header where pressure is substantially constant over the period being studied, and
- simple hydro turbines in dam configurations where the water column length is short and water inertia effects are minimal.

Per unit parameters for this model are entered on base of T_{rate} (turbine MW rating). If no value is entered for T_{rate}, the generator MVA base is used.

The range of fuel valve travel and of fuel flow is unity. Thus the largest possible value of V_{max} is 1.0 and the smallest possible value of V_{min} is zero. V_{max} may, however, be reduced below unity to represent a loading limit that may be imposed by the operator or a supervisory control system. For gas turbines V_{min} should normally greater than zero and less than w_{fnl} to represent a minimum firing limit. The value of fuel flow at maximum output must be less than, or equal to unity, depending on the value of K_{turb}.

The parameter T_{eng} is provided for use in representing diesel engines where there is a small but measurable transport delay between a change in fuel flow setting and the development of torque. Teng should be zero in all but special cases where this transport delay is of particular concern.

The parameter *Flag* is provided to recognize that fuel flow for a given fuel valve stroke, can be proportional to engine speed. This is the case for GE gas turbines and for diesel engines with positive displacement shaft driven fuel injectors. Flag should be set to unity for all GE gas turbines and most diesel engines. Flag should be set to zero where it is known that the fuel control system keeps fuel flow independent of engine speed.

The load limiter module may be used to impose a maximum output limit, such as an exhaust temperature limit. To do this the time constant T_{fload} should be set to represent the time constant in the measurement of temperature (or other signal), and the gains of the limiter, K_{pload}, K_{iload}, should be set to give prompt stable control when on limit. The load limit can be deactivated by setting the parameter L_{dref} to a high value.

The parameter D_m can represent either the variation of engine power with shaft speed or the variation of maximum power capability with shaft speed. If D_m is positive it describes the falling slope of the engine speed versus power characteristic as speed increases. A slightly falling characteristic is typical for reciprocating engines and some Aeroderivative turbines. If D_m is negative the engine power is assumed to be unaffected by shaft speed, but the maximum permissible fuel flow is taken to fall with falling shaft speed. This is characteristic of single shaft industrial gas turbines.

This model includes a simple representation of a supervisory load controller. This controller is active if the parameter K_{imw} is non-zero. The load controller is a slow acting reset loop that adjusts the speed/load reference of the turbine governor to hold the electrical power output of the unit at its initial condition value (P_{mwset}). The load reference of the supervisory load control loop (P_{mwset}) is given a value when the model is initialized and stored in VAR(L+6). The load controller must be adjusted to respond gently relative to the speed governor. Setting K_{imw} to 0.001 corresponds to a relatively slow acting load controller and may be used as a normal estimate.

The parameters A_{set}, K_a, and T_a describe an acceleration limiter.

The parameter, db, is the speed governor dead band. This parameter is stated in terms of per unit speed. In the majority of applications of GGOV1 it is recommended that this value be set to zero.

The parameters, T_{sa}, T_{sb}, are provided to augment the exhaust gas temperature measurement subsystem in gas turbines. For example, they may be set to values such as 4., 5. to represent the radiation shield element of large gas turbines.

The parameters, R_{up}, R_{down}, specify the maximum rate of increase and decrease of the output of the load limit controller (K_{pload}/K_{iload}). These parameters should normally be set, 99/-99, but may be given particular values to represent the temperature limit controls of some GE heavy duty engine controls.

18.19. Model PWTBD1

PWTBD1 may be used to represent the Pratt & Whitney Turboden turbine-governor. The governor system for this model is based on a governor consisting of a generator electric power sensor with PI control. Typical parameters listed below (as provided by the manufacturer) represents a 2.4 MW turbine. These should be reviewed for units of other sizes.

Trate, Turbine rating (MW)	2.4
Kp, Proportional gain	0.36
Ki, Integral gain	0.18
VRmax, PI controller maximum limit [pu]	1
VRmin, PI controller minimum limit [pu]	0
Tv, Control valve Time Constant	0.2
Lo, Control valve open rate limit (>0) [pu/sec]	0.25
Lc, Control valve close rate limit (<0) [pu/sec]	-0.25
Vmax, Maximum valve area [pu]	1
Vmin, Minimum valve area [pu]	0
Tb1	2.2
Tb2	-2
P(V) curve, x1	0
P(V) curve, y1	0
P(V) curve, x2	0.125
P(V) curve, y2	0.122
P(V) curve, x3	0.211
P(V) curve, y3	0.526
P(V) curve, x4	0.322
P(V) curve, y4	0.896
P(V) curve, x5	0.433
P(V) curve, y5	0.966
P(V) curve, x6	0.544
P(V) curve, y6	0.986
P(V) curve, x7	0.656
P(V) curve, y7	0.994
P(V) curve, x8	0.767
P(V) curve, y8	0.998
P(V) curve, x9	0.878
P(V) curve, y9	0.999
P(V) curve, x10	0.989
P(V) curve, y10	1
P(V) curve, x11	1
P(V) curve, y11	1

18.20. Turbine Load Controllers

Simulations where there is large frequency deviations or power mismatches may require the modeling of the relatively slow reset controllers that manage the action of the turbine governor. The ULCFB1 model was added to represent the adjustment made to governor's speed or load reference. While the proper time scale for the managing controller is slow in relation to that of the governing and supervising loops, there is, nevertheless, a wide variations in the speed of response of turbine load reference controllers. At the more active end of the spectrum, a load controller may be able to completely cancel a deviation of output within as little as 30 seconds, while a reset time of a few minutes would be common in large steam plants. The load controllers of gas turbine plants would typically be quick. The ULCFB1 model can be used with most of the standard PSS®E turbine governor models. It will modify the speed or load reference of the governor.

Chapter 19
Modeling dc Transmission

This chapter describes various dc line models and their modeling in PSS®E. Although the description given indicates that dc line models are called from the connection routines (CONEC and CONET), at PSS®E-30, several dc line models have been tableized (i.e., use of dc line models does not require calls in CONEC and CONET).

19.1. General Considerations

Because dc transmission behavior is dominated by its controls, these controls must be modeled, but, because the bandwidth of the controls is far greater than that of the PSS®E simulation in general, it is usually not practical to represent the detailed dynamics of these controls. Figure 19.1, "Arrangement of dc Transmission Control" details dc transmission controls. Each converter bridge is controlled by a local feedback loop of bandwidth consistent with the firing delay accuracy requirements of the rectification/inversion process. These local loops work independently to maintain bridge current or voltage at desired values. The desired values are provided by an outer control loop that works in a supervisory role and coordinates the action of the several converter bridges and the ac power system.

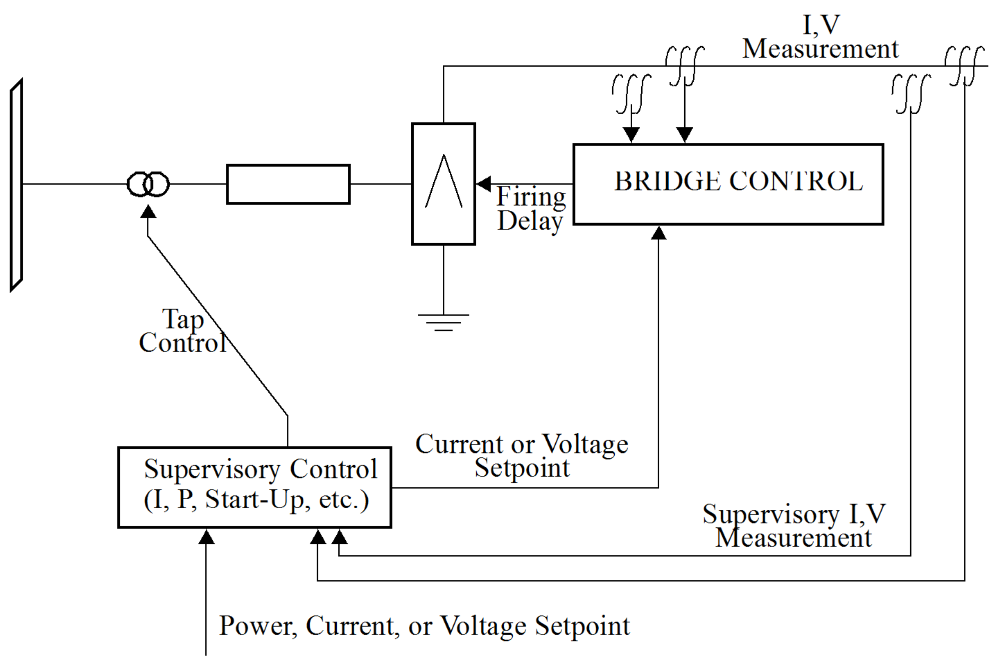


Figure 19.1. Arrangement of dc Transmission Control

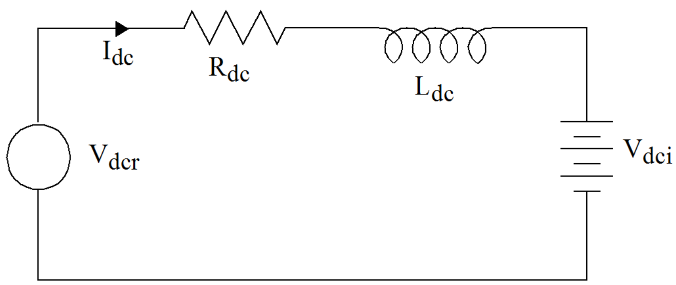
The behavior of the bridges and their inner control loops is illustrated by Figure 19.2, "Forced Control of dc Converter Operation by Broad Bandwidth Feedback Loop". A rectifier bridge, for example, may be regarded as an adjustable voltage source forcing current through transmission system resistance and inductance against the constant back-emv of the inverter as shown in Figure 19.2, "Forced Control of dc Converter Operation by Broad Bandwidth Feedback Loop"a. A simple current control could be set up by applying current setpoint changes to rectifier voltage on a open-loop basis with a gain equal to dc resistance as shown in Figure 19.2, "Forced Control of dc Converter Operation by Broad Bandwidth Feedback Loop"b. A step change of current setpoint would produce the time response shown in Figure 19.2, "Forced Control of dc Converter Operation by Broad Bandwidth Feedback Loop"b, in which dc voltage changes in a step and the current follows with a delay time constant determined by inductance and resistance. This time constant would be small in relation to those of principal importance elsewhere in PSS®E, but not negligible.

A real dc transmission rectifier is not operated by adjusting its output voltage in this open-loop manner; rather, the local bridge control is a feedback loop that adjusts firing delay to control the dc current to a setpoint, as shown by Figure 19.2, “Forced Control of dc Converter Operation by Broad Bandwidth Feedback Loop”c. The controller transfer function depends on details of the bridge design and is usually quite complex, nonlinear, and of broad bandwidth in relation to the 0 to 30 rad/sec bandwidth over which PSS®E simulation is applicable. A typical response of a bridge control loop to a step change of current setpoint is shown in Figure 19.2, “Forced Control of dc Converter Operation by Broad Bandwidth Feedback Loop”c. The feedback controller is able to force the dc current rapidly to its new value by transient overadjustment of the rectifier voltage. This rapid forced response of the rectifier and its local control loop is completed in a time that is generally shorter than the shortest time interval that can be recognized within the bandwidth of PSS ®E.

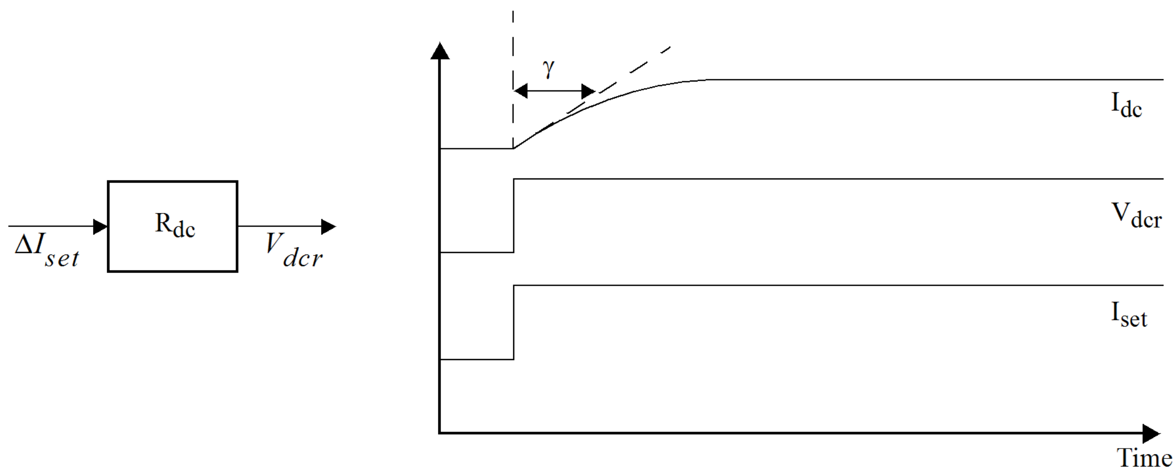
Because the local converter bridge controls of dc transmission and the associated response of dc current and voltage are so rapid in relation to the time scale of most PSS®E simulations, several PSS®E models (CDC4, CDC6, CEELRIT, CMDWAST, CHIGATT, CMFORDT, etc.) treat dc converter pairs as if they move instantaneously to their new operating point when any of their input signals or ac feed voltages are changed. These pseudo steady-state, HVDC dynamic models calculate the active and reactive power loading of the HVDC converters using steady-state converter relationships similar to those used for power flow except that transformer taps remain fixed and the direct current and dc voltage or margin angle may be varied to model the effects of higher level controls. These PSS®E dc transmission models, then, are not concerned with the internal dynamic behavior of dc converters and lines, just as the ac network model is not concerned with the internal transient behavior of transformers and three-phase transmission lines.

The pseudo steady-state, HVDC dynamic models are not able to directly represent the mode of operation where the rectifier firing angle is not at a limit and the inverter margin angle is also not at a limit or controlling voltage, because this condition does not occur in the steady state. This temporary dynamic condition may occur during startup and/or a cycle or two following a disturbance. If the recovery is expected to be slow, as may be the case if the ac system is weak, then some pseudo steady-state models may depress direct current and dc voltage during a disturbance and ramp up voltage and current at a user specified rate following the disturbance to approximate the HVDC recovery characteristics. Other models, such as CDC6, will only do this following a block or bypass.

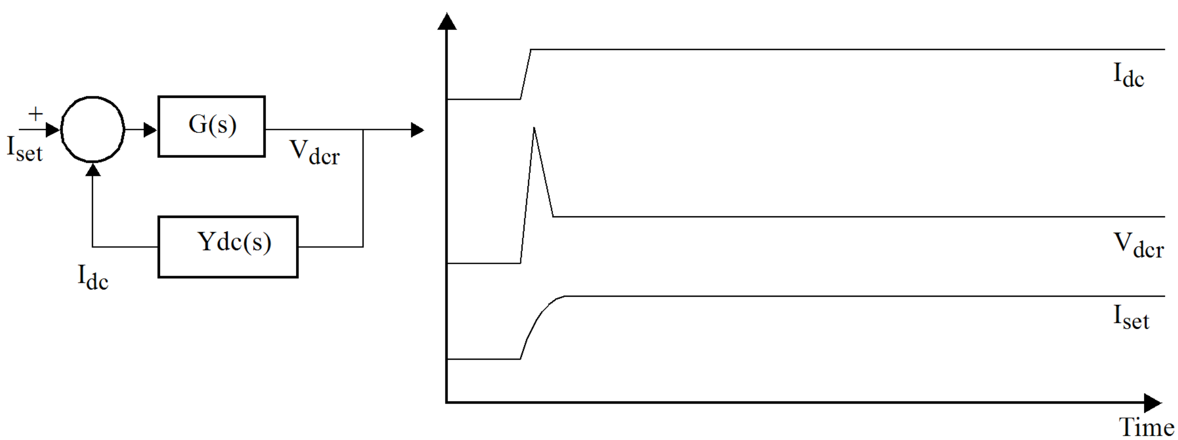
HVDC models, such as CDCVUP, represent the temporary dynamic condition when neither converter is at a firing angle or a margin angle limit and both are fighting for control of current. The dynamic interaction between the rectifier and inverter voltage-sensitive current limits, which determines the dc voltage and current recovery following a disturbance, is explicitly represented in these models without having to represent the high-speed HVDC controller and system L/R dynamics.



a. Simple dc Line Current Control Configuration, Adjustable Rectifier



b. Open-Loop Rectifier Current Control



c. Feedback Rectifier Current Control

Figure 19.2. Forced Control of dc Converter Operation by Broad Bandwidth Feedback Loop

PSS®E also includes HVDC models such as CASEA1 and CDCRL that represent some high-frequency controller effects and the L/R dynamics of the dc transmission. These models use an internal integration time step that is shorter than that used by the network and other PSS®E models.

All PSS®E dc transmission models are concerned with the transient behavior of the outer, or supervisory, levels of the dc controls because the maneuvering of the dc power flow by this control has a strong influence on the ac system.

The modeling of dc transmission recognizes three distinct types of action by the controls:

1. Normal regulation of dc converter operation to maintain specified constant current or constant power transfer with coordination of rectifier and inverter current setpoints

2. Temporary overriding of dc converter normal operating setpoints in response to disturbances of ac system voltages during faults

3. Modulation of the dc power setpoint by a supplementary control device, the purpose of which is, for example, to assist in the damping of rotor angle swings in the ac system

The modeling of the normal regulating control of the dc converters includes the basic control principle, illustrated by Direct Control(dc) Current Regimes, that underlies all dc transmission operation. Individual dc transmission models represent different normal regime manipulations of the current and voltage setpoints and delay angle limits defining Figure 6-12.

Normal control action is overridden by special control actions when ac or dc voltages at the converters reach abnormal levels that may cause commutation difficulties, excessive currents, or unacceptable harmonics. PSS®E dc transmission models execute these overriding control actions when the positive sequence ac voltages or dc voltages at the converters reach specified levels. The execution of protective actions in model CDC4 does not necessarily represent actions a real dc converter would take. Rather, it represents the user's decision to simulate the blocking, bypassing, unblocking, or unbypassing of the converters when the specified voltage conditions are encountered. The modeling of protective action, as distinct from implementation of the user's decision, is impossible in PSS®E for the following reasons:

1. The protection of a dc converter is dependent on individual phase-to-ground and phase-to-phase voltage wave forms and these are not available in PSS®E dynamic simulations, which consider only the positive sequence fundamental frequency aspect of system performance.

2. The protection of each bridge is determined by the internal details of the bridge firing controls, which operate in a bandwidth far beyond the low-frequency band covered by PSS®E and which, therefore, are not modeled in PSS®E.

The positive voltage levels at which the dc line would execute its various control actions are quite likely to be different for different disturbances such as line-to-ground faults, line-to-line faults, and so on.

All dc transmission dynamic models have access to all dc transmission data and variables used in power flow (see Direct Current Line Data). Additional parameters and variables, where needed, are defined on the individual model data sheets.

19.1.1. Modeling Asymmetries in the ac System

Positive-sequence phasor equations are used to characterize the ac network in stability programs. Because phasors are used, the high-frequency (>60 Hz) network behavior cannot be represented and the response of the HVDC bridge and pole controls to such behavior cannot be predicted. Also, the use of positive-sequence equations precludes representing most asymmetries on the ac system. However, it is possible to represent the effect on the positive-sequence flows and voltages of a few simple asymmetries, such as faults or circuit outages, by using an equivalent shunt or branch element to represent the impedance of the negative- and zero-sequence networks as seen from the fault.

The negative- and zero-sequence impedance as seen from the fault can be used to calculate the negative- and zero-sequence voltage at the fault, but not elsewhere in the network. Phase voltages may be obtained from the sequence quantities.

For faults at either converter, HVDC models, such as CASEA1, CDCRL, and CDCVUP, use the sequence impedances to calculate the phase voltages at the converter terminals. Three-phase voltages are used to flag possible commutation failures, to calculate the maximum overlap angle – the margin angle needed to obtain the minimum margin area – and to calculate the minimum firing angle required to have sufficient commutation voltage. To do this, an ICON indicating the type of fault must be set when the fault is applied and modeling data must include values for the sequence and fault impedances. When a fault is not at the converter terminals, only the positive sequence effects of faults may be represented. The ICON indicating fault type should be set only for faults placed at the converter buses.

19.1.2. Blocking, Bypassing, and Commutation Failures

When an inverter is bypassed, the dc side is shorted and the ac side is open. The rectifier will continue to circulate a low level of direct current through the shorted inverter at a low voltage. The rectifier will therefore draw some vars but very little power from the ac system and the inverter will draw no power of vars. To simulate a bypass in models such as CASEA1, CDCRL, and CDCVUP, the appropriate ICON is set equal to 1. In models such as CDC6 the bypassing voltage threshold can be raised to force a bypass by changing the appropriate CON.

To simulate an inverter commutation failure, bypass the inverter and apply an ac system shunt at the inverter with a reactance equaling the leakage reactance of the converter transformer. Blocking (turning off a converter) can be simulated by changing the appropriate ICON or by raising the blocking voltage threshold to force a block. The voltage and current recovery following a block or bypass can be represented by most of the HVDC models with varying degrees of user intervention.

19.1.3. Capacitor Commutated Converters

The dc line models discussed in the following paragraphs are appropriate for use with noncapacitor commutated converters only.

19.2. Model CDC4

19.2.1. Normal Operation

The firing angle limits of a dc transmission line generally have a wider range on a transient basis than in the steady state, as illustrated by Figure 19.3, “Ranges of Alpha and Gamma Angles in Power Flow and Dynamic dc Transmission Simulations”. CDC4 adjusts rectifier and inverter firing delay angles within the dynamic limits to operate the dc transmission in accordance with the combined characteristic shown in Figure 6-12. The scheduled dc voltage and scheduled dc power (or current) are as specified in the power flow working case by the parameters VSCHED, SETVAL and MDC (see Section DC Current Line Data).

The instantaneous current setpoint, I_{set}, is adjusted continuously as shown in Figure 19.4, “CDC4 dc Transmission Control Arrangements”, if the line is in constant power mode (MDC = 1). The inverter current setpoint is assumed to follow the rectifier current setpoint to always provide the current margin, DELTI, as specified in the power flow working case. Changing of the dc operating setpoints VSCHED, SETVAL, and MDC, must be handled by changing the power flow data values via the network changes section of activity ALTR or via activity LOFL and CHNG.

The dc current will fall below the instantaneous rectifier current setpoint, but not below the corresponding inverter current setpoint, if the rectifier firing delay angle reaches its dynamic lower limit, ALFDY. The transmitted power will then fall correspondingly, even when the line is in power control mode (MDC = 1).

CDC4 maintains the desired constant power as long as the inverter-end dc voltage stays above the value VCMODE, but switches to the nominal current setting P_{set}/V_{sched}, if the dc voltage falls below this level. If the control switches out of constant power mode for this reason, it is blocked from returning for a time delay, TCMODE, and may return to power control if the inverter dc voltage rises above VCMODE.

Transformer taps are not adjusted automatically during dynamic simulation runs but may be changed manually via power flow data change dialog (i.e., via network changes in activity ALTR).

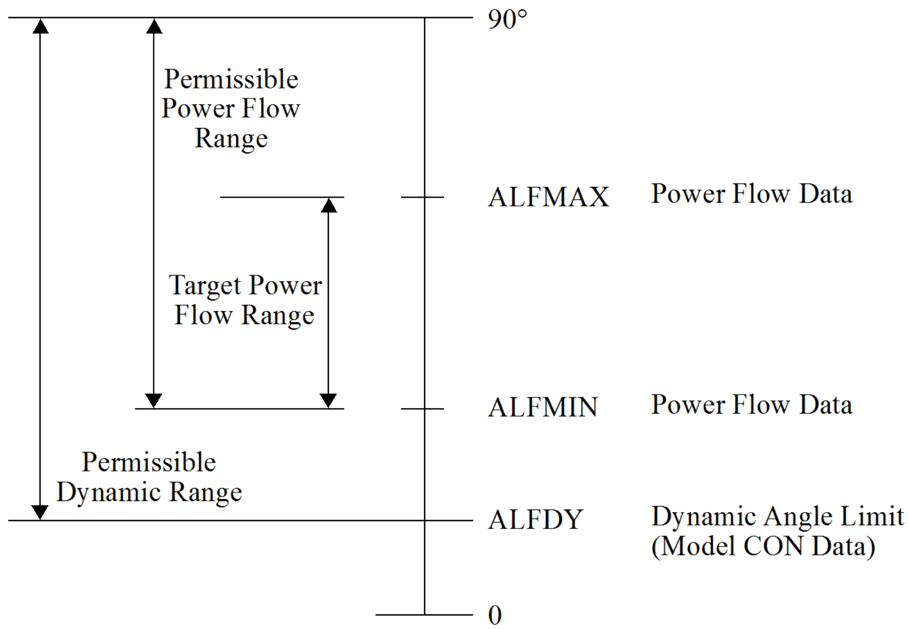


Figure 19.3. Ranges of Alpha and Gamma Angles in Power Flow and Dynamic dc Transmission Simulations

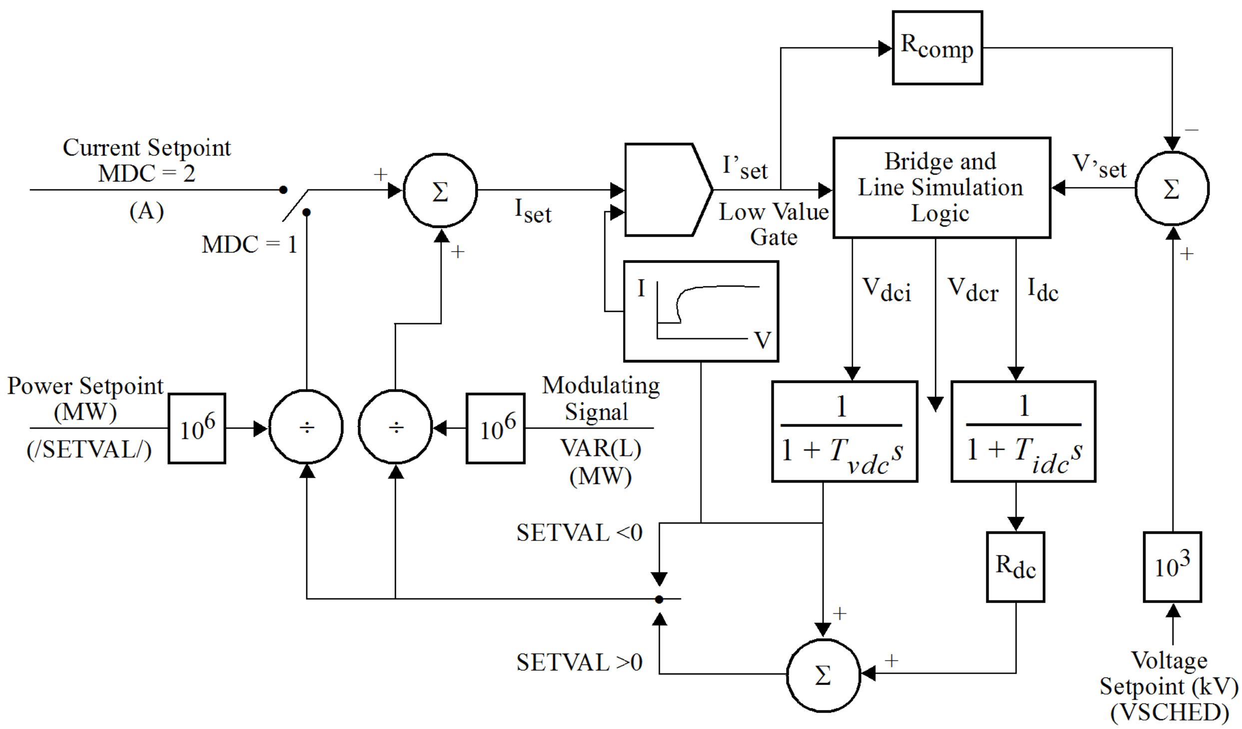


Figure 19.4. CDC4 dc Transmission Control Arrangements

19.2.2. Operation During Transients

All dc transmissions must be protected against commutation failure in the inverter. A commutation failure results in one pair of diodes conducting permanently in the inverter bridge. Because these are normally not on the same leg of the bridge, the dc current flows permanently through one phase-pair of the transformer. Protection, and extinguishing of the two conducting diodes, is handled by bypassing the inverter bridge as shown in Figure 19.5, “Use of Bypass Switch to Allow Shutdown of Inverter After Commutation Failure”. CDC4 models a dc transmission in which the bypass is a fast operating vacuum switch. CDC4 models two actions taken by the dc converters during ac system disturbances:

1. The rectifier and inverter are both shut down (blocked) if the ac voltage at the rectifier falls below the per unit value, VBLOCK.

2. The inverter bypass switch is closed if the inverter end dc voltage falls below the kilovolt value, VBYPAS. The rectifier continues to maintain dc current at scheduled value.

Low dc voltage does not cause blocking of the rectifier unless the rectifier ac voltage is also low. Low ac voltage at the inverter does not cause blocking or bypassing unless the inverter dc voltage is also low. If blocked, the rectifier remains blocked for a minimum of TBLOCK seconds; it may then restart when the per-unit voltage at its ac bus rises to a value of VUNBL. If bypassed, the inverter remains bypassed for a minimum of TBYPAS seconds; it may then reestablish dc voltage when the voltage at its ac bus rises to the per-unit value, VUNBY.

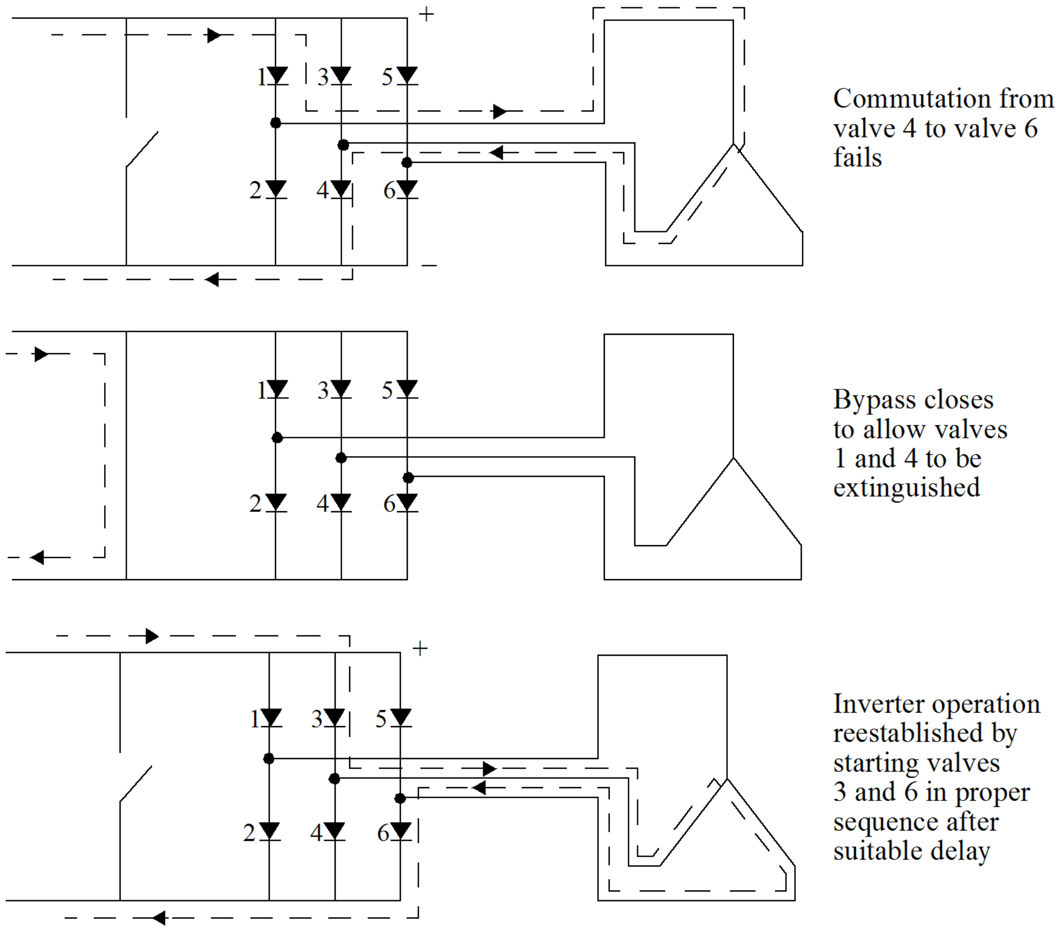


Figure 19.5. Use of Bypass Switch to Allow Shutdown of Inverter After Commutation Failure

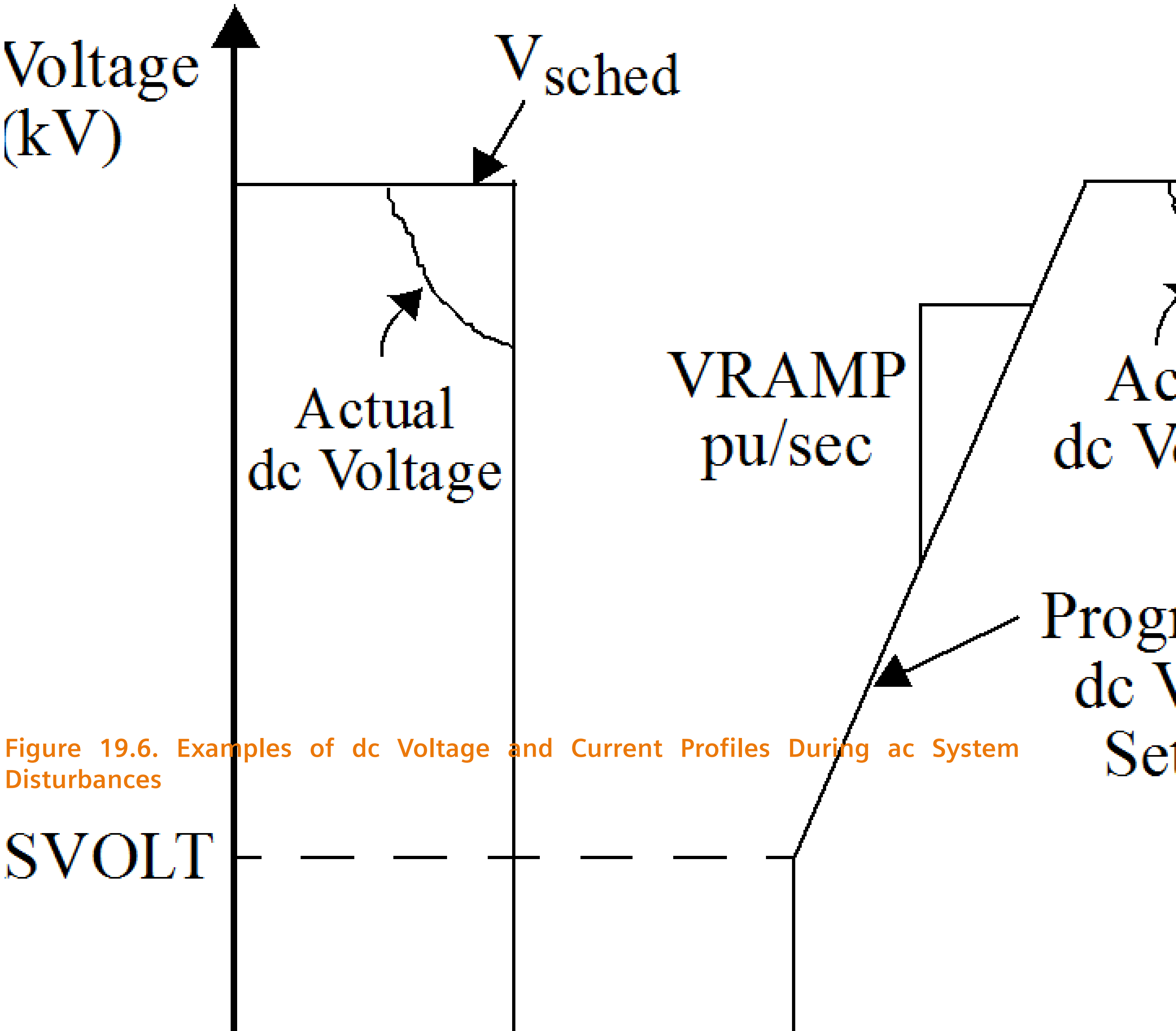


Figure 19.6. Examples of dc Voltage and Current Profiles During ac System Disturbances

When restarting from a blocking, the dc voltage and current instantaneous setpoints follow the programs shown in Figure 19.6, "Examples of dc Voltage and Current Profiles During ac System Disturbances"a. When reestablishing voltage after a bypass, the dc voltage setpoint follows the program shown in Figure 19.6, "Examples of dc Voltage and Current Profiles During ac System Disturbances"b.The voltage and current reestablishment programs are specified by the parameters RSVOLT, RSCUR, VRAMP, and CRAMP. The current setpoints at both rectifier and inverter are overridden at all times by a voltage-dependent current limit as shown in Figure 19.7, "Voltage-Dependent Current Limit for dc Converters". If the voltage-dependent current limit comes into play during reestablishment of dc voltage or current, it will force the dc current to a value below the instantaneous current setpoint. This effect can be largely eliminated by proper coordination of the voltage-dependent current limit profile, voltage reestablishment rate, VRAMP, and current reestablishment rate, CRAMP.

The dc control logic of normal operation is in effect throughout reestablishment of current and/or voltage. Accordingly, the actual current will fall below the rising instantaneous current setpoint at any time that the rectifier encounters its dynamic minimum value of firing delay angle, ALFDY. This situation may be fairly common: Rapid reloading of the dc transmission presents the sending-end ac generation with a sudden, and often large, demand for both real and reactive power, which tends to pull down the ac voltage at the rectifier. This effect may be alleviated by reducing the dc transmission's voltage and current ramping rates to values that allow the voltage regulators of the ac generators to keep up with the reapplied rectifier load.

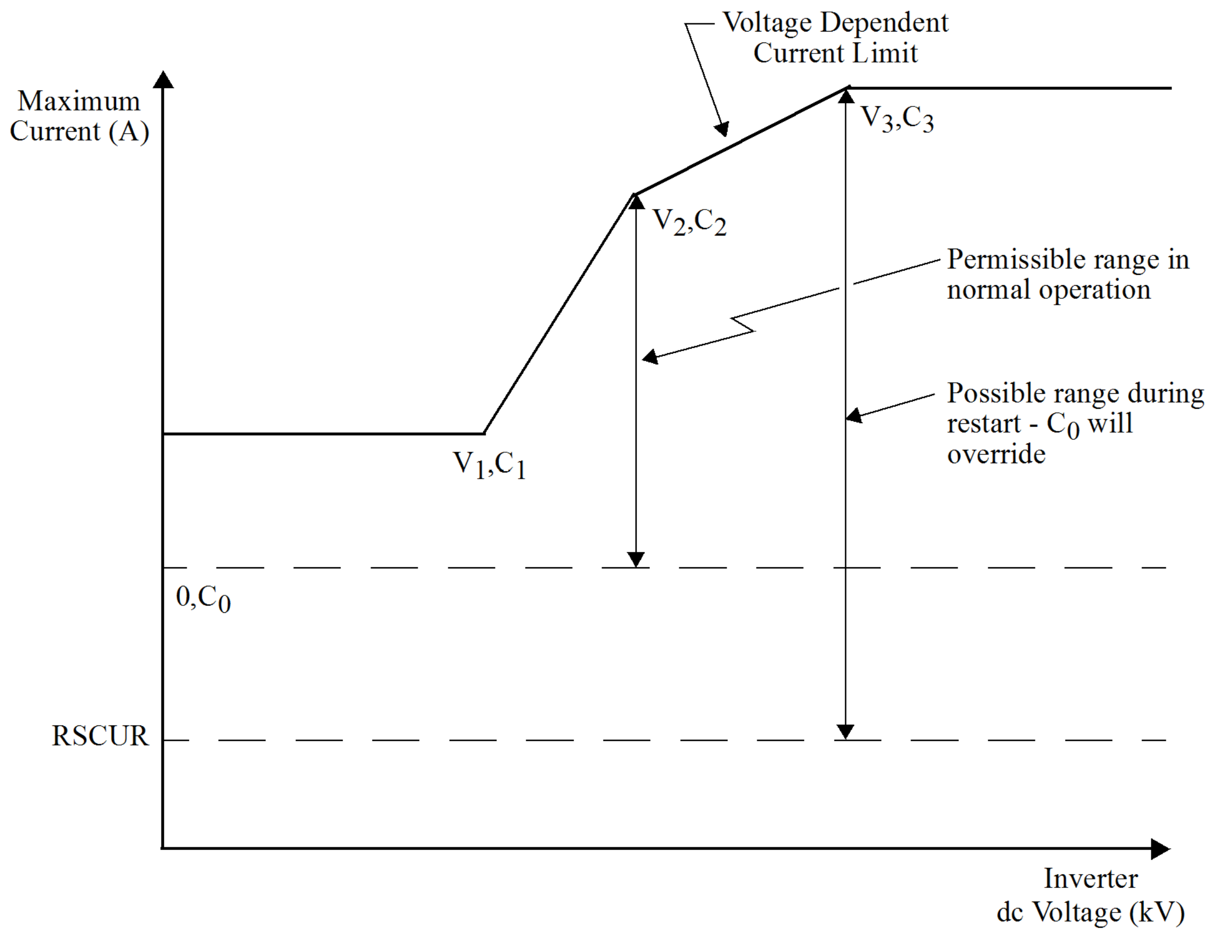


Figure 19.7. Voltage-Dependent Current Limit for dc Converters

19.2.3. Modulating Control

CDC4 accepts a modulating signal via its auxiliary signal input VAR, VAR(L), as shown in Figure 19.4, "CDC4 dc Transmission Control Arrangements". The modulating signal is always assumed to be expressed in terms of megawatts. Accordingly,

1. The modulating signal is added directly to the power setpoint when the line is in power control mode (MDC = 1).

2. The modulating signal is converted to amps by dividing by measured dc voltage and added to the current setpoint when the line is in current control mode (MDC = 2). (Measured dc voltage may be made equal to instantaneous dc voltage by setting the transducer time constants T_{vdc} and T_{idc} in CON's J+2 and J +3 to zero, if desired.)

The modulating signal is recognized when the dc transmission is in its normal operating condition and ignored when the converters are blocked, bypassed, or recovering from a block or bypass operation. The modulating signal may be applied by assigning a nonzero value to VAR(L) by any logic that may be meaningful in a specific simulation. The normal procedure is to call a PSS®E library model such as SQBAUX to represent the production of the modulating signal by a supplementary controller.

The model determining the modulating signal must be called before the call to CDC4 in the CONEC subroutine. The user may combine the outputs of more than one supplementary controller. For example, the modulating signal could be set up as the sum of the outputs of two different controllers, both modeled by SQBAUX, by the logic:

```
CALL SQBAUX(I1,J1,K1,M1,NDC1) CALL SQBAUX(I2,J2,K2,M2,NDC1) VAR(L) = VAR(M1) +
CON(999) * VAR(M2)
```

This logic allows the outputs of the two SQBAUX supplementary controllers to be added together with an arbitrary weighing factor specified by CON(999). The user can make runs comparing the effects of different weighings by changing CON(999). This is often preferable to hard coding a weighing in a statement such as:

```
VAR(L) = VAR(M1) - 0.5 * VAR(M2)
```

The CDC4 model does not represent transmission delays that may occur when a modulating signal is derived at one end of a dc line but acted on by the converter bridge at the opposite end. Any such transmission delays should be represented, when appropriate, in the logic used to calculate VAR(L). Such delays are represented in SQBAUX.

19.2.4. Use of CDC4 when Bridge Firing Angle is Initialized on Power Flow Limit

Model CDC4 does not recognize the power flow firing angle limits ALFMIN and GAMMIN. This is of no consequence when the power flow solution is normal (neither alpha nor gamma is on its power flow limit) or when the dynamic limits ALFDY and/or GAMDY are the same as the corresponding power flow limits ALFMIN and/or GAMMIN.

The distinction between static and dynamic minima does become a difficulty if the initial condition power flow has alpha or gamma at its static minimum. In this case the network solutions made in dynamics' activities STRT and RUN, which recognizes ALFDY and GAMDY, will be different from the converted power flow solution that is the intended initial condition. This difference is not proper because all network solutions prior to the application of a disturbance should be identical to the converted power flow. The difference will cause the value of n in the STRT message, INITIAL CONDITION LOAD FLOW USED n ITERATIONS, to be 2, 3 or more. It may also result in a nonsteady initial condition if the incorrect solution forces excitation system or other variables onto limits.

The user must force the dynamic simulation to use ALFMIN and GAMMIN until a disturbance is initiated, and then ALFDY and GAMDY. Because transients are initiated by user commands, the user must control the switch from ALFMIN to ALFDY as the disturbance is applied. Two approaches are available:

1. Set ALFDY equal to ALFMIN and GAMDY equal to GAMMIN in all initial data setups and initial condition snapshots, and leave it unchanged during execution of STRT and RUN prior to the disturbance. When applying the disturbance manually, change these values to the actual dynamic values by the appropriate changes of CONs. Also, change the values of ALFMIN and GAMMIN to ALFDY and GAMDY. This change is quite easy to do, when making simulation runs, with the aid of PSAS.

2. Automate the adjustment of dynamic firing angle limits by making the initial data setup with the dynamic values of the limits in ALFDY and GAMDY, and replacing them with the static limits by CONEC logic during the predisturbance work. The following statements in CONEC may be used ahead of the CDC4 calls. Spare refers to any unused CON; TST is the time (usually 0) when the disturbance is to be initiated.

   ```
   IF(MODE.NE.4) GO TO 1 CON(spare) = CON(J) CON(spare+1) = CON(J+1) CON(J)
   = ALFMIN(line number) CON(J+1) = GAMMIN(line number) 1 IF(ABS(TIME-
   ```

```
TST).GE.0.1*DELT .OR.KPAUSE.NE.2)GO TO 2 CON(J) = CON(spare) CON(J+1) =
CON(spare+1) 11 ALFMIN(line number) = CON(J) GAMMIN(line number) = CON(J
+1) 2 CONTINUE
```

Both approaches suggest changing ALFMIN and GAMMIN to the dynamic limit values when a disturbance is applied. This change is necessary only if the SQBAUX model is applied to the line in question. In this case, the change should be made whether or not the initial condition power flow has alpha or gamma on its limit.

19.2.5. Calling Sequence

Model CDC4 must be invoked by coordinated calls in subroutines CONEC and CONET as follows:

CONEC: CALL CDC4 (I,J,K,L,M)

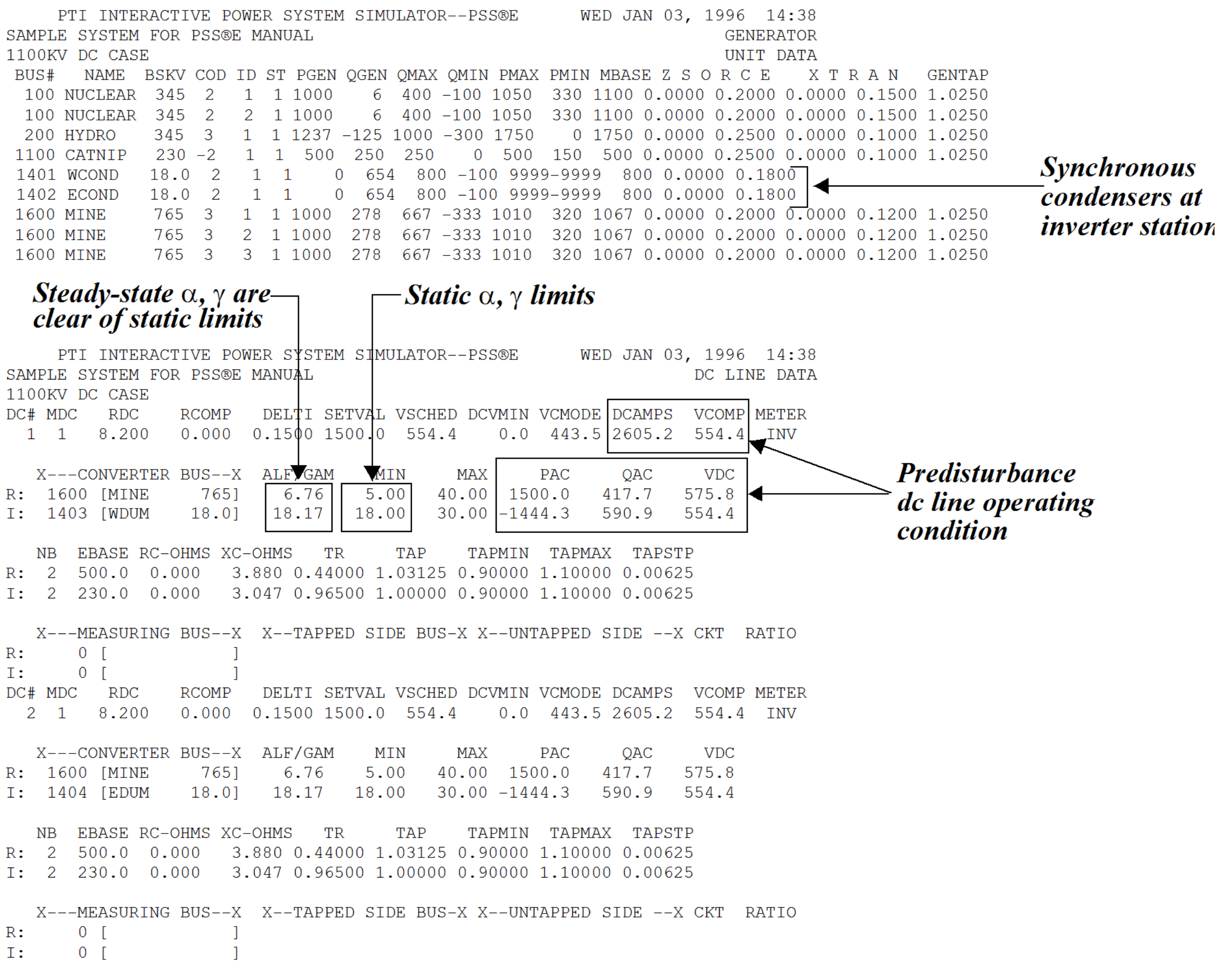
CONET: CALL TDC4 (I,J,K,L,M)

The five calling arguments must have identical values in the two call statements because the simulation logic in subroutine CONEC communicates with the logic in subroutine CONET through the CON, VAR, ICON, and STATE arrays. Activity DYRE inserts the required call statement into both CONEC and CONET when a data record is read with the model name CDC4. The model name TDC4 is not recognized by activity DYRE.

19.2.6. Example Cases

Figure 19.8, “Power Flow Data for dc Lines and Synchronous Condensers in System of Figure 6-15 Predisturbance Condition” through Figure 19.15, “Response to High Impedance L-G Fault at Bus 1200 (Sheet 1 of 3)” illustrate the application of model CDC4 in the sample problem setup shown by Figures 6-15, 6-16, and 6-17. Figure 19.8, “Power Flow Data for dc Lines and Synchronous Condensers in System of Figure 6-15 Predisturbance Condition” shows the generator data pertaining to the two synchronous condensers at buses 1401 and 1402, and the power flow data for the dc transmission lines; these tabulations reflect the initial condition power flow solution. Figure 19.8, “Power Flow Data for dc Lines and Synchronous Condensers in System of Figure 6-15 Predisturbance Condition” also shows that the initial alpha and gamma values are above the static minima (adjustments discussed in Section 19.2.4, “Use of CDC4 when Bridge Firing Angle is Initialized on Power Flow Limit” are not needed) and that the predisturbance current is comfortably within the operating region allowed by the voltage-dependent current limit. Figure 19.9, “Permissible dc Line Operating Domain” shows the dynamic simulation data used to represent the two lines. Of particular interest are the dynamic alpha and gamma minimum values that fall below the power flow minima, and the voltage dependent current limit function specified by CONs J+15 through J+20. Figure 19.10, “dc Line Dynamics Data to Complement Power Flow Data of Figure 19.8, “Power Flow Data for dc Lines and Synchronous Condensers in System of Figure 6-15 Predisturbance Condition”” shows the permissible operating region drawn to scale, while Figure 19.11, “Use of DYRE to Set Up CONEC and CONET Calling CDC4 (Sheet 1 of 2)” shows the output produced when activity DYRE reads the dc line data records shown in Figure 19.9, “Permissible dc Line Operating Domain”. DYRE also produces the CONEC and CONET statements shown in Figure 19.11, “Use of DYRE to Set Up CONEC and CONET Calling CDC4 (Sheet 1 of 2)”. Figure 19.13, “Permissible dc Line Operating Domain” and Figure 19.14, “Permissible dc Line Operating Domain” show CDC4 data sheets filled in to correlate the CON, VAR, and STATE assignments made by DYRE with the individual data items for the two lines. Assignment of dc line variables to output channels requires reference to Figure 19.5, “Use of By-pass Switch to Allow Shutdown of Inverter After Commutation Failure” through Figure 19.14, “Permissible dc Line Operating Domain” to find the VARs and STATEs containing the desired quantities. Plotting alpha and gamma angles for dc line 1, for example, requires that activity CHAN be used to place VAR(23) and VAR(24) in output channels.

Figure 19.15, “Response to High Impedance L-G Fault at Bus 1200 (Sheet 1 of 3)” shows the behavior of the dc transmissions following a fault at bus 1200, the ac side of the inverter station. The fault is represented by a positive-sequence admittance of -j35 per unit, which approximates the effect of a high-impedance, single-phase fault on one of the four 230-kV circuits between buses 1200 and 1201. Figure 19.15, “Response to High Impedance L-G Fault at Bus 1200 (Sheet 1 of 3)” also shows that the terminal voltage of the synchronous condensers falls to 0.72 per unit as a result of the fault. The dc line current initially rises in the attempt to hold constant power with reduced dc voltage. The dc current is then reduced with a time constant of about 0.05 sec as the measured dc voltage at the inverter falls and brings the voltage-dependent current limit into play. Removal of the fault allows the dc current to rise with a similar time constant. The line returns to nominal operating conditions as the inverter terminal ac voltage is returned to nominal value by the voltage regulators of the synchronous condensers.



```
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED JAN 03, 1996  14:38
SAMPLE SYSTEM FOR PSS®E MANUAL                                        GENERATOR
1100KV DC CASE                                                        UNIT DATA
 BUS#    NAME   BSKV COD ID ST PGEN QGEN QMAX QMIN PMAX PMIN MBASE Z S O R C E    X T R A N   GENTAP
  100 NUCLEAR  345  2    1  1 1000    6  400 -100 1050  330 1100 0.0000 0.2000 0.0000 0.1500 1.0250
  100 NUCLEAR  345  2    2  1 1000    6  400 -100 1050  330 1100 0.0000 0.2000 0.0000 0.1500 1.0250
  200 HYDRO    345  3    1  1 1237 -125 1000 -300 1750    0 1750 0.0000 0.2500 0.0000 0.1000 1.0250
 1100 CATNIP   230 -2    1  1  500  250  250    0  500  150  500 0.0000 0.2500 0.0000 0.1000 1.0250
 1401 WCOND   18.0  2    1  1    0  654  800 -100 9999-9999  800 0.0000 0.1800
 1402 ECOND   18.0  2    1  1    0  654  800 -100 9999-9999  800 0.0000 0.1800
 1600 MINE     765  3    1  1 1000  278  667 -333 1010  320 1067 0.0000 0.2000 0.0000 0.1200 1.0250
 1600 MINE     765  3    2  1 1000  278  667 -333 1010  320 1067 0.0000 0.2000 0.0000 0.1200 1.0250
 1600 MINE     765  3    3  1 1000  278  667 -333 1010  320 1067 0.0000 0.2000 0.0000 0.1200 1.0250

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED JAN 03, 1996  14:38
SAMPLE SYSTEM FOR PSS®E MANUAL                                     DC LINE DATA
1100KV DC CASE
DC# MDC    RDC     RCOMP   DELTI SETVAL VSCHED DCVMIN VCMODE DCAMPS  VCOMP METER
  1  1   8.200   0.000  0.1500 1500.0  554.4    0.0  443.5 2605.2  554.4  INV

   X---CONVERTER BUS--X  ALF/GAM    MIN     MAX     PAC     QAC     VDC
R:  1600 [MINE     765]   6.76     5.00   40.00  1500.0   417.7   575.8
I:  1403 [WDUM    18.0]  18.17    18.00   30.00 -1444.3   590.9   554.4

   NB  EBASE RC-OHMS XC-OHMS   TR      TAP    TAPMIN  TAPMAX  TAPSTP
R:  2  500.0  0.000   3.880 0.44000 1.03125 0.90000 1.10000 0.00625
I:  2  230.0  0.000   3.047 0.96500 1.00000 0.90000 1.10000 0.00625

   X---MEASURING BUS--X  X--TAPPED SIDE BUS-X X--UNTAPPED SIDE --X CKT  RATIO
R:      0 [            ]
I:      0 [            ]
DC# MDC    RDC     RCOMP   DELTI SETVAL VSCHED DCVMIN VCMODE DCAMPS  VCOMP METER
  2  1   8.200   0.000  0.1500 1500.0  554.4    0.0  443.5 2605.2  554.4  INV

   X---CONVERTER BUS--X  ALF/GAM    MIN     MAX     PAC     QAC     VDC
R:  1600 [MINE     765]   6.76     5.00   40.00  1500.0   417.7   575.8
I:  1404 [EDUM    18.0]  18.17    18.00   30.00 -1444.3   590.9   554.4

   NB  EBASE RC-OHMS XC-OHMS   TR      TAP    TAPMIN  TAPMAX  TAPSTP
R:  2  500.0  0.000   3.880 0.44000 1.03125 0.90000 1.10000 0.00625
I:  2  230.0  0.000   3.047 0.96500 1.00000 0.90000 1.10000 0.00625

   X---MEASURING BUS--X  X--TAPPED SIDE BUS-X X--UNTAPPED SIDE --X CKT  RATIO
R:      0 [            ]
I:      0 [            ]
```


Figure 19.8. Power Flow Data for dc Lines and Synchronous Condensers in System of Figure 6-15 Predisturbance Condition

CDC4

dc Line Model

CALL CDC4 (I,J,K,L,M) from CONEC		
CALL TCD4 (JI,J,K,L,M) from CONET		

This is dc line	#______	I,
This model uses CONs starting with	#______	J,
and STATEs starting with	#______	K,
and VARs starting with	#______	L,
and ICONs starting with	#______	M.

CONs	#	Value	Description
J		5	ALFDY, minimum alpha for dynamics (degrees)
J+1		15	GAMDY [a], minimum gamma for dynamics (degrees)
J+2		0.05	TVDC, dc voltage transducer time constant (sec)
J+3		0.05	TIDC, dc current transducer time constant (sec)
J+4		0.6	VBLOCK, rectifier ac blocking voltage (pu)
J+5		0.65	VUNBL, rectifier ac unblocking voltage (pu)
J+6		0.1	TBLOCK, minimum blocking time (sec)
J+7		0.6	VBYPAS, inverter dc bypassing voltage (kV)
J+8		0.65	VUNBY, inverter ac unbypassing voltage (pu)
J+9		0.1	TBYPAS, minimum bypassing time (sec)
J+10		200	RSVOLT, minimum dc voltage following block (kV)
J+11		500	RSCUR, minimum dc current following block (amps)
J+12		5.	VRAMP, voltage recovery rate (pu/sec)
J+13		5.	CRAMP, current recovery rate (pu/sec)
J+14		400	C ∅ , minimum current demand (amps)
J+15		300	V1, voltage limit point 1 (kV)
J+16		1000	C1, Current limit point 1 (amps); ≥C ∅
J+17		500	V2, voltage limit point 2 (kV)

CONs	#	Value	Description
J+18		3000	C2, current limit point 2 (amps)
J+19		500	V3, voltage limit point 3 (kV)
J+20		3000	C3, current limit point 3 (amps)
J+21		0.1	TCMODE, minimum time stays in switched mode (sec)

[a]Ignored if in gamma control (i.e., GAMMAX = GAMMIN in power flow).

STATEs	#	Description
K		Measured inverter dc voltage (V)
K+1		Measured inverter dc current (amps)

VARs	#	Description
L		Other signals, MW
L+1		RESTR, time unblocks or unbypass-es (sec)
L+2		VRF, voltage ramping factor
L+3		CRF, current ramping factor
L+4		VCOMP, compensating dc voltage (V)
L+5		PACR, rectifier ac real power (pu)
L+6		QACR, rectifier ac reactive power (pu)
L+7		PACI, inverter ac real power (pu)
L+8		QACI, inverter ac reactive power (pu)
L+9		VDCI, inverter dc voltage (V)
L+10		VDCR, rectifier dc voltage (V)
L+11		DC, dc current (amps)
L+12		ALFA, alpha (degrees)
L+13		GAMA, gamma (degrees)
L+14		TIME, reswitches mode

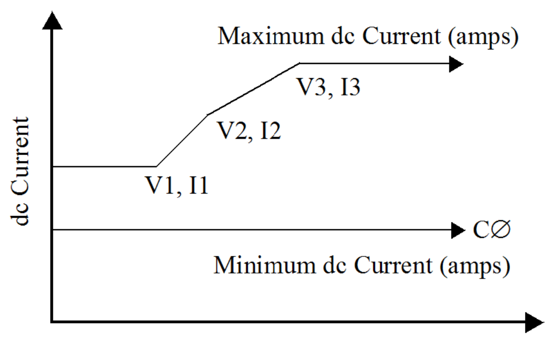
ICONs	#	Description
M		Bypass control flag [a] : 0 = Not by-passed 1 = Bypassed 2 = Unbypass-ing
M+1		Blocking control flag*: 0 = Not blocked 1 = Blocked 2 = Unblocked

ICONs	#	Description
M+2		Switched mode control flag*: 0 = Normal 1 = Mode switched

[a]Not intended to be changed by the user.

Note: Statement must be added to CONEC to sum any supplementary signals into VAR(L).

I, 'CDC4', ALFDY, GAMDY, TVDC, TIDC, VBLOCK, VUNBL, TBLOCK, VBYPAS, VUNBY, TBYPAS, RSVOLT, RSCUR, VRAMP, CRAMP, C ∅ , V1, C1, V2, C2, V3, C3, TCMODE/



Voltage-Dependent Upper Current Limit

```
n 'CDC4' 5 15 .05 .05 .6 .65 .1 .6 .65 .1 200 500
5. 5. 400 300 1000 500 3000 500 3000 .1/
```

Data record to be included in input file for activity DYRE

Figure 19.9. Permissible dc Line Operating Domain

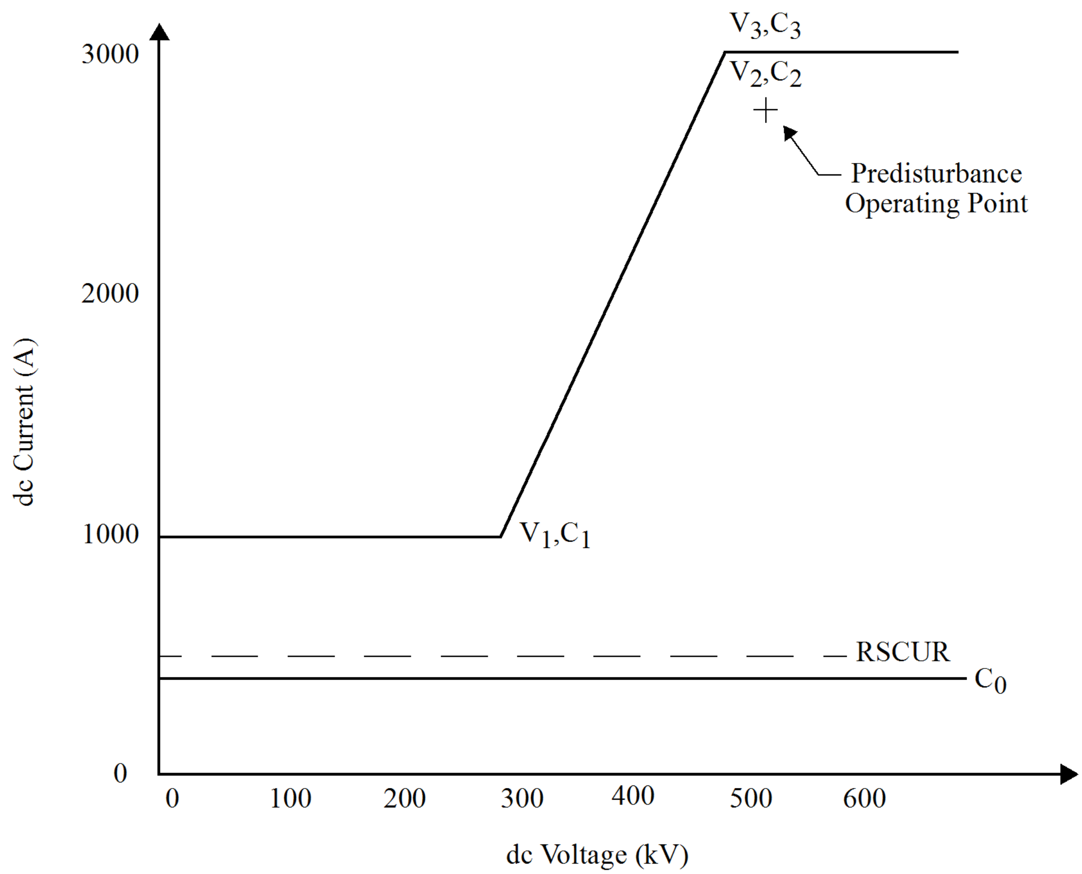


Figure 19.10. dc Line Dynamics Data to Complement Power Flow Data of Figure 19.8, “Power Flow Data for dc Lines and Synchronous Condensers in System of Figure 6-15 Predisturbance Condition”

```
ACTIVITY? dyre

ENTER DYNAMICS DATA SOURCE FILENAME: scdc1.dyr      <---- File of dynamics raw data

ENTER FILENAME FOR SUBROUTINE CONEC: cce            <---- Place CONEC here

ENTER FILENAME FOR SUBROUTINE CONET: cte            <---- Place CONET here

ENTER FILENAME FOR PSSPLT RELAY CHARACTERISTIC DATA:

NEXT AVAILABLE ADDRESSES ARE:
   CON  STATE    VAR   ICON
     1      1      1      1
ENTER STARTING CON, STATE, VAR, ICON OR CARRIAGE RETURN  <---- Fresh data setup

OUT OF FILE DATA--SWITCH TO TERMINAL INPUT MODE

GENERATOR MODELS USE:
 CONS        1-   120
 STATES      1-    51

EXCITER MODELS USE:
 CONS      121-   200
 STATES     52-    75
 VARS        1-     2

GOVERNOR MODELS USE:
 CONS      201-   254
 STATES     76-    91
 VARS        3-    10

OTHER MODELS USE:
 CONS      255-   298
 STATES     92-    95     Assigned to two CDC4 calls
 VARS       11-    40
 ICONS       1-     6


SUMMARY OF MODELS READ:

GENS:  GENROU GENSAL
            6      3

EXSYS: SCRX   SEXS   IEEEX1
          3      4      2

GOVS:  TGOV1  HYGOV
            6      1

MISC:  CDC4
          2

NEXT AVAILABLE ADDRESSES ARE:
   CON  STATE    VAR   ICON
   299     96     41      7

COMPILE AND CLOAD4 BEFORE RUNNING SIMULATIONS

ENTER FILENAME FOR COMPILING FILE (0 TO EXIT): cpe
```

Figure 19.11. Use of DYRE to Set Up CONEC and CONET Calling CDC4 (Sheet 1 of 2)

```
      SUBROUTINE CONEC                                File cce.flx made by DYRE
C
$INSERT COMON4.INS
C
      CALL CDC4   (    1,  255,    92,    11,     1)
      CALL CDC4   (    2,  277,    94,    26,     4)    CDC4 calls generated by DYRE
C
      RETURN
      END
      SUBROUTINE USRXXX(MC,SLOT,IT)
      INTEGER MC,SLOT,IT
      SELECT (IT)
      FIN
      RETURN
      END

      SUBROUTINE CONET                                File cte.flx made by DYRE
C
$INSERT COMON4.INS
C
      CALL TDC4   (    1,  255,    92,    11,     1)    TDC4 calls generated by DYRE
      CALL TDC4   (    2,  277,    94,    26,     4)
C
      IF (.NOT. IFLAG) GO TO 9000
C
C   NETWORK MONITORING MODELS
C
C
 9000 CONTINUE
C
      RETURN
      END
```

Figure 19.12. Use of DYRE to Set Up CONEC and CONET Calling CDC4 (Sheet 2 of 2)

CDC4

dc Line Model

CALL CDC4 (I,J,K,L,M) from CONEC		
CALL TCD4 (JI,J,K,L,M) from CONET		
This is dc line	# 1	I,
This model uses CONs starting with	# 255	J,
and STATEs starting with	# 92	K,
and VARs starting with	# 11	L,
and ICONs starting with	# 1	M.

CONs	#	Value	Description
J	255		ALFDY, minimum alpha for dynamics (degrees)
J+1	256		GAMDY [a], minimum gamma for dynamics (degrees)
J+2	257		TVDC, dc voltage transducer time constant (sec)

CONs	#	Value	Description
J+3	258		TIDC, dc current transducer time constant (sec)
J+4	259		VBLOCK, rectifier ac blocking voltage (pu)
J+5	260		VUNBL, rectifier ac unblocking voltage (pu)
J+6	261		TBLOCK, minimum blocking time (sec)
J+7	262		VBYPAS, inverter dc bypassing voltage (kV)
J+8	263		VUNBY, inverter ac unbypassing voltage (pu)
J+9	264		TBYPAS, minimum bypassing time (sec)
J+10	265		RSVOLT, minimum dc voltage following block (kV)
J+11	266		RSCUR, minimum dc current following block (amps)
J+12	267		VRAMP, voltage recovery rate (pu/sec)
J+13	268		CRAMP, current recovery rate (pu/sec)
J+14	269		C ∅ , minimum current demand (amps)
J+15	270		V1, voltage limit point 1 (kV)
J+16	271		C1, Current limit point 1 (amps); >C ∅
J+17	272		V2, voltage limit point 2 (kV)
J+18	273		C2, current limit point 2 (amps)
J+19	274		V3, voltage limit point 3 (kV)
J+20	275		C3, current limit point 3 (amps)
J+21	276		TCMODE, minimum time stays in switched mode (sec)

[a]Ignored if in gamma control (i.e., GAMMAX = GAMMIN in power flow).

STATEs	#	Description
K	92	Measured inverter dc voltage (V)

STATEs	#	Description
K+1	93	Measured inverter dc current (amps)

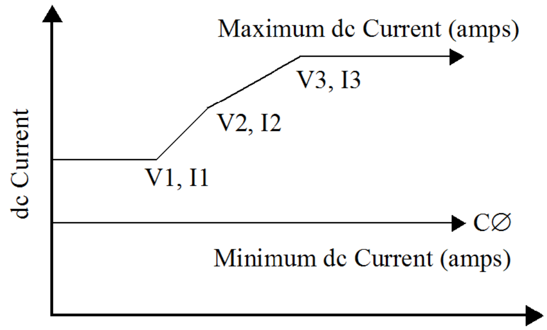
VARs	#	Description
L	11	Other signals, MW
L+1	12	RESTR, time unblocks or unbypass-es (sec)
L+2	13	VRF, voltage ramping factor
L+3	14	CRF, current ramping factor
L+4	15	VCOMP, compensating dc voltage (V)
L+5	16	PACR, rectifier ac real power (pu)
L+6	17	QACR, rectifier ac reactive power (pu)
L+7	18	PACI, inverter ac real power (pu)
L+8	19	QACI, inverter ac reactive power (pu)
L+9	20	VDCI, inverter dc voltage (V)
L+10	21	VDCR, rectifier dc voltage (V)
L+11	22	DC, dc current (amps)
L+12	23	ALFA, alpha (degrees)
L+13	24	GAMA, gamma (degrees)
L+14	25	TIME, reswitches mode

ICONs	#	Description
M	1	Bypass control flag [a] : 0 = Not by-passed 1 = Bypassed 2 = Unbypass-ing
M+1	2	Blocking control flag*: 0 = Not blocked 1 = Blocked 2 = Unblocked
M+2	3	Switched mode control flag*: 0 = Normal 1 = Mode switched

[a]Not intended to be changed by the user.

Note: Statement must be added to CONEC to sum any supplementary signals into VAR(L).

I, 'CDC4', ALFDY, GAMDY, TVDC, TIDC, VBLOCK, VUNBL, TBLOCK, VBYPAS, VUNBY, TBYPAS, RSVOLT, RSCUR, VRAMP, CRAMP, C ∅ , V1, C1, V2, C2, V3, C3, TCMODE/



Voltage-Dependent Upper Current Limit

```
1 'CDC4' 5 15 .05 .05 .6 .65 .1 .6 .65 .1 200 500
5. 5. 400 300 1000 500 3000 500 3000 .1/
```

Data record to be included in input file

Figure 19.13. Permissible dc Line Operating Domain

CDC4

dc Line Model

CALL CDC4 (I,J,K,L,M) from CONEC		
CALL TCD4 (JI,J,K,L,M) from CONET		
This is dc line	# 2	I,
This model uses CONs starting with	# 277	J,
and STATEs starting with	# 94	K,
and VARs starting with	# 26	L,
and ICONs starting with	# 4	M.

CONs	#	Value	Description
J	277		ALFDY, minimum alpha for dynamics (degrees)
J+1	278		GAMDY [a], minimum gamma for dynamics (degrees)
J+2	279		TVDC, dc voltage transducer time constant (sec)
J+3	280		TIDC, dc current transducer time constant (sec)
J+4	281		VBLOCK, rectifier ac blocking voltage (pu)
J+5	282		VUNBL, rectifier ac unblocking voltage (pu)
J+6	283		TBLOCK, minimum blocking time (sec)

CONs	#	Value	Description
J+7	284		VBYPAS, inverter dc bypassing voltage (kV)
J+8	285		VUNBY, inverter ac unbypassing voltage (pu)
J+9	286		TBYPAS, minimum bypassing time (sec)
J+10	287		RSVOLT, minimum dc voltage following block (kV)
J+11	288		RSCUR, minimum dc current following block (amps)
J+12	289		VRAMP, voltage recovery rate (pu/sec)
J+13	290		CRAMP, current recovery rate (pu/sec)
J+14	291		C ∅ , minimum current demand (amps)
J+15	292		V1, voltage limit point 1 (kV)
J+16	293		C1, Current limit point 1 (amps); >C ∅
J+17	294		V2, voltage limit point 2 (kV)
J+18	295		C2, current limit point 2 (amps)
J+19	296		V3, voltage limit point 3 (kV)
J+20	297		C3, current limit point 3 (amps)
J+21	298		TCMODE, minimum time stays in switched mode (sec)

[a]Ignored if in gamma control (i.e., GAMMAX = GAMMIN in power flow).

STATEs	#	Description
K	94	Measured inverter dc voltage (V)
K+1	95	Measured inverter dc current (amps)

VARs	#	Description
L	26	Other signals, MW
L+1	27	RESTR, time unblocks or unbypasses (sec)
L+2	28	VRF, voltage ramping factor
L+3	29	CRF, current ramping factor

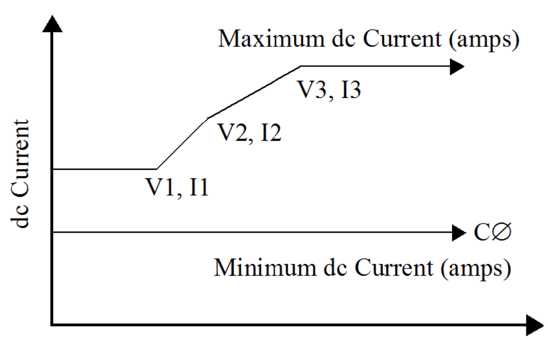
VARs	#	Description
L+4	30	VCOMP, compensating dc voltage (V)
L+5	31	PACR, rectifier ac real power (pu)
L+6	32	QACR, rectifier ac reactive power (pu)
L+7	33	PACI, inverter ac real power (pu)
L+8	34	QACI, inverter ac reactive power (pu)
L+9	35	VDCI, inverter dc voltage (V)
L+10	36	VDCR, rectifier dc voltage (V)
L+11	37	DC, dc current (amps)
L+12	38	ALFA, alpha (degrees)
L+13	39	GAMA, gamma (degrees)
L+14	40	TIME, reswitches mode

ICONs	#	Description
M	4	Bypass control flag [a] : 0 = Not bypassed 1 = Bypassed 2 = Unbypassing
M+1	5	Blocking control flag*: 0 = Not blocked 1 = Blocked 2 = Unblocked
M+2	6	Switched mode control flag*: 0 = Normal 1 = Mode switched

[a]Not intended to be changed by the user.

Note: Statement must be added to CONEC to sum any supplementary signals into VAR(L).

I, 'CDC4', ALFDY, GAMDY, TVDC, TIDC, VBLOCK, VUNBL, TBLOCK, VBYPAS, VUNBY, TBYPAS, RSVOLT, RSCUR, VRAMP, CRAMP, C ∅ , V1, C1, V2, C2, V3, C3, TCMODE/



Voltage-Dependent Upper Current Limit

```
2 'CDC4' 5 15 .05 .05 .6 .65 .1 .6 .65 .1 200 500
5. 5. 400 300 1000 500 3000 500 3000 .1/
```

Data record to be included in input file for

Figure 19.14. Permissible dc Line Operating Domain

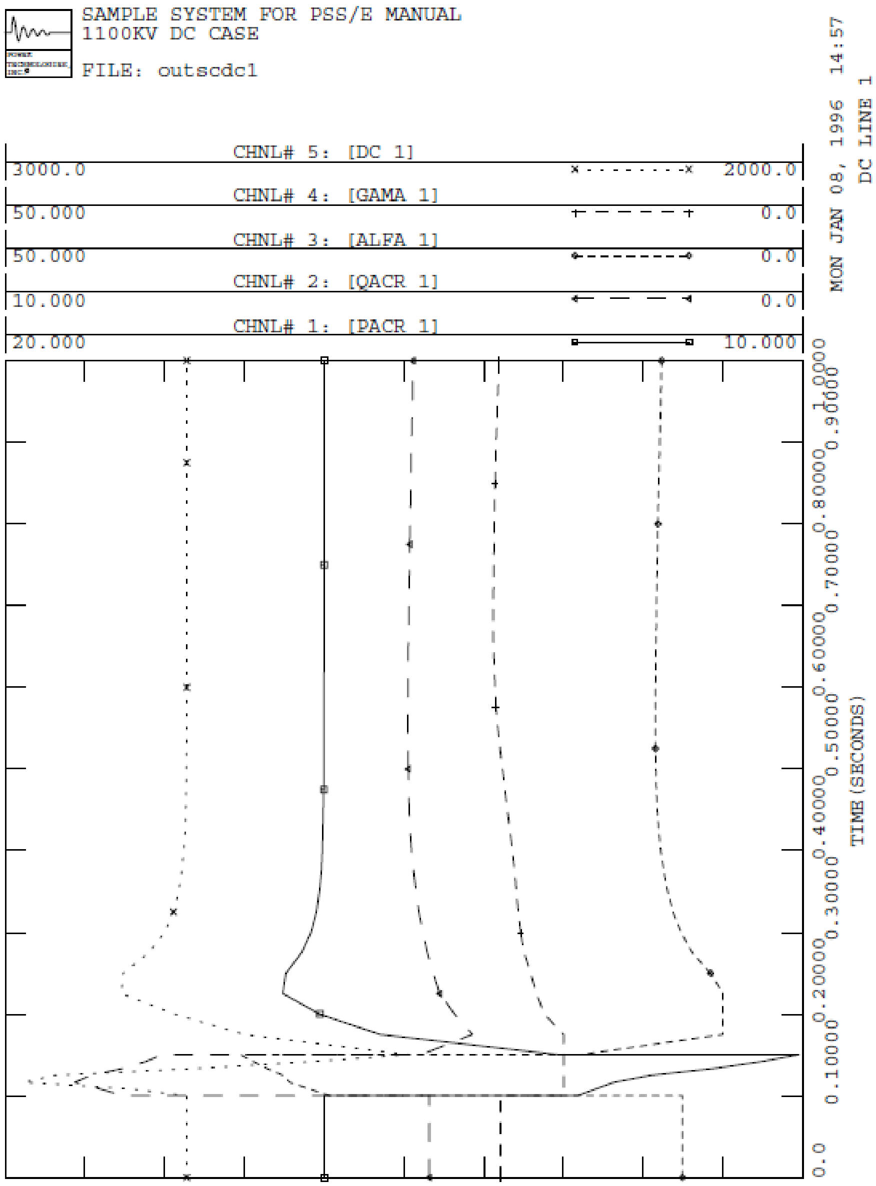


Figure 19.15. Response to High Impedance L-G Fault at Bus 1200 (Sheet 1 of 3)

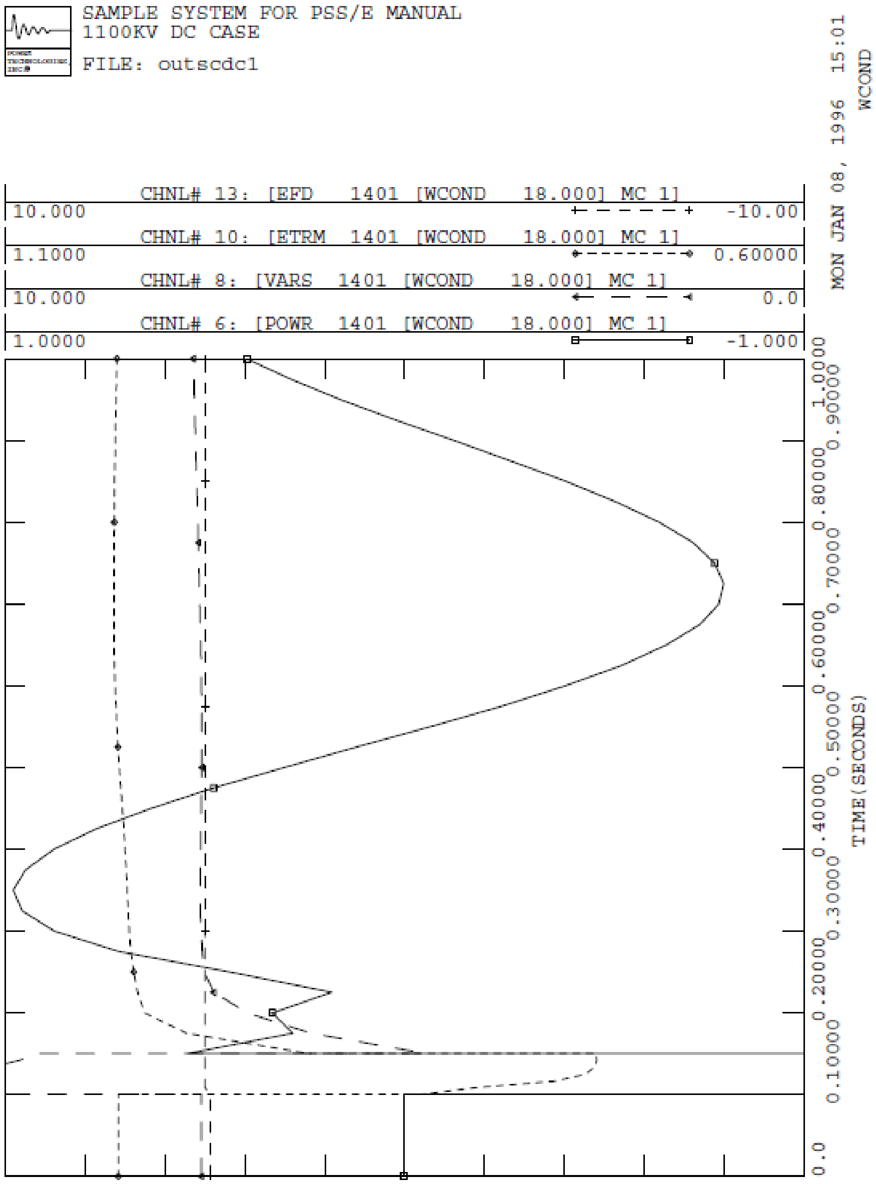


Figure 19.16. Response to High Impedance L-G Fault at Bus 1200 (Sheet 2 of 3)

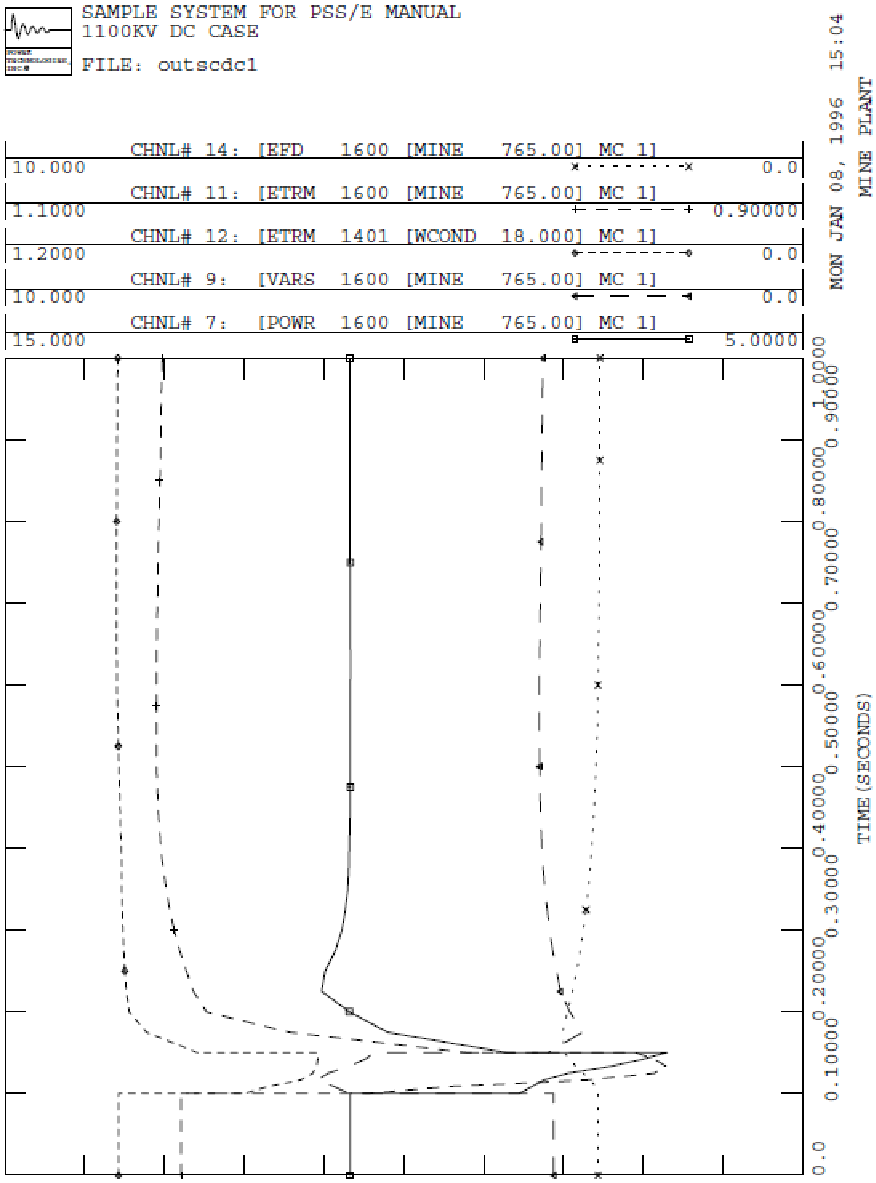


Figure 19.17. Response to High Impedance L-G Fault at Bus 1200 (Sheet 3 of 3)

19.3. Model CDC6

The model CDC6 is recommended for studying new proposed dc lines. It incorporates most of the control logic of CDC4 (The first 21 CONs of this model are identical.), plus some additional protection from the proposed modern lines. The dc control arrangements for this line are shown in Figure 19.18, “CDC6 dc Transmission Control Arrangements”. The blocking, bypassing, and mode switching logic is summarized in Figure 19.19, “CDC6 Blocking and Unblocking Conditions”. This model differs from CDC4 in power control and when converting the megawatt modulating signal. It will divide by a measured rectifier voltage rather than measured current times dc resistance if power output is set at the rectifier end (SETVAL>0).

This model allows for delayed automatic blocking of the line based on low rectifier ac voltage. A timer is started when the rectifier ac voltage goes below VDEBLK. If the voltage is still below this value, TREBLK seconds later, the line blocks. Following this block, the line cannot restart until TREBLK seconds after the ac rectifier voltage goes above VUNBY.

This model also allows a low inverter ac voltage to send a signal via a communication channel to the rectifier to shut the line down. This action is modeled by the instantaneous inverter ac blocking voltage, VINBLK, and the delay, TCOMB. The line will stay blocked until TINBLK seconds after the ac inverter voltage goes above VUNBY. TINBLK should include the communication delay in getting the signal from the inverter to the rectifier. Also, if the ac voltage goes below VACBYP on the inverter, a timer is started. If after TDEBYP seconds the ac inverter voltage is still below VACBYP, the inverter will be placed into full electronic bypass. The line will unbypass TUNBY seconds after the ac inverter voltage goes above VUNBY. The blocking, bypassing and mode switching logic is summarized in Figure 19.19, “CDC6 Blocking and Unblocking Conditions”.

19.4. Model CDC6A

This model is identical to model CDC6 except for the items listed below.

1. VAR(L+18), $I_{measured}$ current, VAR (L+19), $I_{desired}$ before VDCL, and VAR(L+20), VDCL output are for output purposes only. They are used by the Celilo-Sylmar margin switching unit, MSU1.

2. VAR(L+21), GAMMOD allows the user to impose a gamma modulation signal. This value will be used only with a constant gamma model in the power flow (i.e., GAMMAX = GAMMIN).

3. VAR(L+22) and VAR(L+23), current modulation inputs downstream from the VDCL. This is commonly referred to as low level modulation.

If the user does not set VAR(L+21) through VAR(L+23), the model will behave identically to CDC6.

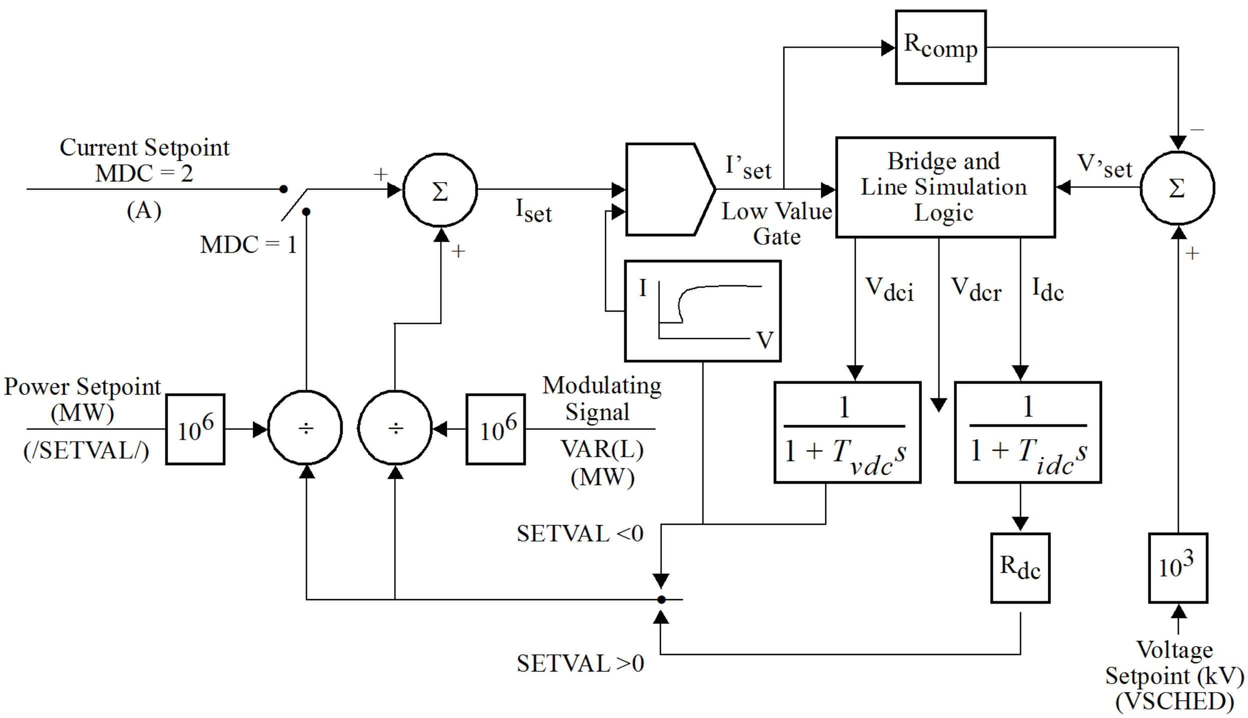


Figure 19.18. CDC6 dc Transmission Control Arrangements

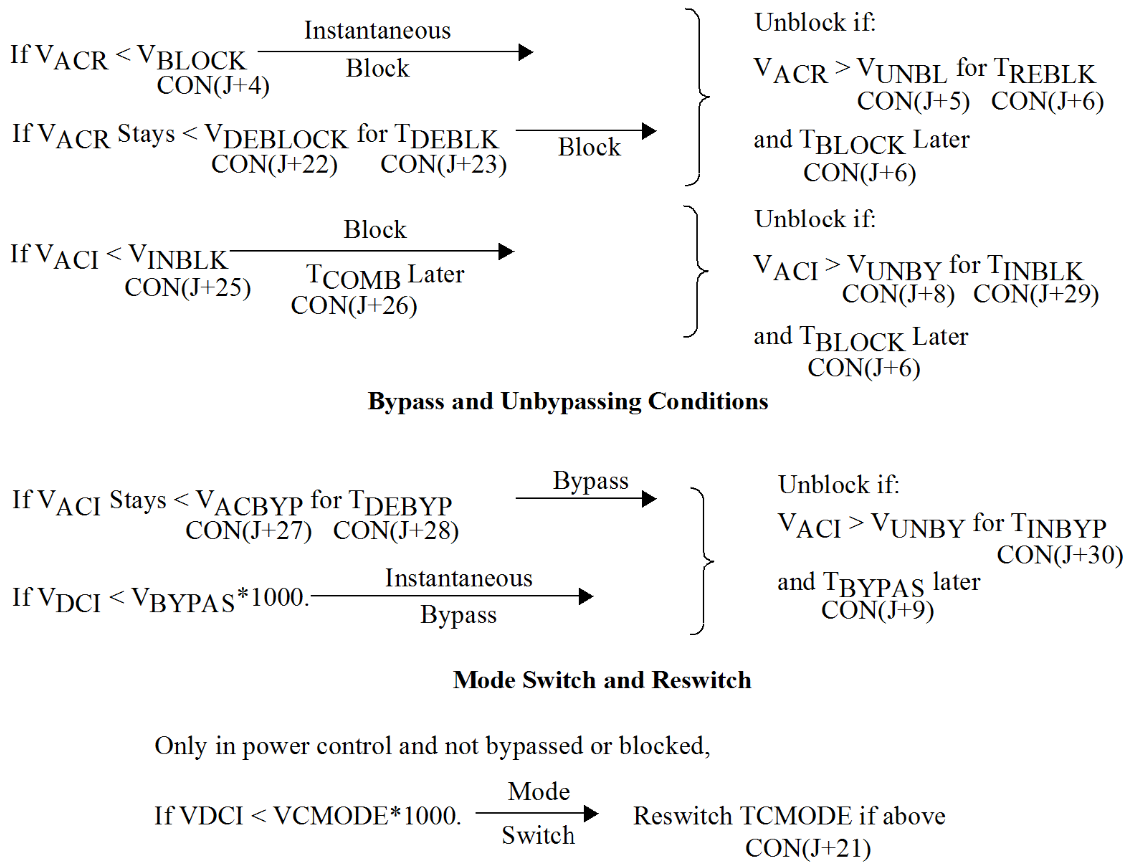


Figure 19.19. CDC6 Blocking and Unblocking Conditions

19.5. CDC7T Model for the HVDC Cable and Overhead Line

19.5.1. Introduction

The PSS®E CDC7T model simulates a pole of the 2-terminal HVDC transmission. There is a significant difference between this model and generic HVDC models available in the PSS®E dynamic library, such as CDC4T or CDC6T.

The latter models assume an instantaneous response of the dc system to disturbances coming from the adjacent grids. They use the same algebra as the power flow model to update converter parameters (alpha, gamma) at every each integration step. They assume that converters are capable of maintaining the steady-state control algorithm using the same set points as in power flow. There is a special algorithm of simulating blocking and by-passing HVDC that uses some threshold voltages on ac and dc sides. Setting up these thresholds requires experience because they are very sensitive to how strong the interconnection to the system is.

The CDC7T model simulates the dynamics of the dc line and converter controls as it can be seen from the description below. At the same time, this is a generic HVDC model in terms that a configuration of the dc circuit and algorithm of converter controls are typical for a conventional HVDC.

19.5.2. DC Circuit arrangement simulated by the CDC7T model

A dc circuit arrangement that can be simulated by the CDC7T model is shown in Figure 19.20, “A DC Circuit Arrangement Simulated by the CDC7T Model”. A dc line may comprise overhead lines from both rectifier and inverter sides and a cable. An overhead dc line is represented by its dc resistance and some equivalent inductance. A cable is represented by its dc resistance, equivalent inductance and capacitance. A small resistance representing the cable damping is placed in series with the cable capacitance.

The model does not include frequency dependent sub-models for the overhead line or cable, therefore for the equivalent inductance and capacitance respective values for the fundamental frequency are recommended.

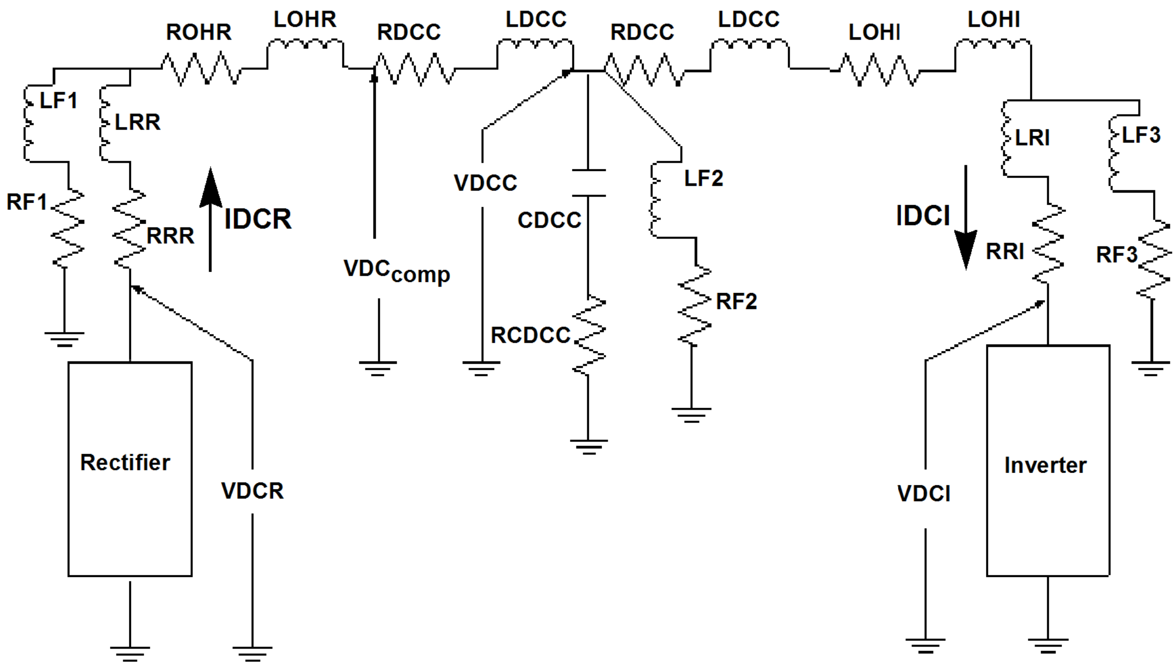


Figure 19.20. A DC Circuit Arrangement Simulated by the CDC7T Model

Although the dc line can be represented by a T-circuit with the lumped Rdc and Ldc parameters, for the sake of flexibility the model uses resistances and inductances of overhead lines on rectifier (ROHR, LOHR) and inverter (ROHI, LOHI) sides, resistance, inductance, and capacitance of the dc cable (RDCC, LDCC, CDCC), and resistance and inductance of smoothing reactors on both sides (RRR, LRR and RRI, LRI).

By changing ICON(M+3) from 1 to 2 the model switches from the mixed overhead-cable dc line to just overhead line. It is not recommended to make this transition by reducing the cable capacitance because of potential numeric problems. Also, if the user wishes to model a pure overhead-line, it is recommended that RDCC & LDCC be set to zero.

The model allows to simulate faults in the dc system. Three fictitious LR-shunts have been added to the model as it is shown in Figure 19.20, "A DC Circuit Arrangement Simulated by the CDC7T Model". During normal operation, parameters of these shunts have been set to very big numbers to have almost zero currents in these shunts. To simulate faults in any of three points of the dc circuit, namely on the terminals of the overhead line from the rectifier side, on the terminals of the overhead line on the inverter side, and in the middle point of the cable, both inductance and resistor of a respective shunt should be reduced. To avoid numerical instability, the ratio of fault inductance to fault resistance (i.e., the L/R ratio) should be kept constant at 0.1.

19.5.3. Controls Algorithm

Analysis of operation of numerous existing available HVDC projects reveals the following 3 major configurations of converter controls.

Control configuration 1:

- Rectifier in dc current control
- Inverter in gamma control

Control configuration 2:

- Rectifier in dc current control
- Inverter in dc voltage control

Control configuration 3:

- Rectifier in dc voltage control
- Inverter in dc current control

The control configuration 1 was used for historically first HVDC projects. The second configuration is typical for modern HVDC transmissions with overhead dc lines or comparatively short cables. For HVDCs with a long cable the control configuration 3 is very likely to be implemented.

Choice of the control configuration depends on many factors, beginning with the value of a short circuit ratio in points of interconnection of HVDC terminals to the system. That is why the CDC7T model has a provision for choosing the control configuration. Accordingly to the selected control configuration, some parameters of controls must be adjusted as it is shown below.

For HVDC lines with a long HVDC cable a special control is needed to monitor the so called compounded dc voltage VDComp of the cable terminal on the rectifier side and keep it not greater than nominal voltage. In the description of converter controls below characteristics of controls are “tied up” to this point.

Converter controls

Controls of both converters can be simulated based on the same structure, which includes 3 controllers, namely

- DC current controller
- DC voltage controller
- Gamma controller.

The basic converter control configuration is shown in Figure 19.21, “Basic Converter Control Configuration”. The outputs of dc current, dc voltage, and gamma controllers are used as inputs for the mode selector, which is a maximum signal selector for the rectifier and minimum signal selector for the inverter. The selected signal is processed by the PI-controller whose output is the alpha angle order (α order).

To avoid steady-state instability in situations when, due to ac voltage fluctuations on both sides, rectifier sits on its minimal alpha limit and the inverter is in gamma control, additional signals proportional to the dc current error are added to the outputs of the dc voltage and gamma controllers. The Current Error Control (CEC), shown in Figure 19.21, “Basic Converter Control Configuration”, is supposed to favorably change the slope of the converter characteristic around the steady-state operating point. The CEC contribution is determined by non-linear gains that are represented by hard-coded look-up tables in the model.

CDC7T model can accept one auxiliary signal input (auxiliary signal index 1). The auxiliary signal has to be in units of MW. The current order (I_{order}) is calculated by dividing the sum of rectifier side power order and any auxiliary signal input by the rectifier side filtered dc voltage.

Values for margins of controlled variables should be set depending on the selected control configuration as shown in Table 19.1, "Rectifier: margins of controlled variables for different control configurations" and Table 19.2, "Inverter: margins of controlled variables for different control configurations".

Table 19.1. Rectifier: margins of controlled variables for different control configurations

	Control configuration 1	Control configuration 2	Control configuration 3
DC current margin	0.0	0.0	-0.1
DC voltage margin	N/A	N/A	0.0
Gamma margin	N/A	N/A	N/A

Table 19.2. Inverter: margins of controlled variables for different control configurations

	Control configuration 1	Control configuration 2	Control configuration 3
DC current margin	0.1	0.1	0.0
DC voltage margin	N/A	0.0	N/A
Gamma margin	0.0	N/A	10 degrees
Gamma order	12 – 18 degrees	N/A	25 – 30 degrees

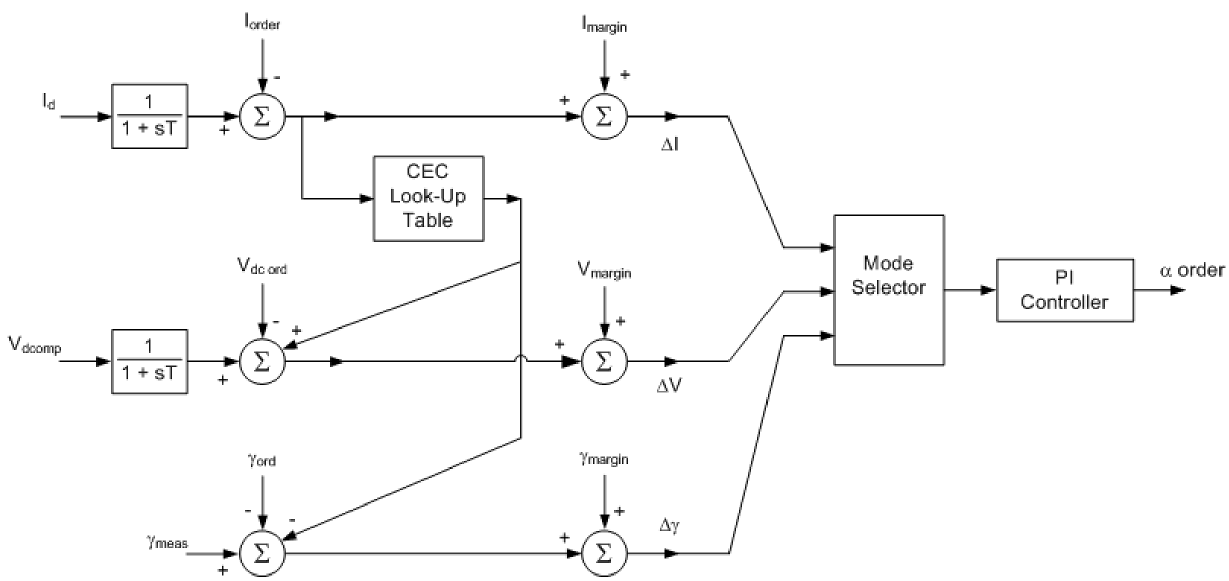


Figure 19.21. Basic Converter Control Configuration

The Voltage Dependent Current Order Limit (VDCOL) algorithm implemented in the CDC7T model is shown in Figure 19.22, "VDCOL Controller for CDC7T". This is based on the generic Vd-Id characteristics of Figure 19.23, "Typical VDCOL Control". The compounded dc voltage (Vdcomp) is processed through a lag block and multiplied by a non-linear gain. The time constant of the former is set to up or down value depending on whether the dc voltage is increasing or decreasing. The non-linear gain (which represents the Vd-Id characteristics) is simulated using lookup tables, one for rectifier and another for inverter, whose 5 pairs of coordinates are provided as last 20 CONs of the model. The output of the VDCOL (which is a current limit) is compared with the current order, and the minimum of the two is used as an input to the dc current controller.

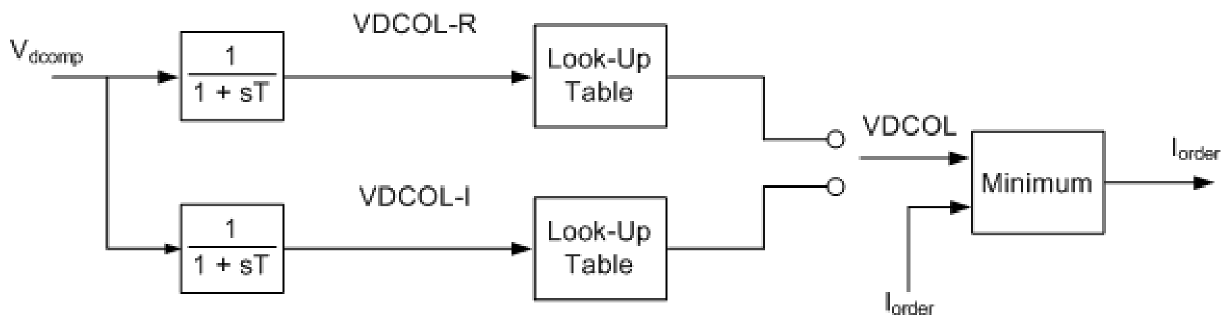


Figure 19.22. VDCOL Controller for CDC7T

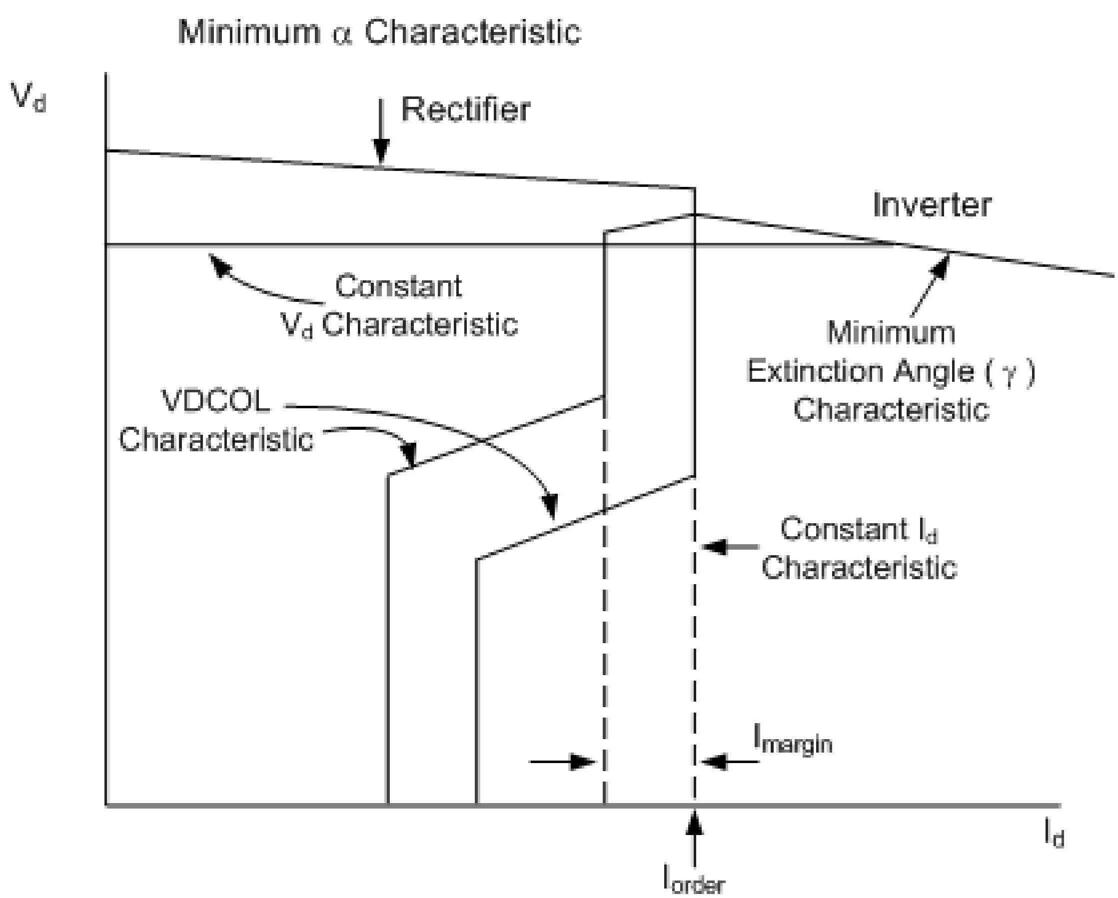


Figure 19.23. Typical VDCOL Control

Figure 19.24, "VDCOL DC Current Order for Rectifier and Inverter" depicts an example of how the current orders of the rectifier and inverter may change with the Vdcomp.

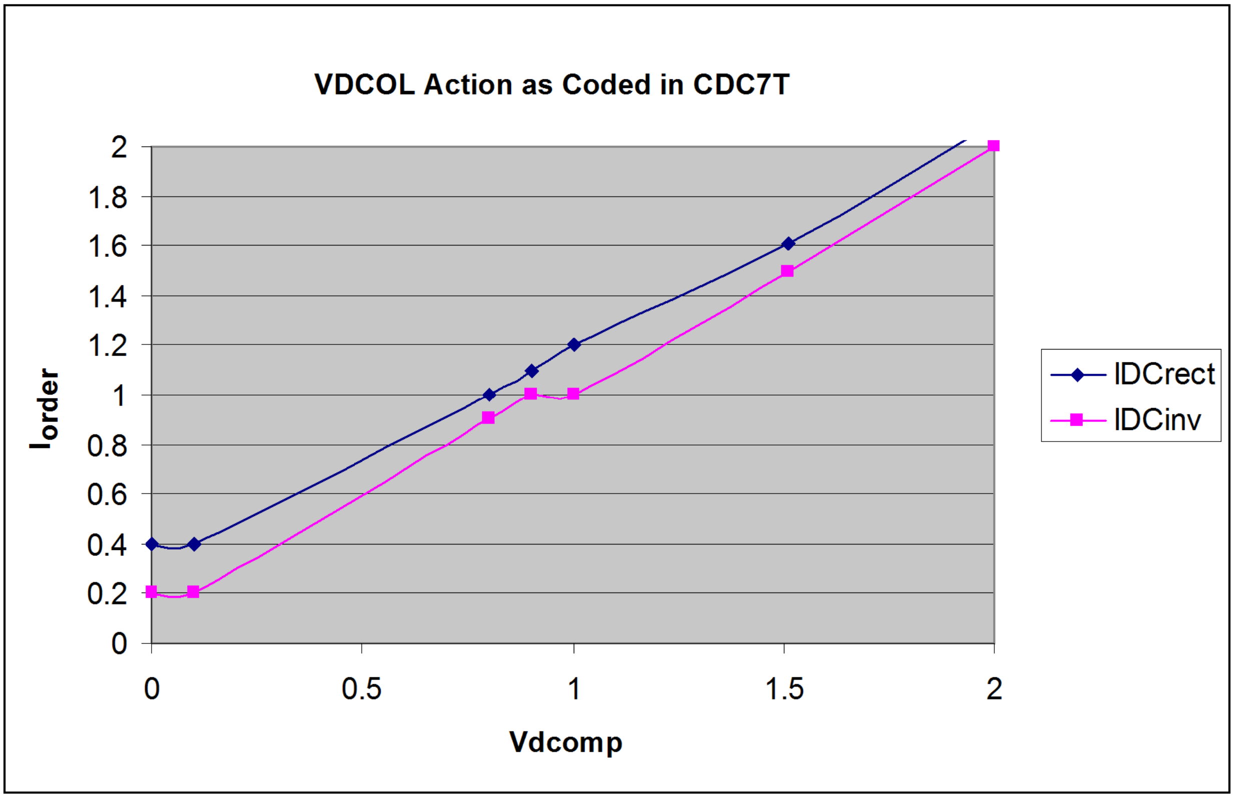


Figure 19.24. VDCOL DC Current Order for Rectifier and Inverter

This dynamic simulation model is initialized from the power flow HVDC model and uses all the pertinent information from the power flow.

The CDC7T model datasheet is in the *PSS ® E Model Library*. The model uses 75 CONs, 17 STATEs, and 26 VARs, many of which can be used for plotting.

The model uses 4 integer variables (ICONs) to control the simulation and select the control configuration option. The first ICON can be used to simulate blocking/unblocking of the HVDC. Normally it is set as zero. At any instant of the simulation setting ICON(M) =1 will start blocking the HVDC. It is simulated by reducing the DC current order at a rate given by CON(J+52). Unblocking can be simulated by setting ICON(M)=2 by increasing the DC current order at a rate given by CON(J+53).

ICON(M+2) is used to select the control configuration by setting its value respectively (1, 2 or 3). Accordingly, with the controllable variable margins and gamma order, these parameters are:

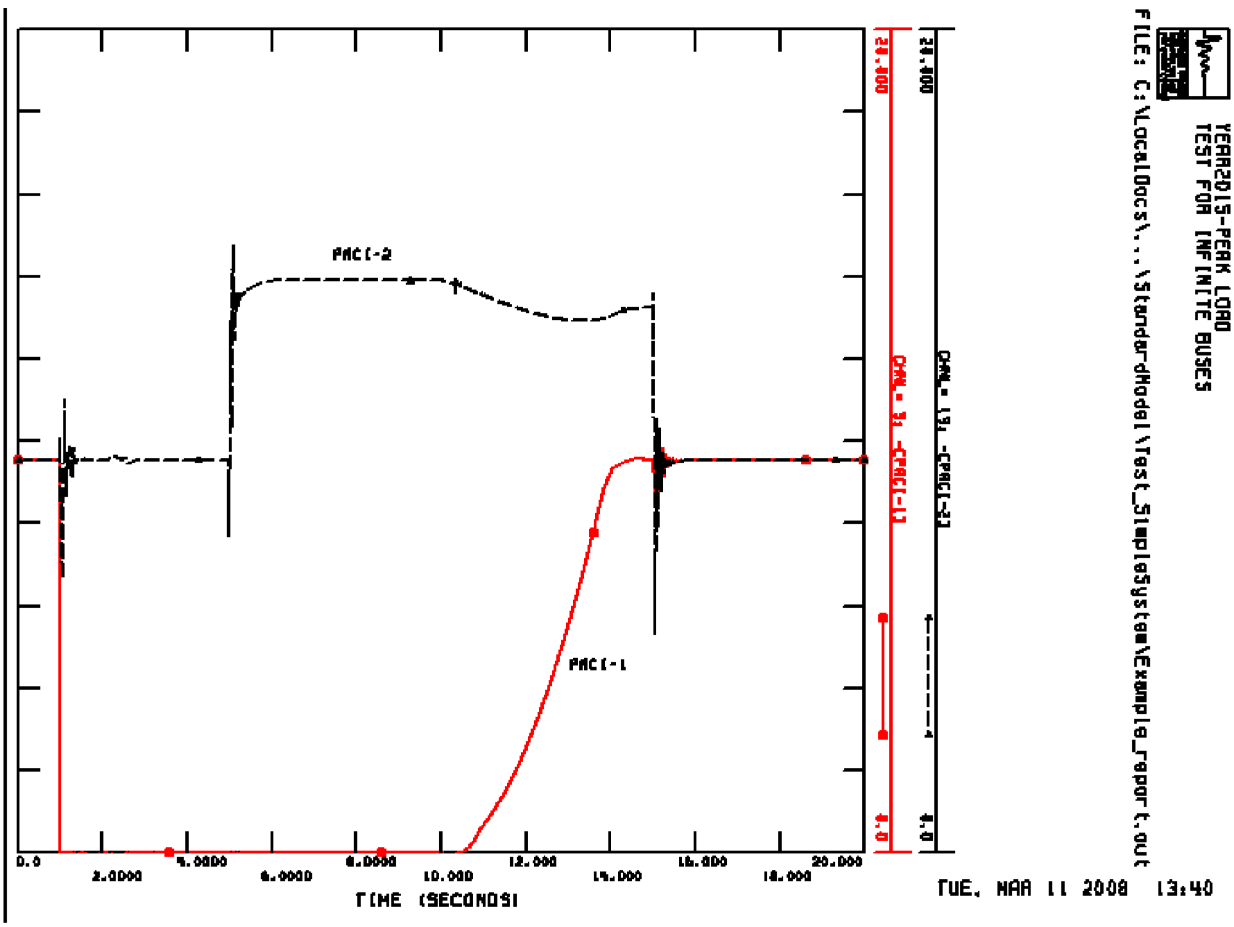
CONs	#	Value	Notation	Description
J+26			IMargR	Current margin, rectifier, pu
J+27			IMargI	Current margin, inverter, pu
J+28			VMargR	Voltage margin, rectifier, pu

CONs	#	Value	Notation	Description
J+29			VMargI	Voltage margin, inverter, pu
J+30			GMargR	Gamma margin, rectifier, pu
J+31			GMargI	Gamma margin, inverter, pu
...				
J+49			GAMA_ORDER1	Control configuration 1
J+50			GAMA_ORDER2	Control configuration 3

must be consistent with the selected control configuration.

By setting ICON(M+1) = 1 and VAR(L+24) (dc power order, p.u.) to any desirable value, it is possible to simulate change in HVDC power including simulation of its overload capability. The model allows obtaining the MW-input from the Auxiliary System model DC2SIG and placing it into VAR(L).

The internal integration is embedded into the model that allows the use of normal integration step for PSS®E simulation.



0sec<T<1sec – unperturbed run

T=1.0 sec – dc line fault on inverter side of the pole 1

T=1.5 sec. – blocking pole 1 with the rate of 2000 A/sec.

T=5 sec. – overloading pole 2 by 50%

T=10 sec. – unblocking pole1 with the rate of 500 A/sec.

T=15 sec. – restore the system

Example of Complex Simulation for a dc Line with the Long Cable

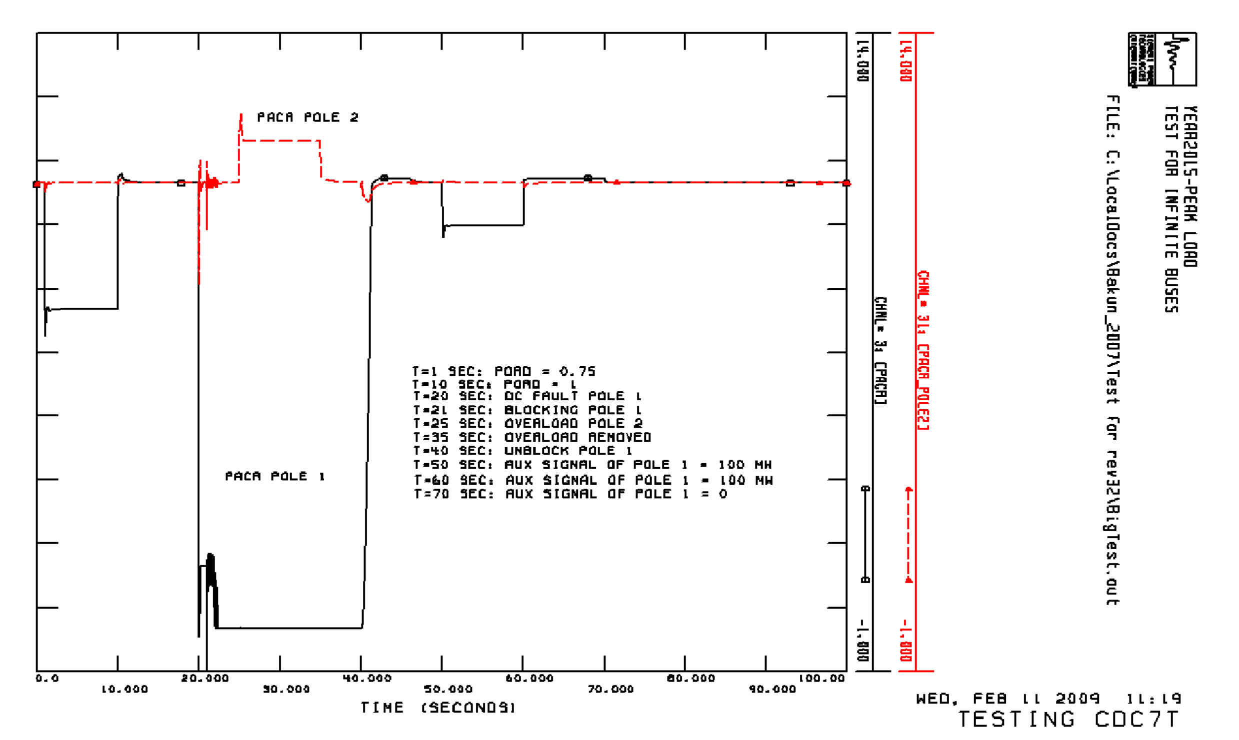


Figure 19.25. Another Example of Complex Simulation for a dc Line with the Long Cable

19.5.4. Parameters of the DC circuit

Several CONs in the beginning of the model datasheet correspond to parameters of the dc circuit and also provide the information about the HVDC rating:

CONs	#	Value	Notation	Description
J+2			LRR	rectifier smoothing reactor inductance, mH

CONs	#	Value	Notation	Description
J+3			RRR	rectifier smoothing reactor resistance, Ohm
J+4			LRI	inverter smoothing reactor inductance, mH
J+5			RRI	inverter smoothing reactor resistance, Ohm
J+6			LOHR	inductance of O/H DC line from rectifier side, mH
J+7			ROHR	resistance of O/H DC line from rectifier side, Ohm
J+8			LOHI	inductance of O/H DC line from inverter side, mH
J+9			ROHI	resistance of O/H DC line from inverter side, Ohm
J+10			LDCC	inductance of DC Cable line, mH
J+11			RDCC	resistance of DC Cable Line, Ohm
J+12			CDCC	DC line capacitance, mkF
J+13			LF1	DC shunt 1 inductance, mH
J+14			RF1	DC shunt 1 resistance, Ohm
J+15			LF2	DC shunt 2 inductance, mH
J+16			RF2	DC shunt 2 resistance, Ohm
J+17			LF3	DC shunt 3 inductance, mH
J+18			RF3	DC shunt 3 resistance, Ohm
J+19			RCDCC	Losses associated with the dc cable capacitance, Ohm
J+20			IDCRated	Rated DC current, A
J+21			VDCRated	Rated DC voltage, kV

The program calculates parameters of the equivalent circuit (Fig. 2.1) as:

- Equivalent resistance and inductance on the rectifier side

```
RDCR = ROHR+RDCC/2.
```

```
LDCR = LOHR+LDCC/2.
```

- Equivalent resistance and inductance on the inverter side

```
RDCI = ROHI+RDCC/2.
```

```
LDCI = LOHI+LDCC/2.
```

19.6. Models PAUX1, PAUX2, SQBAUX, CPAAUX, HVDCAU

It is not practical for the dynamic simulation model library to accommodate every conceivable form of controller that could be used to modulate the power or current setpoint of a dc transmission system. The library does, however, have models of the most common types used and proposed. Any combination and number of these can be connected to a single dc line. (See Section 19.2.3, “Modulating Control” for discussion on how to apply the model’s output to the dc line.) Models CPAAUX, SQBAUX and PAUX1 all give modulation based on deviation of frequency from nominal. PAUX2 modulates based on angle deviation. Model HVDCAU allows modulation based on branch current or power flow, frequency difference between two buses, or voltage or frequency at a single bus. Though initially intended to be used only as a GAMMA modulation signal, appropriate selection of CONs (gain) can allow it to be used to modulate power or current. All the models will print an appropriate message and be ignored if the bus specified by the user is not found. The timing and constants for these models will vary based on the system the models are connected to and the intended use of the modulations.

19.7. Models MTDC01 and MTDC03

19.7.1. General Description

The modeling philosophy of multiterminal models MTDC01 and MTDC03 are similar to that of the PSS®E two-terminal models CDC4 and CDC6. All these models assume that the local converter bridge controls and the associated response of dc current and voltage are rapid in relation to the time scale of PSS®E simulations. Like the power flow modeling of the multiterminal dc, this stability model assumes that the user can limit a certain amount of communication by choice of data. Figure 19.26, "Converter Controls" shows the block diagram of the dc line controls as modeled at all the converters except the voltage-controlling bus. The control mode (MDC) is set in the power flow and should not be changed during a simulation. Blocking of the entire line should be made by setting the appropriate ICON to 1. All the other switches are set automatically by the model. Figure 19.27, "Voltage-Dependent Current Limit for dc Converters" shows the voltage-dependent current limits (VDCL) logic modeled. Depending on the input data specified, the curve will use either measured ac or dc voltage as an input. If V_3 is set to zero, the voltage-dependent current limits are ignored for this converter.

Like the two-terminal models, current following a block is controlled by a ramp based on a user-supplied initial restarting current, RSCURi, and current ramp rate, CRMPi (Figure 19.6, "Examples of dc Voltage and Current Profiles During ac System Disturbances"). Unlike the two-terminal lines, which have several types of logic for blocking, an automatic block occurs in MTDC01 and MTDC03 only when a current reversal occurs or voltage is so bad at a converter that it cannot produce the desired current. No other automatic unblocking is run by this model; it is left to the user to control this function either by blocking manually via a change in the appropriate ICONs with ALTR or by a user-written code in CONEC. Measured ac voltages and measured dc voltages are stored in STATES and are available to the user. An example of a user-written blocking code is shown in Section 19.7.2, "Example".

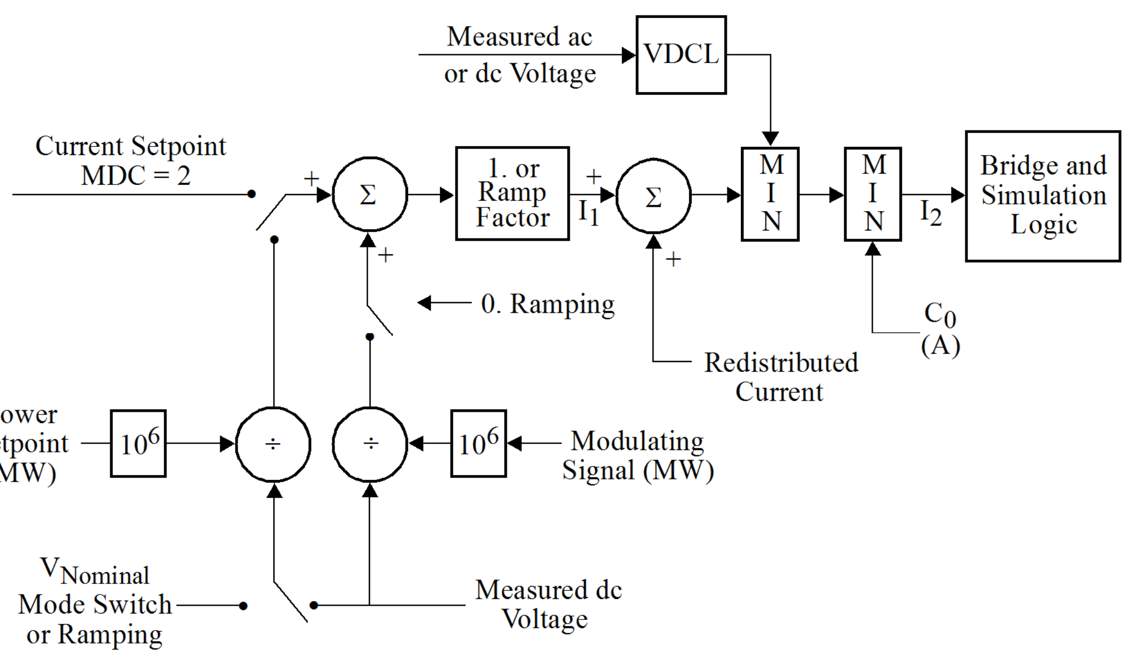


Figure 19.26. Converter Controls

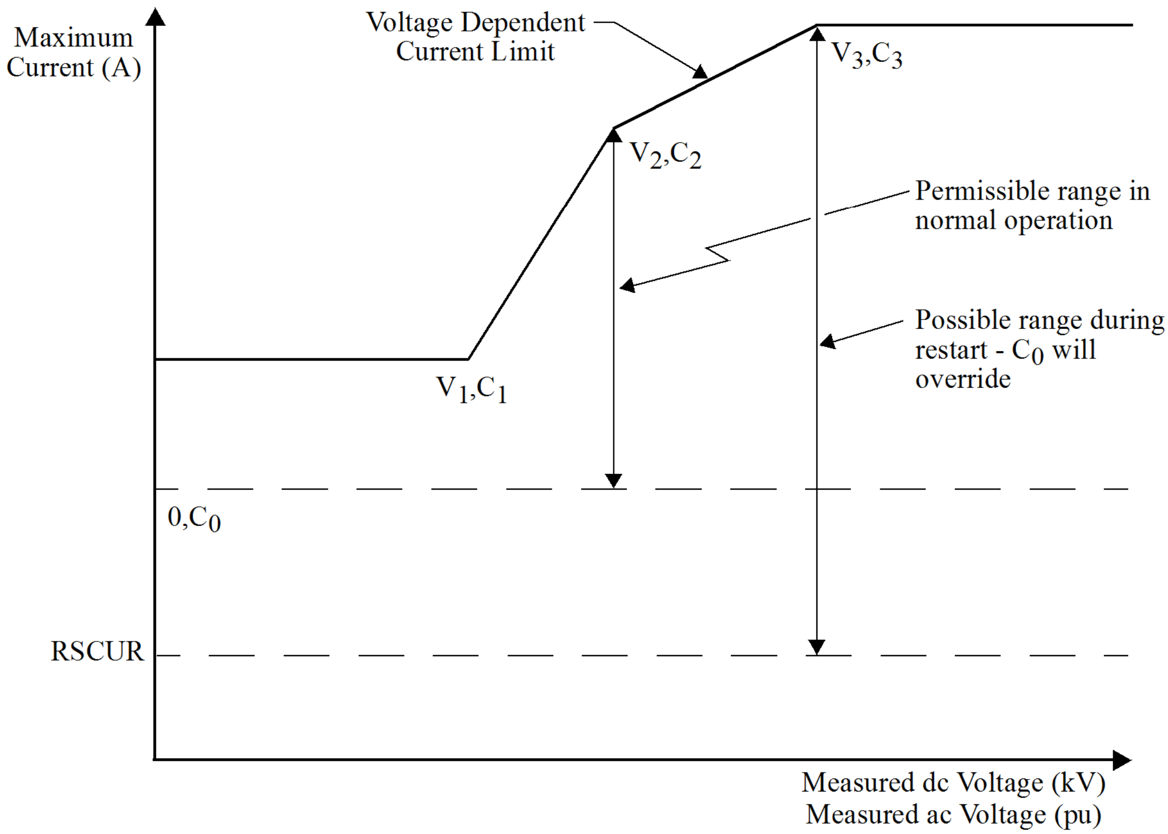


Figure 19.27. Voltage-Dependent Current Limit for dc Converters

Figure 19.26, "Converter Controls" shows a redistributed current value that a central controller would provide. The central controller in this model is assumed to know when a converter is blocked. If a converter is blocked or ramping up, the difference between I_1 (see Figure 19.26, "Converter Controls"), where I_1 must be greater than or equal to C_o, and desired current based on set values is redistributed to all other converters according to the distribution factors (DCPF). The central controller also is assumed to recognize a rectifier not able to make its desired current and will again cause a current redistribution based on distribution factors.

Figure 19.28, "Voltage-Controlling Converter dc Control" shows the control logic simulated for the voltage-controlling bus. Its voltage recovery logic following a block is like the two-terminal model shown in Figure 19.7, "Voltage-Dependent Current Limit for dc Converters". The bridge and simulation logic for this dynamic model is identical to that used in the power flow with two exceptions: Taps are always blocked, and each converter has a minimum angle specified by model's input data. Modulation is assumed to be local. The user may, by writing a code, simulate any master controller modulation. In MTDC01, a modulation signal cannot be used directly by the voltage-controlling converter. However, because it acts, essentially, as a slack bus by applying modulating signals to the other converters, the signal can be applied at this converter. Any of the dc modulating models can be used. As with the two-terminal model, the user will have to edit CONEC to place the VARs in the appropriate locations. The voltage-dependent current limits are ignored at the voltage-controlling bus and this converter is not permitted to block. The IMIN value is checked and warning messages will be printed whenever current goes below this value at the voltage controlling bus.

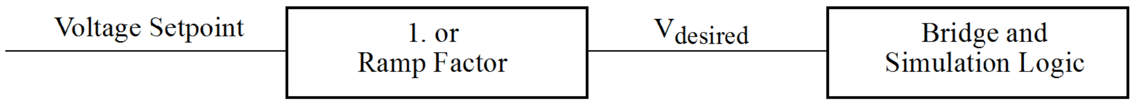


Figure 19.28. Voltage-Controlling Converter dc Control

MTDC01 is restricted to a model of up to 5 converters. This model will not allow representation of negative converters or ground paths.

MTDC03 allows any representation allowed in the power flow. During simulation, if the voltage controlling bus on all rectifiers on a single pole are blocked, all rectifiers on a single pole are blocked and all converters on that pole are blocked. The user must set all the appropriate ICONs on that pole to 2 to start ramping up of all set points. Note that redistribution of currents on this model is done on an individual pole basis. Users will have to modify set points (SETVAL) if they wish power/current to be redistributed to the other poles.

19.7.2. Example

Calls for the MTDC01/TTDC01 model are automatically generated by DYRE and the procedure for setting this model up is similar to that for the 2-terminal model. For the sample system described in Multiterminal DC Networks, Figure 19.29, “Example DOCU for Four-Terminal Line” shows the resulting DOCU. Inspection of the data indicates that all measuring transducers are assumed to be instantaneous, i.e., they were entered as a zero. The user wished to block the entire line, if the measured ac voltage dropped below a certain value at either rectifier, and a block of just the inverter if the ac voltage at the inverter dropped below a particular value. The user noted from the DOCU that STATEs 64 through 78 and ICONs 16 through 22 were being used by the model and filled in the data sheet appropriately (Example Case Data Sheet). The user also noted that the next available CON would be 4392, and double checked that data using RSTR. Figure 19.30, “Example Code for Automatic Blocking” shows the code written to run the blocking and subsequent unblocking. This code was placed in CONEC immediately following the model.

```
         PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      WED JAN 10, 1996  08:06
    ADDITION OF DC LINE TO BASE CASE DEMO LOADFLOW
    FOR PSS®E MANUAL

    REPORT FOR CONEC MODELS                                BUS   200 [HYDRO    500]

                *** CALL MTDC01( 1,  200,   64,   22,   16,   17) ***

         MTDC#   C O N ' S     STATE'S   V A R ' S     ICON'S   V A R ' S
            1    200-  275    64-   78    22-   57    16-   22    17-   21

                                # X-- CONVERTERS --X
                                1   200 HYDRO    500
                                2   201 HYDRO    500
                                3   160 INVJCT  18.0
                                4   161 INVJCT  18.0

         DY1     TVAC1    TVDC1    TIDC1    RSVLT1   RSCUR1    VRMP1    CRMP1
        3.000    0.000    0.000    0.000      0.00    50.00    0.000    3.000

            C0-1     V1-1     C1-1     V2-1     C2-1     V3-1     C3-1
           200.0    350.0    300.0    400.0    500.0    475.0    650.0

         DY2     TVAC2    TVDC2    TIDC2    RSVLT2   RSCUR2    VRMP2    CRMP2
        5.000    0.000    0.000    0.000      0.00    50.00    0.000    3.000

            C0-2     V1-2     C1-2     V2-2     C2-2     V3-2     C3-2
           200.0    350.0    300.0    400.0    500.0    475.0    650.0

         DY3     TVAC3    TVDC3    TIDC3    RSVLT3   RSCUR3    VRMP3    CRMP3
       10.000    0.000    0.000    0.000      0.00    50.00    0.000    3.000

            C0-3     V1-3     C1-3     V2-3     C2-3     V3-3     C3-3
           200.0    350.0    200.0    400.0    500.0    475.0    650.0

         DY4     TVAC4    TVDC4    TIDC4    RSVLT4   RSCUR4    VRMP4    CRMP4
       10.000    0.000    0.000    0.000    100.00     0.00    5.000    0.000

            C0-4     V1-4     C1-4     V2-4     C2-4     V3-4     C3-4
           200.0      0.0      0.0      0.0      0.0      0.0      0.0

         DY5     TVAC5    TVDC5    TIDC5    RSVLT5   RSCUR5    VRMP5    CRMP5
        0.000    0.000    0.000    0.000      0.00     0.00    0.000    0.000

            C0-5     V1-5     C1-5     V2-5     C2-5     V3-5     C3-5
             0.0      0.0      0.0      0.0      0.0      0.0      0.0

                              TCMODE      DCMODE     VCMODE
                             0.00000         2      400.000

       ALF/GAM    MIN     MAX     PAC      QAC   NB   EBASE    RC      XC     TR     TAP
      1   9.39   8.00   10.00   320.9    138.5   4    500.0  0.000 19.000 0.2200 0.0100
      2   9.39   8.00   10.00   320.9    138.5   4    500.0  0.000 19.000 0.2200 0.0100
      3  19.19  18.00   20.00  -300.0    141.4   4    230.0  0.000 10.000 0.4520 0.0100
      4  19.19  18.00   20.00  -300.0    141.4   4    230.0  0.000 10.000 0.4520 0.0100
    REPORT FOR CONET MODELS                                BUS   200 [HYDRO    500]

                *** CALL TTDC01( 1,  200,   64,   22,   16,   17) ***

         MTDC#   C O N ' S     STATE'S   V A R ' S     ICON'S   V A R ' S
            1    200-  275    64-   78    22-   57    16-   22    17-   21

                                # X-- CONVERTERS --X
                                1   200 HYDRO    500
                                2   201 HYDRO    500
                                3   160 INVJCT  18.0
                                4   161 INVJCT  18.0
```

STATEs being used by model

ICONs being used

Figure 19.29. Example DOCU for Four-Terminal Line

MTDC01

Multiterminal dc Line Model

CALL MTDC01 (I,J,K,L,M,LAUX) from CONEC		
CALL TTDC01 (I,J,K,L,M,LAUX) from CONET		
This is multiterminal dc line	#______	I,
using CONs starting with	#______	J,
and STATEs starting with	#______	K,
and VARs starting with	#______	L,
and ICONs starting with	#______	M,
and VARs starting with	#______	LAUX.

CONs	#	Value	Description
J		3.0	DY1, minimum angle converter 1 (degrees)
J+1		0.	TVAC1, ac voltage transducer converter 1 (sec)
J+2		0.	TVDC1, dc voltage transducer converter 1 (sec)
J+3		0.	TIDC1, current transducer converter 1 (sec)
J+4		0.	RSVLT1, minimum dc voltage following block, converter 1[(1)] (kV)
J+5		50.	RSCUR1, minimum dc current following block, converter 1[(2)] (amps)
J+6		0.	VRMP1, voltage recovery rate, converter 1[(1)] (pu/sec)
J+7		3.	CRMP1, current recovery rate, converter 1[(2)] (pu/sec)
J+8		200.	C0-1, minimum current demand converter 1 [(4)] (amps)
J+9		350.	V1-1, voltage limit point 1, converter 1 [(2)] (kV)
J+10		300.	C1-1, current limit point 1, converter 1 [(2)] (amps)
J+11		400.	V2-1, voltage limit point 2, converter 1 [(2)] (kV)
J+12		500	C2-1, current limit point 2, converter 1 [(2)] (amps)
J+13		475	V3-1, voltage limit point 3, converter 1 [(2)] (kV)

CONs	#	Value	Description
J+14		650	C3-1, current limit point 3, converter 1 (2) (amps)
J+15		5.	DY2, minimum angle converter 2 (degrees)
J+16		0.	TVAC2, ac voltage transducer converter 2 (sec)
J+17		0.	TVDC2, dc voltage transducer converter 2 (sec)
J+18		0.	TIDC2, current transducer converter 2 (sec)
J+19		0.	RSVLT2, minimum dc voltage following block, converter 2(1) (kV)
J+20		50.	RSCUR2, minimum dc current following block, converter 2(2) (amps)
J+21		0.	VRMP2, voltage recovery rate, converter 2(1) (pu/sec)
J+22		3.	CRMP2, current recovery rate, converter 2(2) (pu/sec)
J+23		200.	C0-2, minimum current demand converter 2 (4) (amps)
J+24		350.	V1-2, voltage limit point 1, converter 2 (2) (kV)
J+25		300.	C1-2, current limit point 1, converter 2 (2) (amps)
J+26		400.	V2-2, voltage limit point 2, converter 2 (2) (kV)
J+27		500.	C2-2, current limit point 2, converter 2 (2) (amps)
J+28		475.	V3-2, voltage limit point 3, converter 2 (2) (kV)
J+29		650.	C3-2, current limit point 3, converter 2 (2) (amps)
J+30		10.	DY3, minimum angle converter 3 (degrees)
J+31		0.	TVAC3, ac voltage transducer converter 3 (sec)
J+32		0.	TVDC3, dc voltage transducer converter 3 (sec)
J+33		0.	TIDC3, current transducer converter 3 (sec)

CONs	#	Value	Description
J+34		0.	RSVLT3, minimum dc voltage following block, converter 3(1) (kV)
J+35		50.	RSCUR3, minimum dc current following block, converter 3(2) (amps)
J+36		0.	VRMP3, voltage recovery rate, converter 3(1) (pu/sec)
J+37		3.	CRMP3, current recovery rate, converter 3(2) (pu/sec)
J+38		200.	C0-3, minimum current demand converter 3 (4) (amps)
J+39		350.	V1-3, current limit point 1, converter 3 (2) (kV)
J+40		200.	C1-3, current limit point 1, converter 3 (2) (amps)
J+41		400.	V2-3, voltage limit point 2, converter 3 (2) (kV)
J+42		500.	C2-3, current limit point 2, converter 3 (2) (amps)
J+43		475.	V3-3, voltage limit point 3, converter 3 (2) (kV)
J+44		650.	C3-3, current limit point 3, converter 3 (2) (amps)
J+45		10.	DY4, minimum angle converter 4 (degrees)
J+46		0.	TVAC4, ac voltage transducer converter 4 (sec)
J+47		0.	TVDC4, dc voltage transducer converter 4 (sec)
J+48		0.	TIDC4, current transducer converter 4 (sec)
J+49		100.	RSVLT4, minimum dc voltage following block, converter 4(1) (kV)
J+50		0.	RSCUR4, minimum dc current following block, converter 4(2) (amps)
J+51		5.	VRMP4, voltage recovery rate, converter 4(1) (pu/sec)

CONs	#	Value	Description
J+52		0.	CRMP4, current recovery rate, converter 4[(2)] (pu/sec)
J+53		200.	C0-4, minimum current demand converter 4 [(4)] (amps)
J+54		0.	V1-4, voltage limit point 1, converter 4[(2)] (kV)
J+55		0.	C1-4, current limit point 1, converter 4[(2)] (amps)
J+56		0.	V2-4, voltage limit point 2, converter 4[(2)] (kV)
J+57		0.	C2-4, current limit point 2, converter 4[(2)] (amps)
J+58		0.	V3-4, voltage limit point 3, converter 4[(2)] (kV)
J+59		0.	C3-4, current limit point 3, converter 4[(2)] (amps)
J+60		0.	DY5, minimum angle converter 5 (degrees)
J+61		0.	TVAC5, ac voltage transducer converter 5 (sec)
J+62		0.	TVDC5, dc voltage transducer converter 5 (sec)
J+63		0.	TIDC5, current transducer converter 5 (sec)
J+64		0.	RSVLT5, minimum dc voltage following block, converter 5[(1)] (kV)
J+65		0.	RSCUR5, minimum dc current following block, converter 5[(2)] (amps)
J+66		0.	VRMP5, Voltage recovery rate, converter 5[(1)] (pu/sec)
J+67		0.	CRMP5, current recovery rate, converter 5[(2)] (pu/sec)
J+68		0.	C0-5, minimum current demand converter 5 [(4)] (amps)
J+69		0.	V1-5, voltage limit point 1, converter 5 [(2)] (kV)
J+70		0.	C1-5, current limit point 1, converter 5 [(2)] (amps)

CONs	#	Value	Description
J+71		0.	V2-5, voltage limit point 2, converter 5 (2) (kV)
J+72		0.	C2-5, current limit point 2, converter 5 (2) (amps)
J+73		0.	V3-5, voltage limit point 3, converter 5 (2) (kV)
J+74		0.	C3-5, current limit point 3, converter 5 (2) (amps)
J+75		0.	TCMODE (sec)

STATEs	#	Description
K	64	Measured ac voltage, converter 1 [a]
K+1	65	Measured ac voltage, converter 1*
K+2	66	Measured ac voltage, converter 1*
K+3	67	Measured ac voltage, converter 2*
K+4	68	Measured ac voltage, converter 2
K+5	69	Measured ac voltage, converter 2
K+6	70	Measured ac voltage, converter 3 [b]
K+7	71	Measured ac voltage, converter 3
K+8	72	Measured ac voltage, converter 3
K+9	73	Measured ac voltage, converter 4
K+10	74	Measured ac voltage, converter 4
K+11	75	Measured ac voltage, converter 4
K+12	76	Measured ac voltage, converter 5
K+13	77	Measured ac voltage, converter 5
K+14	78	Measured ac voltage, converter 5

[a]Rectifier voltages

[b]Inverter voltage

VARs	#	Description
L		V_{AC} bus converter 1
L+1		P_{AC} bus converter 1
L+2		Q_{AC} bus converter 1
L+3		V_{DC} converter 1
L+4		IDC converter 1
L+5		Angle converter 1
L+6		V_{AC} bus converter 2
L+7		P_{AC} bus converter 2
L+8		Q_{AC} bus converter 2
L+9		V_{DC} converter 2
L+10		IDC converter 2
L+11		Angle converter 2

VARs	#	Description
L+12		V_{AC} bus converter 3
L+13		P_{AC} bus converter 3
L+14		Q_{AC} bus converter 3
L+15		V_{DC} converter 3
L+16		IDC converter 3
L+17		Angle converter 3
L+18		V_{AC} bus converter 4
L+19		P_{AC} bus converter 4
L+20		Q_{AC} bus converter 4
L+21		V_{DC} converter 4
L+22		IDC converter 4
L+23		Angle converter 4
L+24		V_{AC} bus converter 5
L+25		P_{AC} bus converter 5
L+26		Q_{AC} bus converter 5
L+27		V_{DC} converter 5
L+28		IDC converter 5
L+29		Angle converter 5
L+30		Internal VARs required by model
L+31		
L+32		
L+33		
L+34		
L+35		

ICONs	#	Description
M [a]	16	Entire line blocking flag: 0 = Not blocked 1 = Blocked 2 = Unblocking
M+1	17	Converter 1 flag(3): 0 = Normal operation 1 = Blocked 2 = Unblocking
M+2 [b]	18	Converter 2 flag(3)
M+3	19	Converter 3 flag(3)
M+4	20	Converter 4 flag(3)
M+5	21	Converter 5 flag(3)
M+6	22	Mode switch flag: 0 = Normal 1 = Mode switch

[a]ICON to be changed to block entire line.

[b]ICON to be changed to block converter 3 (inverter)

VARs	#	Description
LAUX		Auxiliary signal converter 1(5)
LAUX+1		Auxiliary signal converter 2(5)

VARs	#	Description
LAUX+2		Auxiliary signal converter 3[(5)]
LAUX+3		Auxiliary signal converter 4[(5)]
LAUX+4		Auxiliary signal converter 5[(5)]

Notes:

(1) Used only at voltage controlling converter.

(2) Used at all except voltage controlling converter.

(3) Set to zero if this is voltage controlling converter (i.e., not used).

(4) Used as minimum current allowed even at voltage controlling bus.

(5) At voltage controlling inverter, only used if in gamma control (i.e., ANGMX = ANGMN in power flow).

I, 'MTDC01', DY1, TVAC1, TVDC1, TIDC1, RSVLT1, RSCUR1, VRMP1, CRMP1, C0-1, V1-1, C1-1, V2-1, C2-1, V3-1, C3-1, DY2, TVAC2, TVDC2, TIDC2, RSVLT2, RSCUR2, VRMP2, CRMP2, C0-2, V1-2, C1-2, V2-2, C2-2, V3-2, C3-2, DY3, TVAC3, TVDC3, TIDC3, RSVLT3, RSCUR3, VRMP3, CRMP3, C0-3, V1-3, C1-3, V2-3, C2-3, V3-3, C3-3, DY4, TVAC4, TVDC4, TIDC4, RSVLT4, RSCUR4, VRMP4, CRMP4, C0-4, V1-4, C1-4, V2-4, C2-4, V3-4, C3-4, DY5, TVAC5, TVDC5, TIDC5, RSVLT5, RSCUR5, VRMP5, CRMP5, C0-5, V1-5, C1-5, V2-5, C2-5, V3-5, C3-5, TCMODE/

Example Case Data Sheet

```
      CALL MTDC01(    1,  200,    64,    22,    16,    17)
C
C   BLOCK ENTIRE LINE ON LOW RECTIFIER VOLTAGE                   Only check if blocked
C                                                                  Next available CON
      IF (ICON(16).EQ.0)
      .  IF (STATE(64).LT.CON(4392)  .OR.  STATE(67).LT.CON(4392))
      .  .  ICON(16)=1
      .  .  WRITE(LPDEV,9992)                                     Either voltage blocks
 9992 .  .  FORMAT(' BLOCKED MULTI-TERMINAL BECAUSE OF LOW RECTIFIER ',
     #.  .         'VOLTAGE')
      .  ...FIN
      ...FIN
C
C   UNBLOCK ON VOLTAGE RECOVERY
C
      IF (ICON(16).EQ.1)                                          Only check if blocked
      .  IF (STATE(64).GT.CON(4392)  .AND.  STATE(67).GT.CON(4392))
      .  .  ICON(16)=2
      .  .  WRITE(LPDEV,9993)                                     Both voltages must recover
 9993 .  .  FORMAT(' UNBLOCKED DC LINE - VOLTAGE RECOVERED')      Print message is good idea
      .  ...FIN
      ...FIN
C
C   BLOCK INVERTER ON LOW AC VOLTAGE
C
      IF (ICON(19).EQ.0 .AND. STATE(70).LT.CON(4393))
      .  ICON(19)=1
      .  WRITE(LPDEV,9994)
 9994 .  FORMAT(' BLOCKED INVERTER ON LOW AC VOLTAGE')
      ...FIN
C
C   UNBLOCK INVERTER ON RECOVERY
C
      IF (ICON(19).EQ.1 .AND. STATE(70).GT.CON(4393))
      .  ICON(19)=2
      .  WRITE(LPDEV,9995)
 9995 .  FORMAT(' UNBLOCK INVERTER ON VOLTAGE RECOVERY')
      ...FIN
C
```

Figure 19.30. Example Code for Automatic Blocking

After reloading (linking) PSS®E, the user can then change the CONs to appropriate values via ALTR. For an example run, the CONs were set to 0.8 per unit. Figure 19.31, "Example Case" shows the converter power flows that result from a fault near the inverter. The plots show an initial change when the fault is applied and removed and a one time step delay before blocking and unblocking. The one time-step delay is the result of using measured values. The plots show that immediately following the block, the inverter goes to a value and does not start ramping up, because a RSCUR was specified as a value less than IMIN and the IMIN overrides until the current ramps up to it. This example shows that the user will have to take care in specifying the VDCL, IMIN, and restarting values for all converters to simulate reasonable response. In this example, the DCPFs were all equal so power was redistributed evenly. The user does have the ability to change these values to simulate the central coordinator performance.

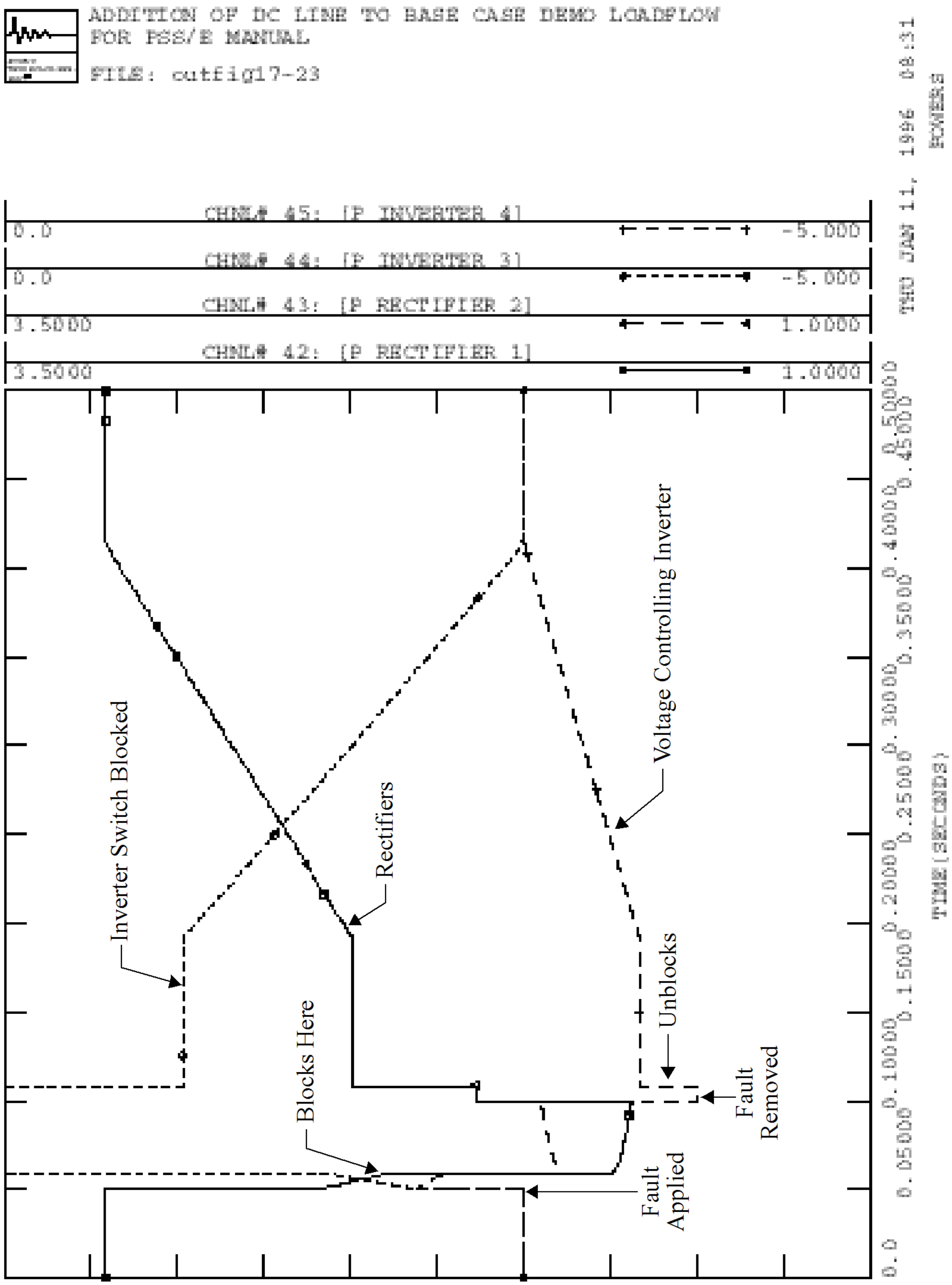


Figure 19.31. Example Case

19.8. Models CASEA1 and CDCRL

These two terminal HVDC models include the *L/R* dynamics of the dc system and high-speed controller dynamics. CDCRL is a generic model and is not intended to specifically represent a particular HVDC system. It provides this level of modeling with a relatively simple controller and may be used to study future HVDC additions or to study installations where only limited information is available on the actual controls. CASEA1 was developed for the Los Angeles Department of Water and Power based upon information provided by ASEA to model the IPP HVDC system. A detailed definition of this model is contained in ASEA report TR-PSC84009. Both of these models must be tuned properly to give meaningful results, and their response may require considerable interpretation. They are therefore not recommended for the inexperienced user. The level of representation provided by these models is only required in very special situations.

19.8.1. Internal Integration Used by Model

These models represent the *L/R* dynamics of the dc line and smoothing reactors as well as the high-frequency firing angle controller dynamics. It is therefore necessary to use time steps in the numerical integrations associated with these processes, which are much shorter than those normally used by PSS®E. Normally in PSS®E, the ac network equations are solved to update the voltages and currents at each integration time step. This process would be very expensive and time consuming if the short time steps associated with the dc process were used. Instead, the dc model uses an internal integration, which takes many short time steps between each ac network solution.

Because the response of the HVDC system depends upon the ac voltage at the rectifier and inverter terminals, and these voltages in turn depend upon the operation of the HVDC system, it is necessary to approximate the ac voltages for times between the ac network solutions. To do this, a two-port Thevenin equivalent of the ac system is used. At each internal integration time step, the ac currents at the invertor and rectifier are calculated as a function of the ac voltages and the dc control and network dynamics. The Thevenin equivalent is then used to calculate new ac voltages for the next time increment. This equivalent is a two–port equivalent, which not only represents the complex self-impedance at the rectifier and invertor, but also represents the complex coupling impedance. At each solution of the ac network, the internal Thevenin voltages are updated.

Two additional refinements are required for this procedure. First, because the ac system is dynamic, the internal Thevenin voltage may be moving with system swings. If this movement is not accounted for, there will be discontinuities at each network solution. The Thevenin complex voltage is therefore changed during the course of the internal integration at a rate that is determined by the discontinuities observed at previous network solutions. The adjustment on the rate of change is subject to a relatively long time constant to prevent numerical problems.

$V_{THEV} = V_{THEV} + (dV_{THEV}) \Delta t$

where:

V_{THEV}

= Complex Thevenin voltage.

dV_{THEV}

= Complex rate of change in Thevenin voltage.

Secondly, the Thevenin impedances may change as a result of faults or outages in the ac network. In most cases, such changes will not be important. However, when a fault is represented at the terminals of the inverter or rectifier, the change would be large enough to affect the solution results. Therefore, data must be entered for the ac network negative- and zero-sequence impedances at the inverter and rectifier and for the impedance of the fault itself. When ICON M+11 is set and indicates a fault of a specified type at the inverter or rectifier the program automatically adjusts the Thevenin impedance to account for this fault. The user must still enter the equivalent fault admittance as a bus shunt in the network. The HVDC model will check the value of the shunt to make sure that it is consistent with the network sequence and fault impedances.

19.8.2. Initializing Thevenin Impedances

A better estimate for Thevenin impedances will result in fewer network iterations and less time to run a simulation. The CASEA1 model requires entering initial values for the Thevenin self- and mutual-impedances of the rectifier and inverter in CONs J+18 through J+23. Equivalent CONs for model CDCRL exist. The model will automatically calculate these values perturbing the current injected at each terminal and observe the change, ΔV, in voltage at both terminals. The complex impedances are of course $\Delta V / \Delta I$.

To activate this calculation, the user initializes the system using activity STRT, sets ICON of M+1 to 1, and runs the simulation for at least eight time steps. The program will print the desired Thevenin impedances. This activity should not be done as part of a normal simulation because the perturbations introduce extraneous disturbances and it should be done for only one HVDC system at a time.

The Thevenin reactance could also be estimated using the power flow as follows:

- Solve the system for the base case condition.
- Convert generators and load.
- Run ORDR, FACT, TYSL.
- Observe the voltage and var output at each converter.
- Change converter transformer tap position at one converter. This will have little effect on the power or var output of the other converter if no control angle limits are encountered.
- Solve using TYSL.
- The Thevenin reactance will be:

$$X_{THEV} = \frac{\Delta V_{MAG}}{\Delta(VAR/V_{MAG})}$$

- Repeat for other converter.

19.8.3. Simulating dc Faults

The CASEA1 and CDCRL models allow the user to simulate a fault on the dc line. The dc fault resistance and the fault location on the dc line must be entered as modeling parameters. If this is done, a dc fault can be applied by setting an appropriate ICON to 1. When the fault is applied, the inverter current will quickly extinguish if its minimum firing angle is set to keep it from operating as a rectifier. The rectifier will continue to supply fault current unless its current setpoint is modified. To do this, set the VAR in which MYDCR is contained to a negative value. After the fault current has extinguished and the deionization period has passed, the HVDC recovery may be indicated by resetting the ICON and VAR to zero.

19.8.4. Simulating ac System Faults at the Converter Terminals

All ac system faults at the converter terminals are simulated by CASEA1 and CDCRL using a procedure similar to that described for the CDCVUP model that follows.

19.9. Model CDCVUP

When either the inverter or rectifier are at control angle limits, this model uses equations similar to those used in the power flow to calculate the power and var requirements of the converters. It is similar in this respect to HVDC dynamic models such as CDC4 and CDC6. The CDCVUP model, however, is also able to represent the dynamics of the temporary condition following a disturbance or during start-up when neither the inverter nor the rectifier are at control angle limits. This model provides a better representation of the current controller response under such conditions. The details of this model are described in "HVDC Models Used in Stability Studies" presented at the 1988 PAS Summer Power Meeting.

Figure 19.32, “Example DOCU for CDCVUP (Sheet 1 of 2)” shows the output from DOCU for this model.

19.9.1. Simulating ac System Faults at the Converter Terminals

When an ac system fault is simulated at one of the converter terminals, the appropriate ICON should be set to tell the model the fault type, i.e., line-to-ground, etc. This allows the model to vary its response based upon the individual phase voltages instead of just basing it on the positive-sequence voltage.

An ac system line-to-ground fault at the inverter using CDCVUP was simulated. Such a fault would probably cause commutation failures, which are modeled by setting the appropriate ICON to 1 and changing the shunt admittance to represent a converter transformer shorted on the dc side. Figure 19.34, “Response to Inverter Fault With Commutation Failures (Sheet 1 of 2)” is a plot of the inverter and rectifier current order and the direct current for this simulation.

19.10. Model DCPOW

Model DCPOW can be used with the CDCVUP and CDCRL two-terminal HVDC models to represent the dynamics of HVDC power controllers. It also represents current margin makeup, which raises both the inverter and rectifier current setpoints to achieve the desired level of current when the inverter assumes current control. This controller is normally much slower than the HVDC pole controls. Typical values for the model parameters follow: TVDCP = 0.1, VDCP-MAX = 1.0, VDCP-MIN = 0.85, and RESET = 4.0. Figure 19.36, "Block Diagram Showing Power Control for dc System (DCPOW)" shows a block diagram for the model.

```
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU JAN 11, 1996  13:41
SAMPLE SYSTEM FOR PSS®E MANUAL
1100KV DC CASE

REPORT FOR CONEC MODELS                                BUS  1403 [WDUM    18.0]

                ***  CALL CDCVUP( 1,     7,  299,    96,    41) ***

             DC#      ICON'S    C O N ' S      STATE'S   V A R ' S
              1      7-   11    299-  339     96-   97    41-   74

X-- RECTIFIER ---X X--- INVERTER ---X MDC RDC RCOMP SETVAL VSCHED VCMODE  DELTI
 1600 MINE     765  1403 WDUM    18.0 1   8.20  0.00 1600.0  554.4    0.0 0.1500

    ALF/GAM    MIN     MAX     PAC     QAC    NB   EBASE    XC     TR      TAP
R:    7.54     5.00   40.00  16.000   4.678   2   500.0   3.880 0.44000 1.02500
I:   18.95    18.00   30.00 -15.370   6.558   2   230.0   3.047 0.96500 0.99375

                      BLFLAG     FLTYP    BYFLAG     BALIM     INVCT
                 ICON(    7)    (    8)   (    9)   (   10)   (   11)
                         0          0          0          0          0

                              DC RATINGS
                           DC(AMPS)   VDC(KV)
                         CON(  299)   (  300)
                            6000.00    500.00

                 RECTIFIER VOLTAGE SENSITIVE CURRENT LIMIT
           C0         C1         V1         C2         V2         V3
  CON(  301)    (  302)    (  303)    (  304)    (  305)    (  306)
         0.150      0.290      0.000      0.290      0.160      0.550
                        TV1      TV2
                   CON(  307)   (  308)
                        0.010     0.010

                  INVERTER VOLTAGE SENSITIVE CURRENT LIMIT
           C0         C1         V1         C2         V2         V3
  CON(  309)    (  310)    (  311)    (  312)    (  313)    (  314)
         0.150      0.290      0.000      0.290      0.160      0.550
                        TV1      TV2
                   CON(  315)   (  316)
                        0.010     0.040

                           FIRING ANGLE CONTROLLER
                   GI        GPR        GPI    MX DA/DT
              CON(  317)  (  318)   (  319)  (  320)
                3600.0      0.5       0.5     6000.00

               RECTIFIER MINIMUMS            INVERTER MINIMUMS
                GAMA         ALFA            GAMA         ALFA
            CON(  321)     (  322)         (  323)      (  324)
              15.0000       6.0000         17.0000     101.0000

                 INVERTER TRANSITION SLOPE    CON(  325)
                            D(DCV)/D(IDC)  =      0.430

                        POSITIVE SEQUENCE IMPEDANCES
    RESISTANCE REACTANCE     RESISTANCE REACTANCE         RESISTANCE REACTANCE
    CON(  326)   (  327)     CON(  328)   (  329)         CON(  330)   (  331)
REC     0.00000    0.00980 INV    0.00240   0.00830 MUTUAL    0.00000    0.00000

                          ZERO SEQUENCE IMPEDANCES
                RESISTANCE   REACTANCE               RESISTANCE    REACTANCE
                CON(  332)    (  333)                CON(  334)    (  335)
   RECTIFIER       0.00001     0.00367   INVERTER       0.00000      0.00827

                         1-PHASE FAULT IMPEDANCES
                RESISTANCE   REACTANCE               RESISTANCE    REACTANCE
                CON(  336)    (  337)                CON(  338)    (  339)
   RECTIFIER       0.00000     0.00706   INVERTER       0.00000      0.00000
```

Figure 19.32. Example DOCU for CDCVUP (Sheet 1 of 2)

```
                     TV1        TV2
                      CON(  85)     (  86)
                          0.010     0.040


                      FIRING ANGLE CONTROLLER

                    GI       GPR      GPI    MX DA/DT
              CON(  87)   (  88)   (  89)   (   90)
                 3600.0     0.5      0.5    6000.0


                                ICON(     5)
 FLAG FOR TYPE OF BRIDGE ANGLE LIMITS =    0

  FOR MINIMUM FIRING ANGLE LIMIT FLAG .GE. 0
  FOR MINIMUM COMMUTATION VOLTAGE FLAG .LT. 0
  FOR MINIMUM MARGIN ANGLE LIMIT ABS(FLAG) .NE. 1
  FOR MINIMUM MARGIN AREA LIMIT  ABS(FLAG) .EQ. 1

               MINIMUM ALPHA
             RECTIFIER   INVERTER
              CON(  92)    (  94)
               6.0000    101.0000

               MINIMUM GAMA
             RECTIFIER INVERTER
              CON(  91)    (  93)
              15.0000     17.0000


        INVERTER TRANSITION SLOPE   CON(   95)
                   D(DCV)/D(IDC) =     0.430


              POSITIVE SEQUENCE IMPEDANCES

                        RESISTANCE     REACTANCE
                        CON(  96)      (  97)
           RECTIFIER    0.0000E+00    0.9800E-02

                        CON(  98)      (  99)
           INVERTER     0.2400E-02    0.8300E-02

                        CON( 100)      ( 101)
           MUTUAL       0.0000E+00    0.0000E+00


                ZERO SEQUENCE IMPEDANCES
                        RESISTANCE REACTANCE
                        CON( 102)      ( 103)
           RECTIFIER    0.1000E-04    0.3670E-02

                        CON( 104)      ( 105)
           INVERTER     0.0000E+00    0.8270E-02

                      FAULT IMPEDANCES
                                RESISTANCE     REACTANCE
                                CON( 106)      ( 107)
   1-PHASE RECTIFIER FAULT      0.0000E+00    0.7060E-02

                                CON( 108)  ( 109)
   1-PHASE INVERTER FAULT       0.0000E+00    0.0000E+00


                            ICON(     3)
 FLAG FOR FAULT LOCATION =     0

  FOR DC LINE-TO-GROUND FAULT FLAG .EQ. 1
  FOR 1-PHASE RECTIFIER FAULT FLAG .EQ. 2
  FOR 1-PHASE INVERTER FAULT  FLAG .EQ. 3

  ICON(   6) EQUAL TO 1 INDICATES THAT THE INVERTER VOLTAGECONTROL IS ACTIVE
```

Figure 19.33. Example DOCU for CDCVUP (Sheet 2 of 2)

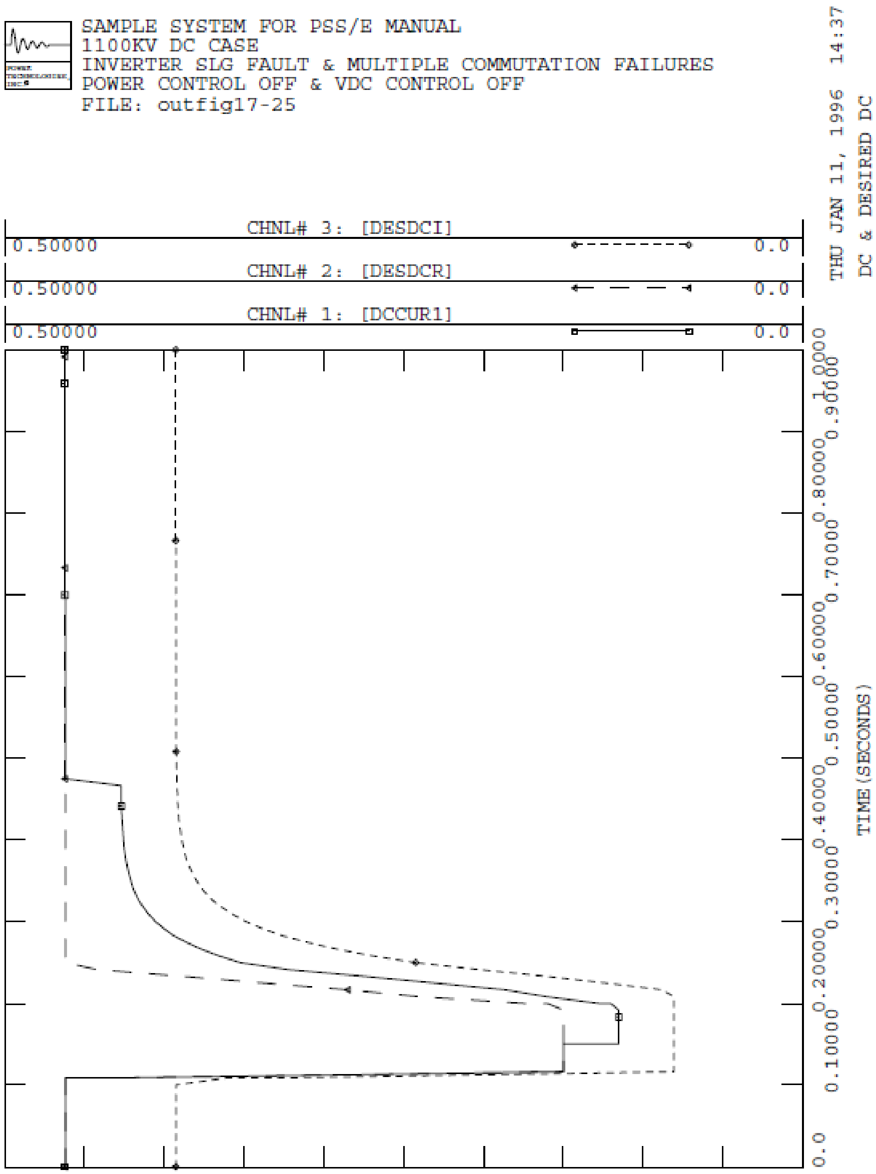


Figure 19.34. Response to Inverter Fault With Commutation Failures (Sheet 1 of 2)

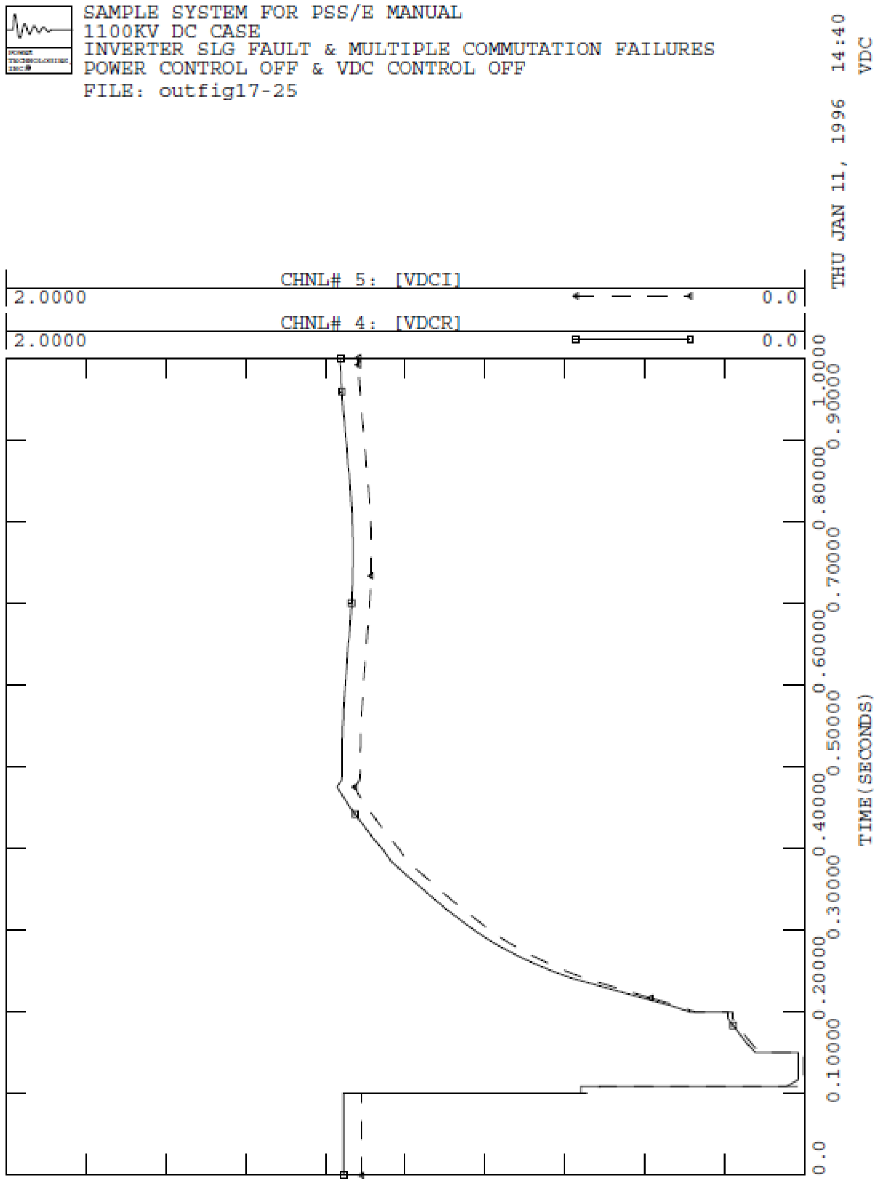
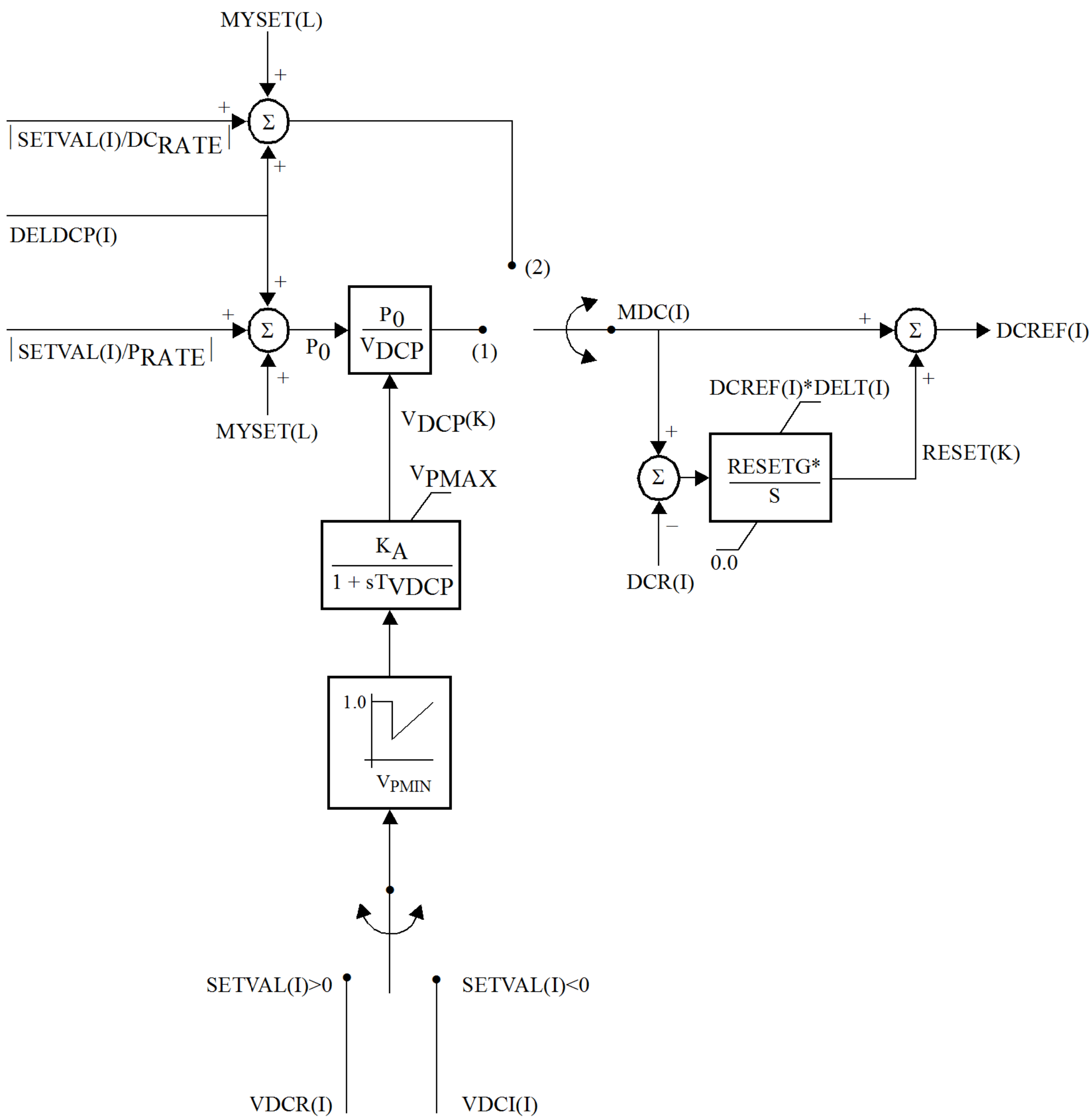


Figure 19.35. Response to Inverter Fault With Commutation Failures (Sheet 2 of 2)



*Integrator reset to zero if bypassed, blocked, or on VDCL.

Figure 19.36. Block Diagram Showing Power Control for dc System (DCPOW)

19.11. Model CDCAB1

Model CDCAB1 was developed by the Technical University of Denmark in cooperation with NESA A/S and ABB Power Systems, sponsored by the Academy of Technical Sciences of Denmark. A detailed technical write-up is available from the Technical University of Denmark, Publication No. 9703. The following is excerpted from this report.

CDAB1 is considered to be a general detailed monopole dc line model though it is based on a vendor-specific design (ABB). The model includes the converters, converter transformers, dc line, and the HVDC control system. In addition to the general features, specific control functions pertinent to the Kontek HVDC interconnection are included (i.e., power modulation, frequency modulation, and emergency power control). The model also includes an inverter voltage controller for long dc cables as well as several dynamics and/or transient control functions. CDCAB1 features a system independent integration time step, which allows important details of the dc control system to be included without severe consequences to overall simulation time.

The model including the converter representation, the basic control features, and the extra control functions are described in the following sections. A block diagram illustrating the components of the HVDC system is shown in Figure 19.37, "Diagram of the HVDC System with Connections to the ac Systems".

19.11.1. Master Controller

The HVDC system can be either in power control or in current control. When the HVDC system is in current control, the current order is limited by a maximum limit IOMAX_MASTER before being sent to the VDCOL. The modulation signals are ignored when the control system is in current control.

The block diagram for the master controller is shown in Figure 19.38, "Master Controller in Power Control" for the HVDC link in power control. The current order is found by dividing the ordered power by a filtered value of the absolute value UDC_ORDER of the measured dc voltage.

In power control, the master controller sets the total power order, which consists of the actual ordered value, and the modulation signals from the frequency controller, the damping controller, and the emergency power controller (EPC). The current order corresponding to the power order is calculated in the lead station. The calculation of the current order is based on a local dc voltage measurement and is delivered to the rectifier and the inverter VDCOLs.

Models of frequency control, damping control, and emergency power control are described in the following sections. When the link is in power control, the modulation signals are added to the power order. In current control, they are ignored. When the emergency power control is operating, the other modulation signals are suspended.

A local frequency less than the nominal frequency (f_{nom}) of the connected ac network results in a reduction of the power for rectifier operation and an increase of power for inverter operation, and conversely if the frequency in the converter station is greater than the nominal frequency.

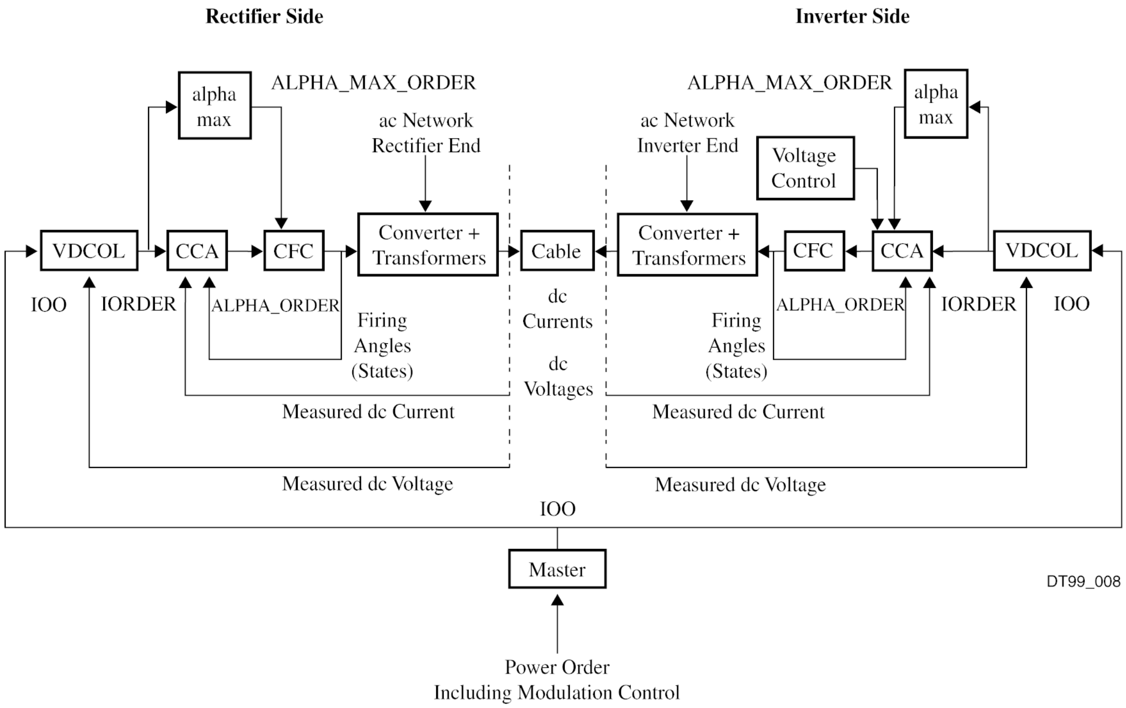


Figure 19.37. Diagram of the HVDC System with Connections to the ac Systems

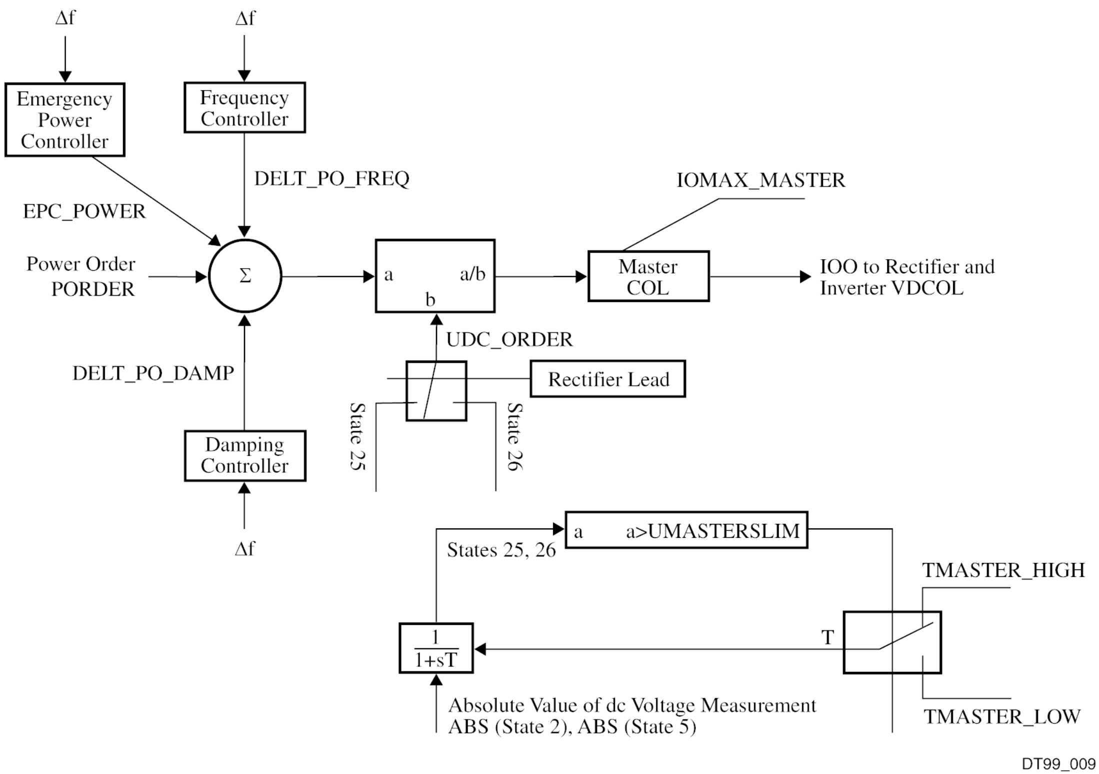


Figure 19.38. Master Controller in Power Control

19.11.2. Frequency Control

A model of the frequency controller used in the Kontek control system is shown in Figure 19.39, "Frequency Controller". This frequency controller is of the proportional type, meaning that a stationary frequency deviation follows from a change in load. The droop of this frequency controller corresponds to the proportional gain K_FREQ_(R,I).

The variables DELT_PO_FREQ_(R,I) are always added to the power order signal according to Figure 19.38, "Master Controller in Power Control". Because the frequency control does not contribute to the modulation signal when the emergency power controller (EPC) is operating, the value of DELT_PO_FREQ(R,I) in Figure 19.38, "Master Controller in Power Control" is equal to the output from the frequency controller when the EPC is not operating, and 0 when the EPC is operating. In this way, the output from the frequency controller (state 19 and 20) always corresponds to the actual frequency deviation.

19.11.3. Damping Control

A model of the damping controller for the Kontek interconnection is shown in Figure 19.40, "Converted Block Diagram for the Damping Controller", where T2DAMP > T1DAMP.

When the output from the damping controller is at the upper or lower limit, the values of the internal variables, named state 21, 22, 23, and 24 in Figure 19.40, "Converted Block Diagram for the Damping Controller", are kept unchanged to avoid an uncontrollable increase of these states.

The variables DELT_PO_DAMP_(R,I) are always added to the power order in the master controller in Figure 19.38, "Master Controller in Power Control". As for the frequency controller, the damping control signal is added to the power order only if the emergency power controller is not active. In this case, DELT_PO_DAMP(R,I) are set equal to the values from the damping controllers and when the EPC is operating the DELT_PO_DAMP_(R,I) values are 0.

19.11.4. Emergency Power Control

The activation of the emergency power controller (EPC) for the Kontek Interconnection immediately suspends other power modulation signals. When the HVDC link is in current control, the EPC and other modulation signals are ignored.

The EPC of the Kontek control system is activated by different criteria. Some are invoked when the frequency deviation has exceeded certain values for a specified time, some when the ac voltage of the converter bus is less/greater than specified values for a specified time, and finally some are activated by external signals.

Depending on the priority of the activated criteria (entries) the power order is ramped up/down with a specified rate. As soon as an entry of a higher priority is activated, the current entry is temporarily stopped on its current value until the entry with the higher priority has increased/decreased the power order with the specified value. In this way, the active entry of the highest priority determines the rate of change of the power order.

A model of the EPC with power steps activated by a specified frequency deviation for a specified time is used.

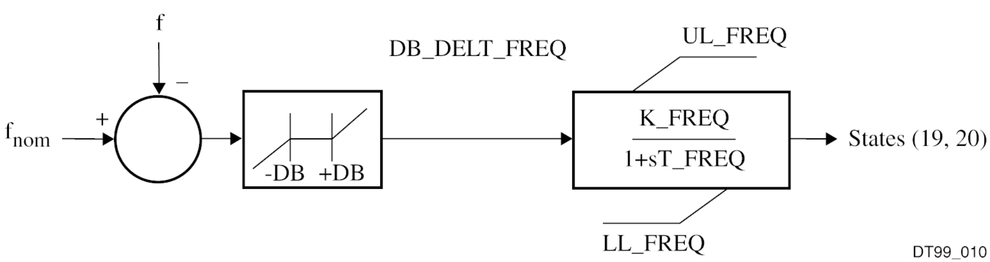


Figure 19.39. Frequency Controller

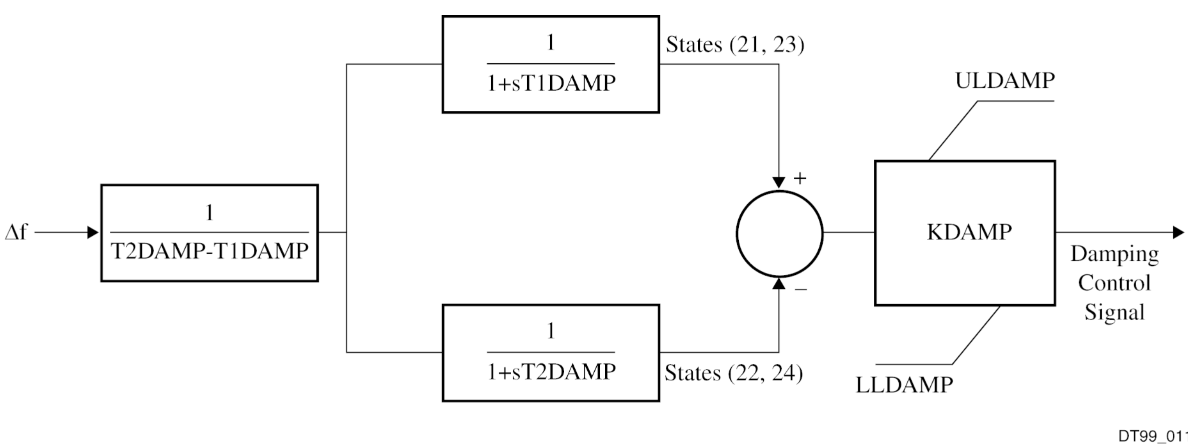


Figure 19.40. Converted Block Diagram for the Damping Controller

19.11.5. Voltage Dependent Current Order Limiter (VDCOL)

A block diagram of the VDCOL is shown in Figure 19.41, "Voltage Dependent Current Order Limiter". The VDCOL restricts the current order when the dc voltage is low, according to Figure 19.42, "VDCOL Characteristic (Current Order as a Function of the dc Voltage)". Note that the maximum current order IOMAX also depends on the actual current order IOO from the master controller in this specific VDCOL.

In situations where the ac voltage falls (e.g., because of an ac fault), the dc voltage also falls due to the slow reaction of the tap changers. In power control, the dc current order without the VDCOL would increase, and this would result in a larger reactive power consumption from the ac network, which would reduce the ac voltage furthermore. In these situations, the VDCOL limits the dc current increase and prevents a voltage collapse in the ac system. Also in situation where the bypass pair is fired, the VDCOL reduces the current so the thyristors in the bypass pair are not overloaded.

The measured dc voltage is used in the VDCOL. A decreasing dc voltage results in a faster reduction of the maximum limit for the current order from the VDCOL than the increasing of the current order for an increasing dc voltage. The time constant T_UP is therefore greater than T_DOWN. This results in a quick reaction during an ac fault and gives, on the other hand, the ac system time to recover form a fault. The time constant is initially set to T_DOWN.

19.11.6. Current Control Amplifier (CCA)

The CCA converts the current order from the VDCOL to an alpha order value. The difference between the current order and the measured dc current (and the current margin CURMARG for the inverter) defines the current error I_ERROR that is fed into a PI controller giving the alpha order.

The CCA takes care of the rectifier current control, the inverter voltage control, and the inverter current control according to the static U_d/I_d characteristic as shown in Figure 19.43, "U_d/I_d Characteristic for the dc Model without the VDCOL". The CCA always tries to increase the alpha order if the measured dc current is greater than the current order (minus the margin for the inverter) and the other way around if it is less.

In normal operation, the rectifier controls the current because the current order given to the rectifier is greater (by the margin) than the current order to the inverter. This means that the inverter normally controls the dc voltage. Hence, the inverter alpha order will always be in the upper limit determined by the alpha-max segment. If the dc voltage in the rectifier cannot be sufficiently increased (either by decreasing alpha or changing the tap changers of the converter transformer) the inverter will take over control of the current and alpha order for the rectifier will be the lower limit, because the current order is higher than the actual dc current. This phenomenon is known as mode shift. In this situation, the rectifier is, in a sense, voltage controlling because the dc voltage is determined by the ac voltage and the minimum alpha.

The CCA is basically a PI controller. The integral part of the CCA is of the nonwindup type; meaning, that the output from the integrator is kept on its upper or lower limit in case one of these limits are reached. The proportional part of the controller is formed by a linearization around the steady-state operating point because small changes in the firing angle mainly come from the proportional part.

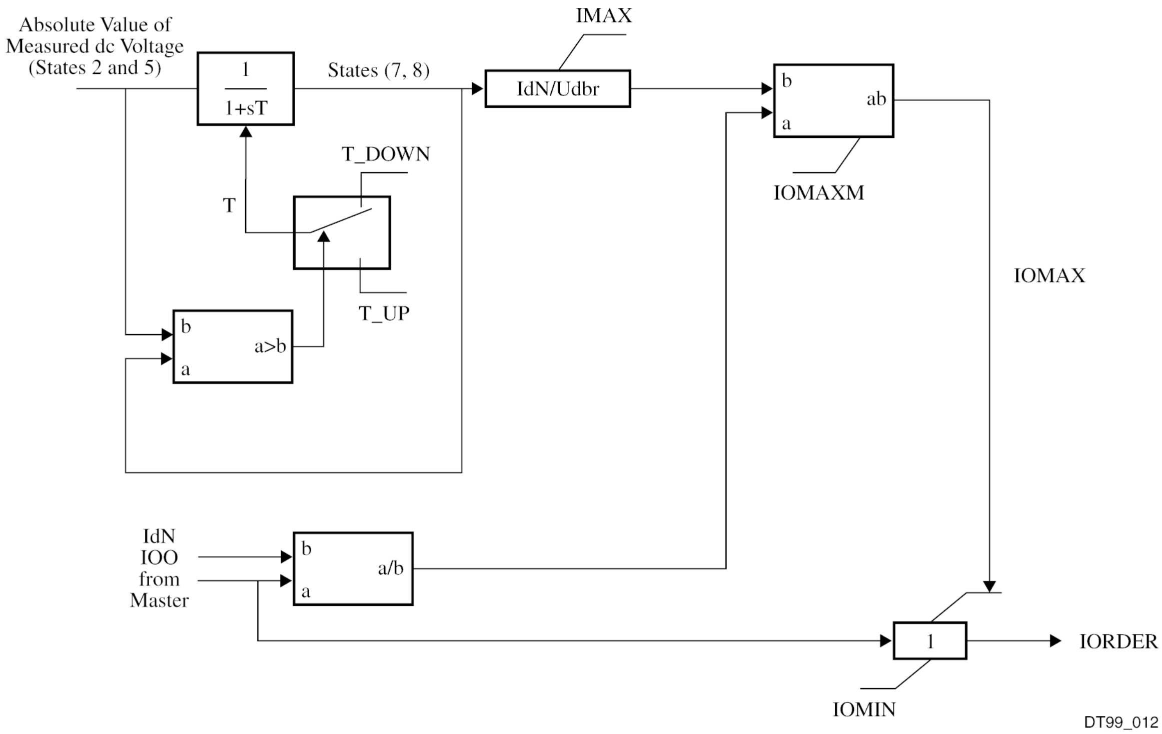


Figure 19.41. Voltage Dependent Current Order Limiter

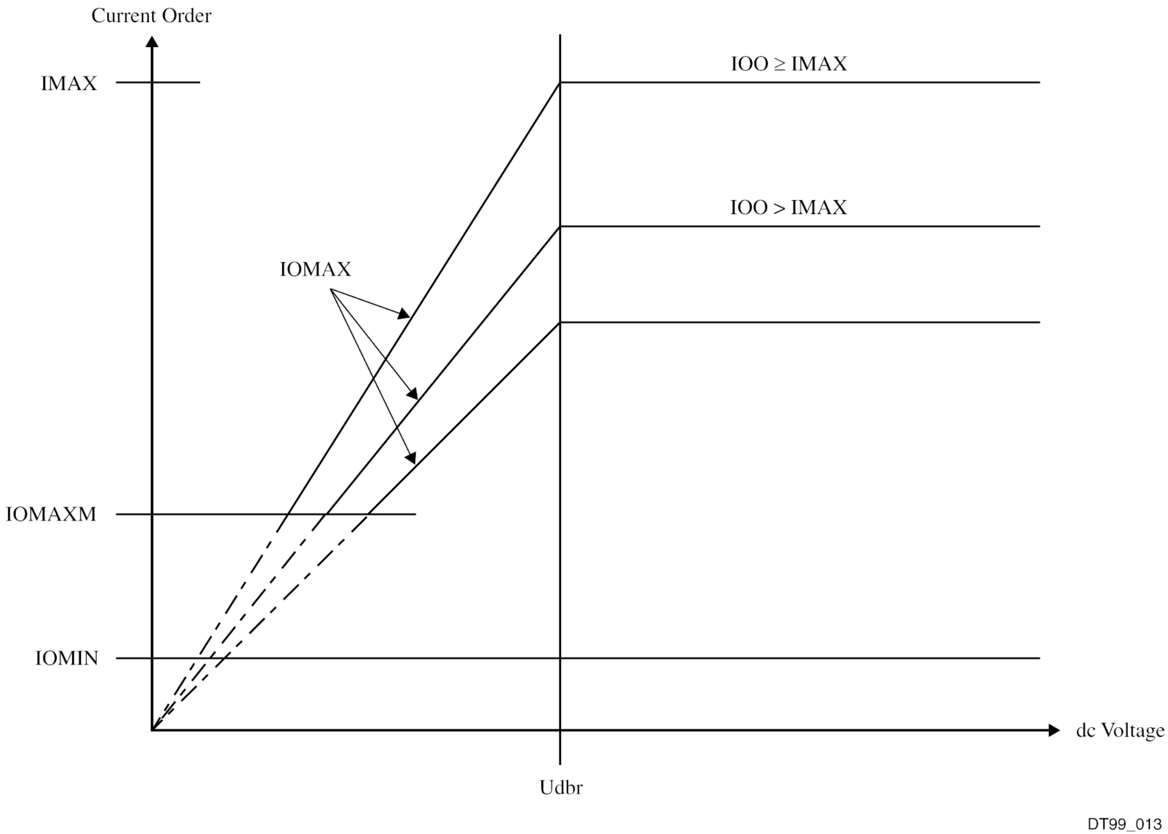


Figure 19.42. VDCOL Characteristic (Current Order as a Function of the dc Voltage)

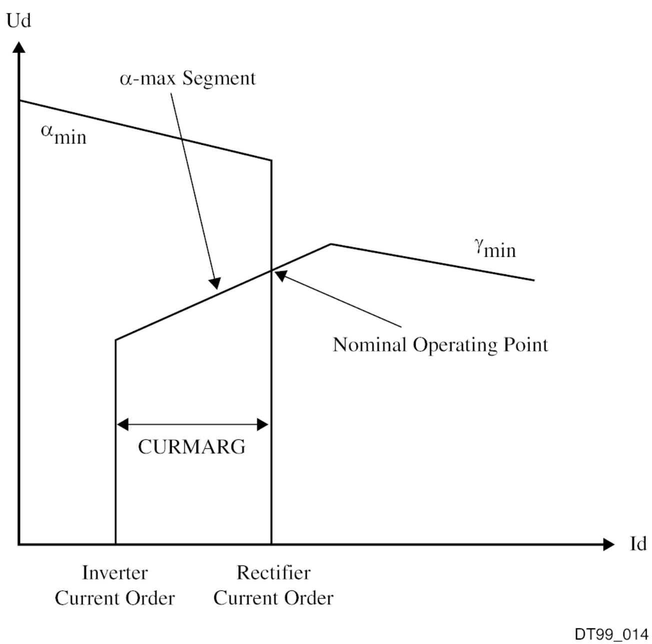


Figure 19.43. U_d/I_d Characteristic for the dc Model without the VDCOL

In steady state, there is no contribution to alpha order from the proportional part for the rectifier because the current error is zero. The contribution for the inverter proportional part of the CCA is on the contrary nonzero because the actual dc current in steady state is greater than the current order from the inverter VDCOL minus the current margin. However, because the D current in the inverter is too large compared to the ordered value, the integral part of the alpha order will be in the upper limit determined by the alpha-max segment.

From Figure 19.44, "Current Control Amplifier", the input to the CCA is supplied with an optional input. This input item is used when the *Inverter Gamma 0 Start* function for the inverter is active. This function is described later.

19.11.7. Alpha-Max Segment

Figure 19.45, "$\#_{max}$ Segment" shows the block diagram of the α -max segment. This model is almost identical with what is done in the real control system of Kontek. The alpha-max segment is the section of the inverter characteristic with the positive slope as seen from the U_d/I_d characteristic shown in Figure 19.43, "U_d/I_d Characteristic for the dc Model without the VDCOL". The nominal operating point is lying somewhere on this segment, which is composed of two parts. The first part keeps the firing angle α constant and is obtained from the fundamental converter equations, which give:

$$\cos\alpha = \frac{\sqrt{2} I_{dc} X_c}{E_{ac}} - \cos\gamma$$

To represent the U_d/I_d characteristic as shown in Figure 19.43, "U_d/I_d Characteristic for the dc Model without the VDCOL", the current inserted in the above equation is a filtered value of the current order and the ac voltage is a measured voltage that is multiplied with the actual transformer ratio (TR in the figure).

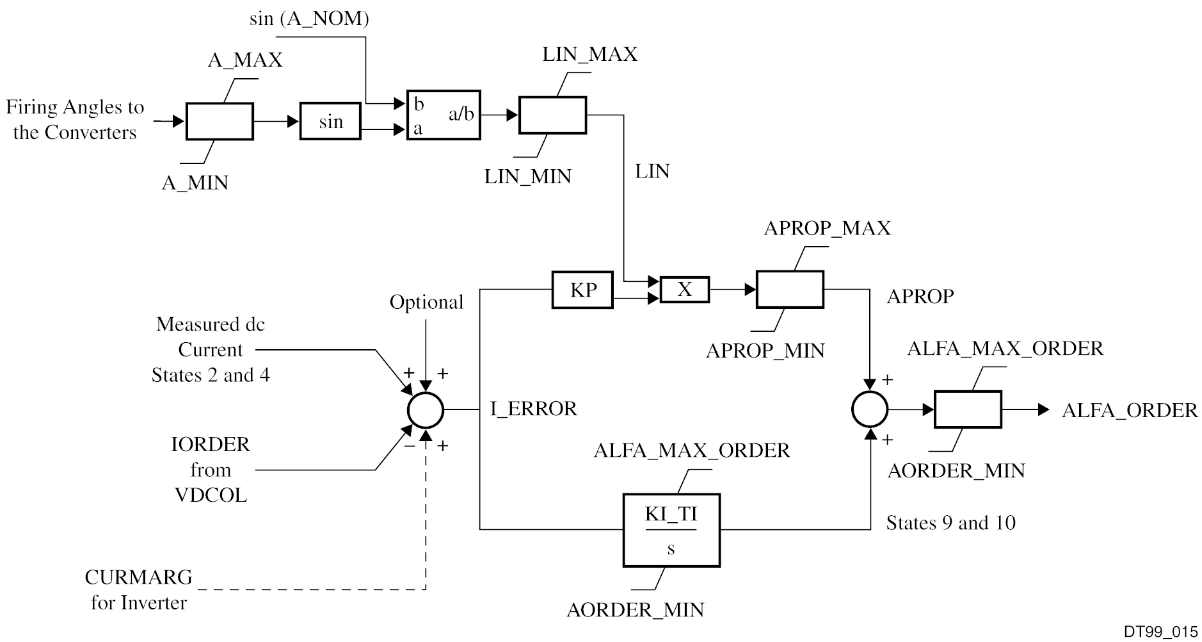


Figure 19.44. Current Control Amplifier

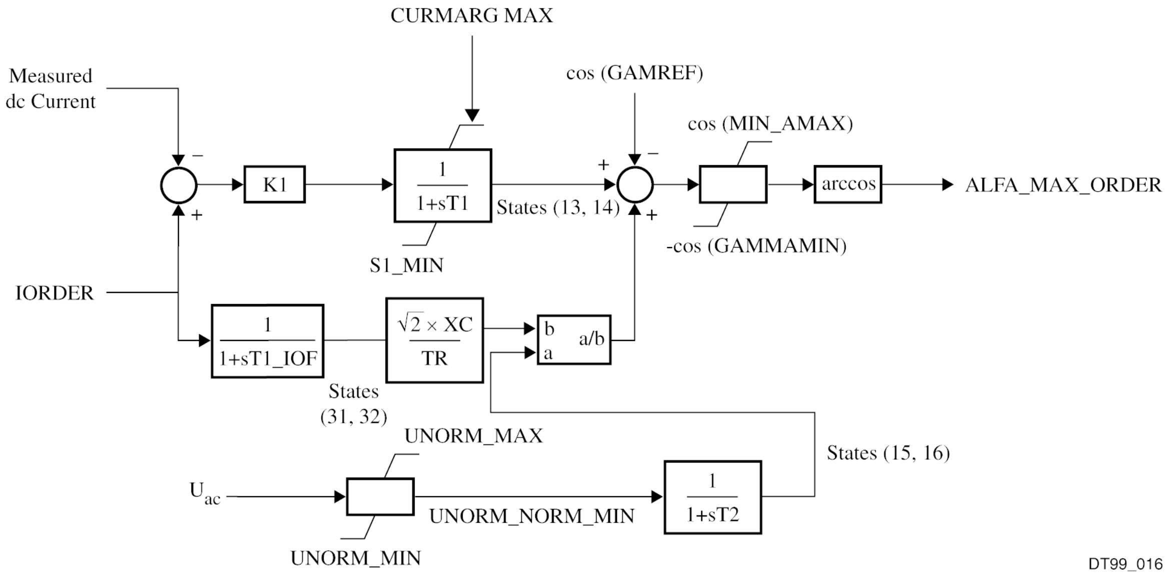


Figure 19.45. $\#_{max}$ Segment

In the model, the γ value (named GAMREF in Figure 19.45, “$\#_{max}$ Segment”) is obtained from the power flow solution. Its value is kept constant during the dynamic simulation. In the real control system, the value of γ inserted is the nominal value. The second part contributes to an additional increase in the positive slope and is proportional to the difference between the current order and the measured dc current (K1 in Figure 19.45, “$\#_{max}$ Segment”).

The upper limit for the output from this controller ALPHA_MAX_ORDER_(R,I) is (180^{o} -GAMMAMIN_(R,I), where GAMMAMIN_(R,I) is the minimum value of inverter gamma for the HVDC link in nominal operation. ALPHA_MAX_ORDER_(R,I) is limited downward by a constant value named MIN_AMAX_(R,I). The output from the alpha-max segment is used as an upper limit for the firing angle in the CCA.

19.11.8. Converger Firing Control (CFC)

The block diagram for the CFC including dynamic current compound and phase shift correction is shown in Figure 19.46, “CFC with Dynamic Current Compound and Phase Shift Correction”. The CFC model is responsible for sending the firing pulses to the valves. The model of the CFC determines the value of alpha put into the converter equations. The firing of the valves are assumed to be equidistant.

The variable DELTA_LIM in Figure 19.46, “CFC with Dynamic Current Compound and Phase Shift Correction” represents the change in firing angle per commutation. Limits on the change in alpha per commutation are imposed and are determined from Figure 19.47, “Limits on the Change in α per Commutation”. Some special considerations for the inverter must be made because it is operated close to the minimum gamma limit in order to reduce the reactive power consumed. After the conduction period, the carriers must be cleared out of the thyristor junctions to make the thyristors capable of withstanding the forward blocking voltage. Therefore, the valves must be biased by a specific negative voltage-time area to be able to commutate properly and in this way correct commutation depends on the remaining voltage-time area of the commutation voltage from the end of the overlap (at time $\pi / \omega - t_u$) and until the voltage becomes positive (at time π / ω). The commutation voltage is proportional to $U_{dio}\sin(\omega t)$ so the voltage-time area A(V-t) is proportional to:

$$A(V - t) \propto \int_{\frac{\pi}{\omega} - t_u}^{\frac{\pi}{\omega}} U_{dio} \sin\omega t dt = \frac{U_{dio}}{\omega}(1 - \cos\omega t_u)$$

The nominal commutation margin γ_{nom} at nominal voltage and frequency holds a margin ($\Delta\gamma$) to the minimum allowed commutation margin. For a given voltage and frequency, the minimum commutation margin γ_{min} is found from the minimum voltage-time area that is equal to the voltage-time area at $\gamma_{nom} - \Delta\gamma$ at nominal voltage and frequency. Because $\omega\, t_u$ expresses the commutation margin, the above equation can be used to find a reasonable value for γ_{min} for the CFC. This gives:

$$\frac{U_{dio}}{\omega}(1 - \cos\gamma_{min}) = \frac{U_{dioN}}{\omega_{nom}}(1 - \cos(\gamma_{nom} - \Delta\gamma))$$

$$\cos\gamma_{min} = 1 - \frac{U_{dio}{}^{\omega}}{U_{dio}{}^{\omega}{}_{nom}}(1 - \cos(\gamma_{nom} - \Delta\gamma))$$

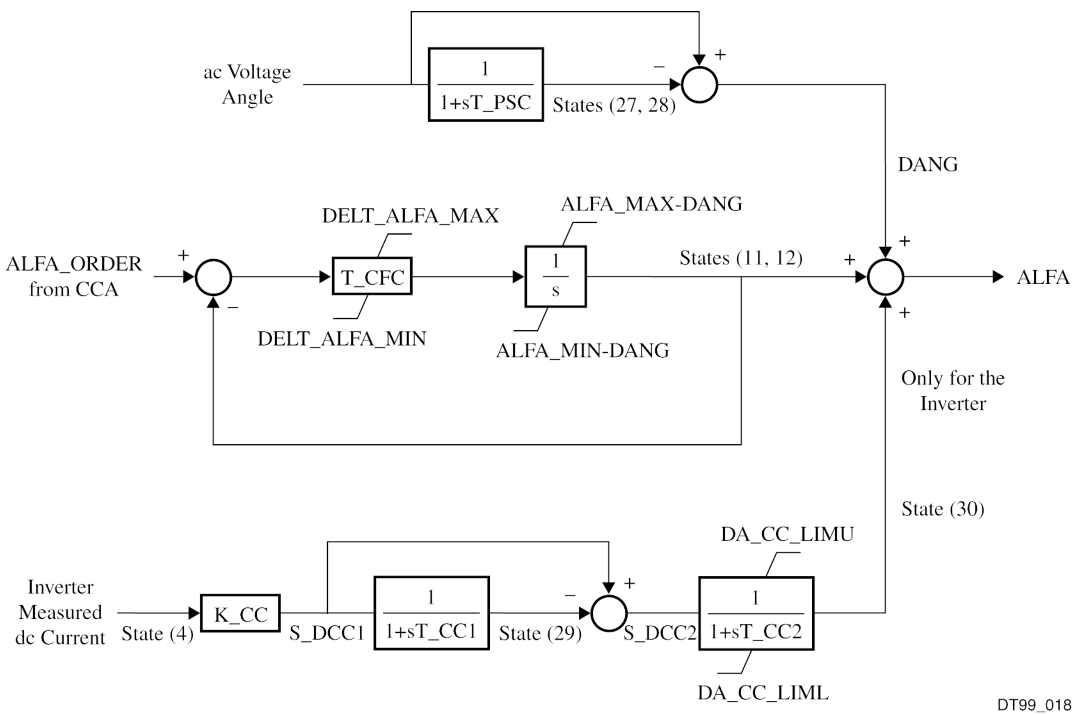


Figure 19.46. CFC with Dynamic Current Compound and Phase Shift Correction

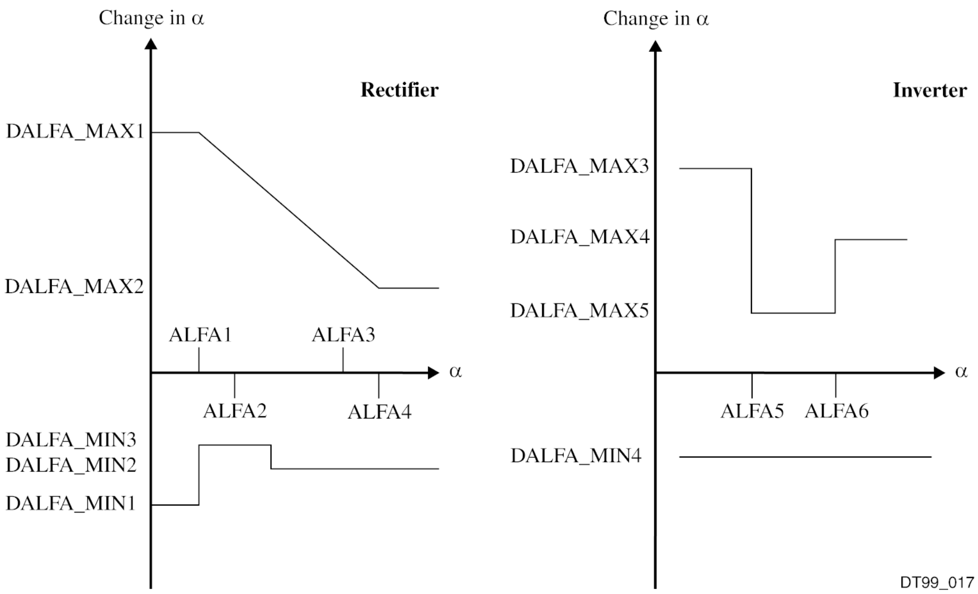


Figure 19.47. Limits on the Change in # per Commutation

Thus, the ordered firing angle from the CFC must not exceed the value corresponding to the calculated γ_{min} value. The upper limit of the inverter CFC is thus determined from:

ALPHA_MAX_I = $180^{o} - \gamma_{min} - u$

where u is the actual overlap angle found from the measured inverter dc current and measured inverter ac voltage.

The firing of the valves are related to the commutation voltage at the connected ac bus. If the phasor voltage angle changes, this represents a displacement in time of the ac phase voltages. In the real control system, the firing of the valves is advanced/delayed according to this displacement, and it takes some time before the control system phase locks the firing pulses to the new phase voltages. This effect is modeled by the phase shift correction both in the rectifier and in the inverter control systems and it is shown in the upper part of Figure 19.46, “CFC with Dynamic Current Compound and Phase Shift Correction”. The phase shift correction outputs an increment (DANG) in the firing angle, which is added to the firing angle from the CFC. DANG increases to positive values for restart in a weak inverter network and decreases to negative values in a weak rectifier network. This means that the firing angle during restart is increased for the inverter and reduced for the rectifier leading to increased dc voltages, by which the dc current increase in the inverter is slowed down, where it on the contrary is speeded up in the rectifier. This effect is very essential in weak networks where the phase angle change is significant.

DANG should also be subtracted from the limits ALFA_MAX_(R,I) and ALFA_MIN_(R,I) on STATE(K+11) and STATE(K+12) adjusting the limits to the new zero-crossing of the phase voltages. The firing angle sent to the control system can in this way never be out of the limits from ALFA_MIN_(R,I) to ALFA_MAX_(R,I) corresponding to a protective firing at these limits.

The lower part of Figure 19.46, “CFC with Dynamic Current Compound and Phase Shift Correction” shows a model of the dynamic current compound function in the inverter end, which exists in the control system for

Kontek. A contribution to the firing angle is added just before the firing. The aim of this function is to improve the small signal stability of the inverter control system. In steady state the inverter is operated close to the constant gamma part of the U_d/I_d characteristic, which has a negative slope, meaning that the rectifier sees the inverter as a negative resistance because the dc voltage decreases with increasing dc current. For small disturbances around the operation point the dynamic current compound function will transiently make the inverter look like a positive resistance.

19.11.9. Converters and Converter Transformers

The input required for and the output generated by the converters and converter transformers is:

Input:	• Firing angle ALFA_(R,I) (state) from CFC. • dc current.
Output:	• dc voltage (state).

The commutations of the single valves are not represented in the model. The converters are represented by the fundamental equations as seen in Figure 19.48, “CDCAB1 Algebraic Equations (Sheet 1 of 2)” based on the rms value of the commutation ac voltage. The commutation resistance and inductance are used in the converter equations together with the tap changer position, which is not changed during the dynamic simulation as mentioned earlier.

Rectifier:

$$(R1)\, U_{dio} = \frac{3\sqrt{2}}{\pi} E_{ac}$$

$$(R2)\, U_{dc} = N\left(U_{dio}\cos\alpha - \frac{3X_c I_{dc}}{\pi} - 2R_c I_{dc}\right)$$

$$(R3)\, E_{ac} = \frac{TR}{TAP} U_{ac,\,net}$$

$$(R4)\, \cos(u + \alpha) = \cos\alpha - \frac{\sqrt{2} I_{dc} X_c}{E_{ac}}$$

$$(R5)\, \tan\phi = \frac{2u + \sin2\alpha - \sin(2u + 2\alpha)}{\cos2\alpha - \cos(2\alpha + 2u)}$$

$$(R6)\, P_{ac,rect} = \frac{\sqrt{18}}{\Pi} I_{dc} \frac{\sqrt{(\cos2\alpha - \cos(2\alpha + 2u))^2 + (2u + \sin2\alpha - \sin(2\alpha + 2u))^2}}{4(\cos\alpha - \cos(\alpha + u))} E_{ac}\cos\phi$$

$$(R7)\, Q_{ac,rect} = \frac{\sqrt{18}}{\Pi} I_{dc} \frac{\sqrt{(\cos2\alpha - \cos(2\alpha + 2u))^2 + (2u + \sin2\alpha - \sin(2\alpha + 2u))^2}}{4(\cos\alpha - \cos(\alpha + u))} E_{ac}\sin\phi$$

Inverter:

$$(I1)\, U_{dio} = \frac{3\sqrt{2}}{\pi} E_{ac}$$

$$(I2)\, U_{dc} = N\left(U_{dio}\cos\gamma - \frac{3X_c I_{dc}}{\pi} - 2R_c I_{dc}\right)$$

$$(I3)\, E_{ac} = \frac{TR}{TAP} U_{ac,\,net}$$

$$(I4)\, \cos(u + \alpha) = \cos\alpha - \frac{\sqrt{2} I_{dc} X_c}{E_{ac}} = -\cos\gamma$$

$$(I5)\, \tan\phi = \frac{2u + \sin2\gamma - \sin(2u + 2\gamma)}{\cos2\gamma - \cos(2\gamma + 2u)}$$

$$(I6)\, P_{ac,inv} = \frac{\sqrt{18}}{\Pi} I_{dc} \frac{\sqrt{(\cos2\alpha - \cos(2\alpha + 2u))^2 + (2u + \sin2\alpha - \sin(2\alpha + 2u))^2}}{4(\cos\alpha - \cos(\alpha + u))} E_{ac}\cos\phi$$

$$(I7)\, Q_{ac,inv} = \frac{\sqrt{18}}{\Pi} I_{dc} \frac{\sqrt{(\cos2\alpha - \cos(2\alpha + 2u))^2 + (2u + \sin2\alpha - \sin(2\alpha + 2u))^2}}{4(\cos\alpha - \cos(\alpha + u))} E_{ac}\sin\phi$$

Figure 19.48. CDCAB1 Algebraic Equations (Sheet 1 of 2)

Symbols for Figure 19-45:

$U_{ac,net}$	rms value of the ac voltage on the network side
E_{ac}	rms value of the ac voltage on the valve side of the converter-transformer
U_{dc}	Average value of the DC voltage at the converters
U_{dio}	Ideal no-load DC voltage
U_{dioN}	Nominal ideal no-load DC voltage
I_{dc}	DC current
X_c	Commutating reactance per bridge
R_c	Commutating resistance per bridge
TR	Transformer ratio
TAP	Tap setting
N	Number of bridges
α	Firing angle
γ	Extinction angle or commutation margin
u	Overlap angle
ϕ	Power angle
P_{ac},Q_{ac}	Active and reactive power consumed from the ac network

Figure 19.49. CDCAB1 Algebraic Equations (Sheet 2 of 2)

It could, however, be an advantage if the user is allowed to change the tap changer position manually during the dynamic simulation as in PSS®E. Only symmetrical conditions are represented. Therefore, the model is only valid for equidistant fixing of the values.

The converter equations assume single overlap (i.e., an overlap angle less than 60°). This is valid when the dc current is not too high (10 pu at normal ac voltage) or if the ac commutating voltage is not too low (0.1 pu at normal dc current). Even during bypass or blocking the overlap angle only exceeds 60° in a very short time interval. The error introduced by using the same converter equations when the overlap angles are greater than 60° is therefore very limited. Another way could be to set the overlap angle equal to 60° in the calculations when it goes beyond 60°. By keeping the value of the overlap angle on 60°, the equations give a dc voltage that is too big and changes more slowly than the actual value does, because it is not sensible to the actual change in the overlap angle. If the overlap angle greater than 60° instead is used in the equations the dc voltage is able to respond to changes in the overlap angle although the assumptions of the equations are not completely fulfilled. The latter is therefore a better solution through still an approximation.

19.11.10. Cable Model and Current Return Path

The input required for and the output generated by the cable model and current return path is:

Input:	• dc voltage from the converters UDC_(R,I).
Output:	• dc currents IDC_(R,I). • Measured dc currents. • Measured dc voltages. • Voltage over the cable capacitance and sheath resistance (state 6).

The cable is represented by discrete elements in a t-equivalent. The line capacitance is represented by a capacitance (CC) in the middle of the cable. In reality, the cable capacitance is primarily a capacitance from the conductor to the sheath. To represent the damping of the cable, a resistance (RC) equal to the resistance of the sheath is therefore placed in series with the cable capacitance to the return. Half of the total line resistance (R_(R,I)) and inductance (L_(R,I)) is placed on each side of the cable capacitance. The resistance (RS_(R,I)) and inductance (LS_(R,I)) of the smoothing reactor are also included.

Instead of a t-equivalent, the cable could be represented by a pi-equivalent. It must then be noted that as the number of differential equations equals the number of inductances and capacitances, it introduces an extra state variable. In this way, the calculation time will be increased. A pi-equivalent and a t-equivalent is considered to give the same accuracy.

The current return path is in this case assumed to be ideal but can, of course, be represented by discrete elements like for the dc line, if, for example, it is an electrode line or a metallic return. As mentioned above, the number of capacitances and inductances must carefully be considered and only included if it is necessary to model the return with higher accuracy. In the case of Kontek the voltage drop over the return is not more than 1 kV (0.25%) and it will not significantly improve the results to model the current return path.

The correlations between the voltages and the currents are described by a differential equation for each capacitance and inductance. These equations are given below. The commutation inductance LC_(R,I) enters into the calculation of the current derivative, only when the converter is not bypassed. LC_(R,I) depend on the actual overlap angle, which means that its value basically lies between 1.5 and 2 times the commutation inductance per phase.

Current direction from inverter to rectifier (negative dc voltage in steady state):

$$I_{CC} = I_{DC\_I} - I_{DC\_R}$$

$$\frac{di_{DC\_R}}{dt} = \frac{(U_{CC} + RC\,I_{CC}) - UDC\_R - (R\_R + RS\_R)I_{DC\_R}}{L\_R + LS\_R + LC\_R}$$

$$\frac{di_{DC\_I}}{dt} = \frac{UDC\_I - (U_{CC} + RC\,I_{CC}) - (R\_I + RS\_I)I_{DC\_I}}{L\_I + LS\_I + LC\_I}$$

$$\frac{dU_{CC}}{dt} = \frac{I_{CC}}{CC}$$

Current direction from rectifier to inverter (positive dc voltage in steady state):

$$I_{CC} = I_{DC\_R} - I_{DC\_I}$$

$$\frac{di_{DC\_R}}{dt} = \frac{UDC\_R - (U_{CC} + RC\,I_{CC}) - (R\_R + RS\_R)I_{DC\_R}}{L\_R + LS\_R + LC\_R}$$

$$\frac{di_{DC\_I}}{dt} = \frac{(U_{CC} + RC\,I_{CC}) - UDC\_I - (R\_I + RS\_I)I_{DC\_I}}{L\_I + LS\_I + LC\_I}$$

$$\frac{dU_{CC}}{dt} = \frac{I_{CC}}{CC}$$

19.11.11. Special Control Functions

The HVDC control system is affected by changes in the ac voltages. Some of the most important control actions as a result of too low ac voltages from the real control system should be included in the model. The rectifier transient controller and inverter gamma 0 start were found to be important for the simulation results and are described in the following paragraphs.

Rectifier Transient Controller

This function is active during and after a fault in the rectifier ac network. During the fault, the dc voltages and the cable voltage are reduced and accordingly the firing angles are at or close to their minimum values.

When the ac voltage suddenly comes back, the rectifier dc voltage increases immediately and an overcurrent arises due to the difference between the large rectifier voltage and the low cable voltage. The smoothing reactor is also a decisive factor for the overcurrent. The overcurrent causes unwanted disturbances in the rectifier ac network so a control action that limits the overcurrent is essential to prevent situations like this.

The required effect is achieved by the rectifier transient controller function where the minimum value of the firing angle in the CCA is increased during and after the fault according to Figure 19.50, “Transient Controller Rectifier”. The function is activated and respectively deactivated when the rectifier ac voltage is below and respectively above a limit that is named UAC_TRCONR in Figure 19.50, “Transient Controller Rectifier”. The minimum limit of the firing angle to the CCA is increased to MAX_AORDER_MIN_R during the fault and is ramped down after the fault to the normal minimum limit value with a rate of D_AORDER_MIN_R. With this function, the rectifier dc voltage after the fault is cleared, is limited due to the greater minimum value of alpha, and, in this way, the risk of a large overcurrent after the fault clearing is reduced.

Also, the rectifier transient controller tends to prevent peak rectification because of the delaying of the firing to the valves. Peak rectification is a phenomenon that occurs when the valves start to conduct later than defined by the firing angles because the cable voltage is greater than the converter voltage at the given alpha. The valves conduct only at the peaks of the commutating voltages.

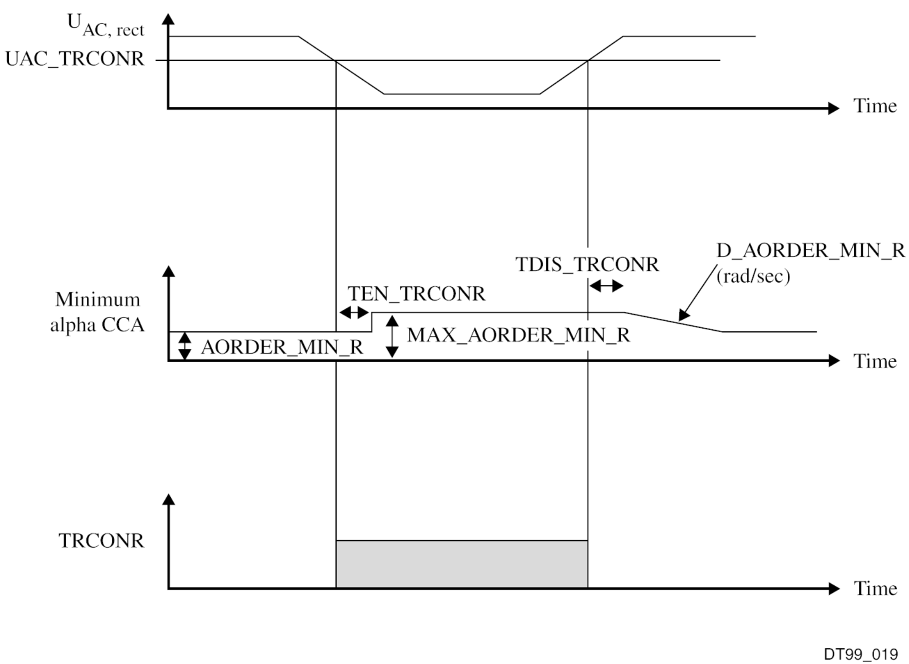


Figure 19.50. Transient Controller Rectifier

Inverter Transient Controller

During a fault in the inverter ac network, there is a considerable risk of commutation failure. Immediately after the fault removal, the recovery voltage is more or less distorted, which increases the risk of repetitive commutation failures when the inverter valves start to conduct. This risk is reduced by increasing the gamma value giving larger margin for the valves to commutate. This is the idea behind the inverter transient controller; the principle in this function is shown in Figure 19.51, “Transient Controller Inverter”.

The function is activated when the ac voltage in the inverter falls below a limit, named TRCONI_ACVOLT_ACTIVE, and is deactivated when the ac voltage exceeds TRCONI_ACVOLT_DEACTIVE. During the fault, the reference gamma is increased with TRCONI_DGAMA with a small time constant TRCONI_TUP. After removal of the fault, gamma decreases to the initial value with a time constant TRCONI_TDOWN, which is in the order of the time required for the ac voltage to stabilize after a fault.

Inverter Gamma 0 Start

During a fault in the inverter ac network, the firing angle in the inverter is decreased to its minimum limit while the firing angle in the rectifier is increased to around 90°. After fault clearing, the rectifier starts to conduct and the cable voltage is built up. After a while the inverter is able to commutate and current in the inverter starts to flow. Ignoring the VDCOL, the same current order is given to the rectifier and the inverter. Because the CCA in both ends have almost the same parameter values, the changes in the firing angles are of about the same speed. The current margin is subtracted from the current order in the inverter CCA while the inverter firing angle is adjusted to give the current order minus the current margin and the rectifier firing angle is adjusted to give the current order. In this way, only the current margin is used to charge the cable and, therefore, the voltage is built up very slowly. Basically, it is the inverter that controls the current.

The VDCOL helps to speed up the recovery of the dc system. Because the magnitude of the dc voltage in the rectifier is larger than in the inverter, the current order given to the rectifier is larger than the current order to the inverter. Thus, a current larger than the current margin is used to charge the cable.

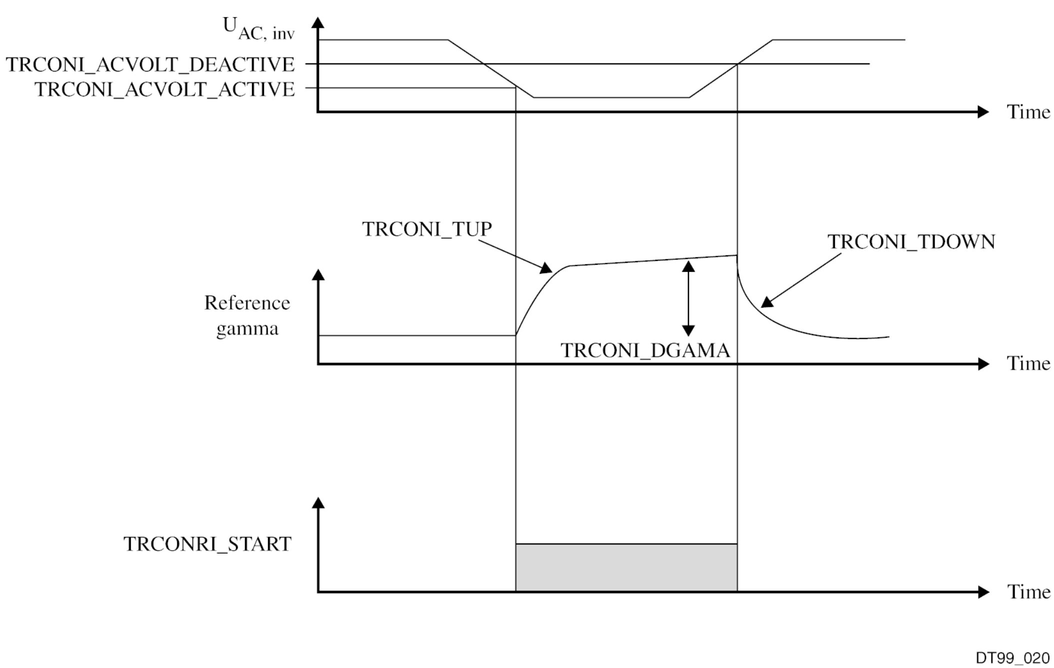


Figure 19.51. Transient Controller Inverter

The increase of the current order stops when the dc voltage has reached a reference (about 70%). When both rectifier and inverter have reached this limit, the cable is charged from the current margin only and, therefore, the voltage is built up slower than before.

The control function inverter gamma 0 start improves the recovery of the dc system considerably. When this function is activated the firing angle to the inverter is forced to a higher value, which has two effects: 1) it delays the start-up of the inverter current, and 2) it increases the inverter dc voltage so the inverter current is reduced. In this way, a larger proportion of the rectifier current is used to build up the cable voltage.

In the control system, α from the CCA is forced to a high value after removal of the fault in the inverter ac system. In the model this is represented by adding an additional current to the optional input in the CCA block diagram. This function is active when the dc voltage in the inverter has been less than a reference (VOLT_EN) for a specified time (TIME_EN) and the ac voltage has exceeded a specified value (GAMST_LIM). The function is disabled when the dc voltage is greater than a value (VOLT_DIS for a specified time (TIME_DIS). The model of the inverter gamma 0 start function is illustrated in Figure 19.52, "Inverter Gamma Start".

Inverter Voltage Control

For long cables, the cable capacitance prevents the rectifier to immediately respond to what happens in the inverter. Therefore, the risk of a commutation failure in the inverter end is larger than when the cable capacitance is smaller. In such cases, the problem could be reduced by adding a voltage control to the inverter control system. Also, the nominal extinction angle γ_{nom} should be increased giving a larger margin. One way to implement a voltage controller is illustrated in Figure 19.53, "Voltage Control for Long Cables".

The output DALFA_VC from this controller should be added to the upper limit ALPHA_MAX_ORDER_I for the firing angle for the CCA allowing the inverter to increase the dc voltage and in this way counteracting for the current increase.

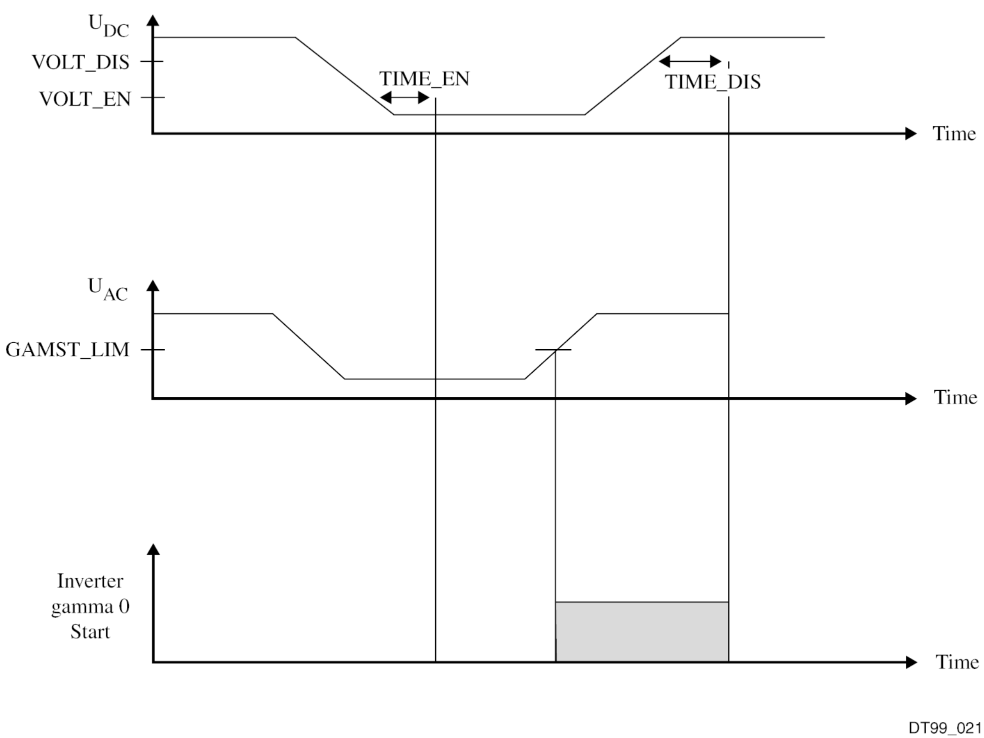


Figure 19.52. Inverter Gamma Start

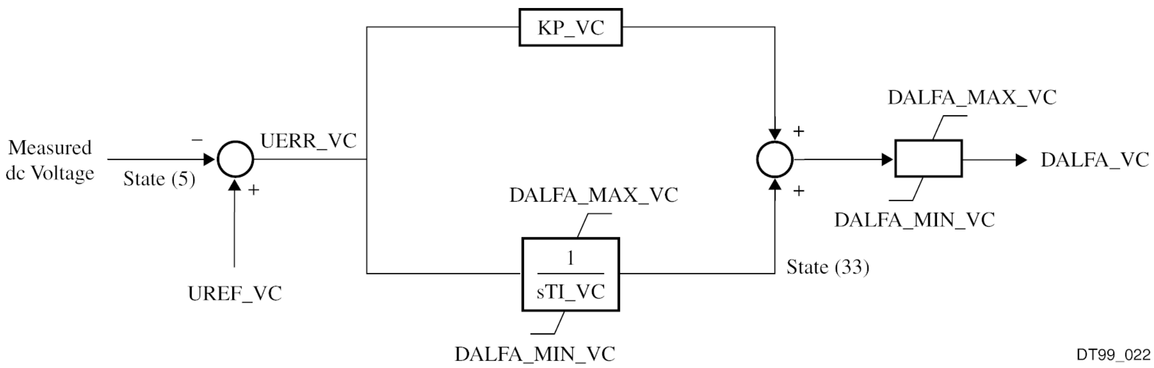


Figure 19.53. Voltage Control for Long Cables

19.12. CDCAB1 Example Case

19.12.1. Power Flow Data (RAWD File) for CDCAB1 Example Case

```
0 100
hvdc test case
nesa/tud/abb dynamic model
1 'dummy2'  400. 1 0. 0. 1 1 1.025 0.
2 'dummy2'  400. 1 0. 0. 1 1 1.025 0.
3 'rec_gen' 400. 3 0. 0. 1 1 1.025 0.
4 'inv_gen' 400. 3 0. 0. 1 1 1.025 0.
5 'load5'   400. 1 0. 0. 1 1 1.025 0.
6 'load6'   400. 1 0. 0. 1 1 1.025 0.
0
5 1 1 1 1 600. 300. 0. 0. 0. 0.
6 1 1 1 1 600. 300. 0. 0. 0. 0.
0
3 1 1202.664 219.01 9999. -9999. 1.025 0 3000. .08625 .9957 0. 0.
1. 1 100. 9999.,-9999.
4 1    7.389 230.63 9999. -9999. 1.025 0 3000. .08625 .9957 0. 0.
1. 1 100. 9999.,-9999.
0
1  3 1 0. .0001 0. 0. 0. 0.,,,, 0. 0. 0. 0. 1 0.
1 -5 1 0. .0001 0. 0. 0. 0.,,,, 0. 0. 0. 0. 1 0.
2  4 1 0. .0001 0. 0. 0. 0.,,,, 0. 0. 0. 0. 1 0.
2 -6 1 0. .0001 0. 0. 0. 0.,,,, 0. 0. 0. 0. 1 0.
0
0
0
1 2 2.1 1500. 400. 0. 2.1 0.1 R 0.
1 2 17. 13. .296 9.25  400. .41 1.0325 1.1625 .8625 .00125 0 0 0
1
2 2 19. 15. .296 9.125 400. .41 1.0400 1.1625 .8625 .00125 0 0 0
1
0
1 0 1. 1. 0 326. 1 326.
2 0 1. 1. 0 326. 1 326.
0
0
0
0
0
0
```

19.12.2. Dynamics Data (DYRE File) for CDCAB1 Example Case

```
3   'GENROU'    1      5.0000      0.60000E-01          0.20000
     0.60000E-01
```

```
      3.0000           0.0000           1.6000           1.5500
         0.70000
     0.85000          0.35000          0.20000      0.90000E-01
         0.38000     /
3      'SEXS'    1    0.10000           10.000           100.00
         0.10000
      0.0000           4.0000                /
4   'GENROU'     1     5.0000      0.60000E-01          0.20000
     0.60000E-01
      3.0000           0.0000           1.6000           1.5500
         0.70000
     0.85000          0.35000          0.20000      0.90000E-01
         0.38000     /
4      'SEXS'    1    0.10000           10.000           100.00
         0.10000
      0.0000           4.0000                /
1   'CDCAB1'          0  0  0  0  0  0  0  0  0  0  0  0  0
 0.10000E-03           0.0000           0.0000      0.20000E-01
          10.000
     0.40000           1500.0           150.00      0.20000E-02
     0.10000E-02
 0.50000E-01           200.00           21.400      0.20000E-02
     0.10000E-02
  0.50000E-0     1     200.00           21.400           113.00
          27.000
      1650.0           1.0000          0.10000      0.28000E+06
     0.10000E-02
 0.25000E-01           280.00            50.00           150.00
          3000.0
 0.10000E-02      0.65000E-01           280.00           450.00
          150.00
      3000.0      0.10000E-01           164.00           5.0000
          15.000
      1.0000          0.60000      0.38350E-01           1.5330
          180.00
     -180.00           5.0000      0.10000E-01           164.00
          5.0000
      15.000           1.0000          0.60000      0.38350E-01
          1.5330
      180.00          -180.00           105.00      0.10000E-03
     0.12000E-01
     0.10000      0.10000E-03           1.1500          0.70000
    -0.50000E-01
      105.00           15.000      0.10000E-03      0.12000E-01
         0.10000
 0.10000E-03           1.1500          0.70000     -0.50000E-01
          105.00
      15.000           1000.0           180.00      0.10000E-02
          1000.0
      105.00           2.0000            5.000           50.000
          70.000
```

```
     100.00         110.00         140.00         6000.0
         6000.0
     5000.0         1000.0         500.00        -3000.0
        -3000.0
    -7000.0        -2500.0       .50000E-01     0.50000E-01
         10.000
 0.20000E-02    0.14400E-02       1.0000        -3.0000
         25.000
 0.50000E-01    0.70000E-01      0.60000         187.50
         40.000
 0.10000E-01    0.80000E-01      0.40000        0.50000
        0.50000
     2625.0     0.50000E-01       0.0000      0.16000E+06
    0.20000E+06
     0.0000         200.00       0.50000         50.000
        -50.000
     0.0000         200.00       0.50000         50.000
        -50.000
 0.70000E-01        1.0000        250.00         50.000
        -50.000
 0.70000E-01        1.0000        250.00         50.000
        -50.000
     51.500         0.0000        0.0000         0.0000
         0.0000
     48.500         48.700        49.500         49.800
         0.0000
     51.500         0.0000        0.0000         0.0000
         0.0000
     48.500         48.700        49.500         49.800
         0.0000
     1.0000         0.0000        0.0000         0.0000
         0.0000
    0.10000         1.0000       0.10000        0.10000
         0.0000
    1.00000         0.0000        0.0000         0.0000
         0.0000
    0.10000         1.0000       0.10000        0.10000
         0.0000
     100.00         0.0000        0.0000         0.0000
         0.0000
     50.000         50.000        50.000         50.000
         0.0000
     100.00         0.0000        0.0000         0.0000
         0.0000
     50.000         55.000        50.000         50.000
         0.0000
     0.50000       0.80000        12.000        -12.000
              /
```

19.12.3. DOCU Report

```
PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      Tue, Oct 14
1997  15:09
HVDC TEST CASE
NESA/TUD/ABB DYNAMIC MODEL

REPORT FOR CONEC MODELS AT ALL BUSES

*** CALL CDCAB1( 1,     1,    41,    17,     1) ***

DC#   C O N S     S T A T E S     V A R S      I C O N S
1     41-244        17-50          1-48          1-13

X--- RECTIFIER ---X X--- INVERTER ----X MDC RDC RCOMP SETVAL VSCHED
VCMODE  DELTI
1 DUMMY2   400      2 DUMMY2   400 2  2.10  2.10 1500.0  400.0
  0.0 0.1000

CUR_DIR FRC_R   FRC_I  PMOD_R  PMOD_I    EC_R    EC_I    VC_I
PSC_R   PSC_I
0       0       0       0       0       0       0       0
0       0

DELTMAX    MANBYP_R    MANBYP_I   T_BYP_MIN     GAMMACF   VAC_NO_CF
        IdN
0.0001      0.0000      0.0000      0.0200     10.0000      0.4000
  1500.0000

CURMARG      TIDC_R      TVDC_R         RS_R         LS_R
L_R      TIDC_I
150.0000      0.0020      0.0010      0.0500    200.0000     21.4000
     0.0020

TVDC_I        RS_I         LS_I          L_I           CC
RC  IOMAX_MSTR
0.0010      0.0500    200.0000     21.4000    113.0000     27.0000
  1650.0000

TMSTR_HIGH   TMSTR_LOW    UMSTRLIM    T_DOWN_R      T_UP_R  Udbr_R(kV)
   IOMAXM_R

     1.0000      0.1000 280000.0000      0.0010      0.0250    280.0000
   450.0000

    IOMIN_R      IMAX_R    T_DOWN_I      T_UP_I  Udbr_I(kV)     IOMAXM_I
    IOMIN_I
   150.0000   3000.0000      0.0010      0.0650    280.0000    450.0000
   150.0000
```

```
     IMAX_I      T_IOF_R       A_MAX_R       A_MIN_R       A_NOM_R    LIN_MAX_R
  LIN_MIN_R
  3000.0000       0.0100      164.0000        5.0000       15.0000
 1.0000       0.6000

       KP_R      KI_TI_R  APROP_MAX_R  APROP_MIN_R  AORDR_MIN_R
T_IOF_I      A_MAX_I
     0.0384       1.5330      180.0000     -180.0000        5.0000
 0.0100     164.0000

    A_MIN_I      A_NOM_I    LIN_MAX_I    LIN_MIN_I          KP_I
KI_TI_I  APROP_MAX_I
     5.0000      15.0000       1.0000       0.6000        0.0384
 1.5330     180.0000

APROP_MIN_I  AORDR_MIN_I         K1_R          T1_R          T2_R     K1_MAX_R
U_NORM_MX_R
  -180.0000     105.0000       0.0001       0.0120        0.1000
 0.0001       1.1500

U_NORM_MN_R     S1_MIN_R   MIN_AMAX_R   GAMMAMIN_R          K1_I
   T1_I         T2_I
     0.7000      -0.0500     105.0000      15.0000        0.0001
 0.0120       0.1000

   K1_MAX_I  U_NORM_MX_I  U_NORM_MN_I     S1_MIN_I    MIN_AMAX_I   GAMMAMIN_I
    T_CFC_R
     0.0001       1.1500       0.7000      -0.0500      105.0000
15.0000    1000.0000

 ALFA_MAX_R  TALFA_MAX_I      T_CFC_I   ALFA_MIN_I       DELTGAM
  ALFA1        ALFA2
   180.0000       0.0010    1000.0000     105.0000        2.0000
35.0000      50.0000

      ALFA3        ALFA4        ALFA5        ALFA6    DALFA_MAX1   DALFA_MAX2
 DALFA_MAX3
    70.0000     100.0000     110.0000     140.0000     6000.0000    6000.0000
  5000.0000

 DALFA_MAX4   DALFA_MAX5   DALFA_MIN1   DALFA_MIN2    DALFA_MIN3   DALFA_MIN4
    T_PSC_R
  1000.0000     500.0000   -3000.0000   -3000.0000    -7000.0000   -2500.0000
     0.0500

    T_PSC_I         K_CC        T_CC1        T_CC2    DA_CC_LIMU   DA_CC_LIML
MX_AOR_MN_R
     0.0500      10.0000       0.0020       0.0014        1.0000
-3.0000      25.0000
```

```
 TEN_TRCONR TDIS_TRCONR  UAC_TRCONR D_AORD_MN_R TRCONI_DGAM   TRCONI_TUP
TRCONI_TDWN
     0.0500      0.0700      0.6000    187.5000     40.0000
 0.0100      0.0800

 TRCONI_V_A  TRCONI_V_D   GAMST_LIM  GAMST_IORD     TIME_EN     TIME_DIS
    VOLT_EN
     0.4000      0.5000      0.5000   2625.0000      0.0500
 0.0000 160000.0000

   VOLT_DIS        DB_R    K_FREQ_R    T_FREQ_R   UL_FREQ_R    LL_FREQ_R
       DB_I
200000.0000      0.0000    200.0000      0.5000     50.0000     -50.0000
     0.0000

   K_FREQ_I    T_FREQ_I   UL_FREQ_I   LL_FREQ_I    T1DAMP_R     T2DAMP_R
    KDAMP_R
   200.0000      0.5000     50.0000    -50.0000      0.0700
 1.0000    250.0000

   ULDAMP_R    LLDAMP_R    T1DAMP_I    T2DAMP_I     KDAMP_I     ULDAMP_I
   LLDAMP_I
    50.0000    -50.0000      0.0700      1.0000    250.0000
50.0000    -50.0000

 EC_R_FL_H1  EC_R_FL_H2  EC_R_FL_H3  EC_R_FL_H4  EC_R_FL_H5   EC_R_FL_L1
 EC_R_FL_L2
    51.5000      0.0000      0.0000      0.0000      0.0000
48.5000      48.7000

 EC_R_FL_L3  EC_R_FL_L4  EC_R_FL_L5  EC_I_FL_H1  EC_I_FL_H2   EC_I_FL_H3
 EC_I_FL_H4
    49.5000     49.8000      0.0000     51.5000      0.0000
 0.0000      0.0000

 EC_I_FL_H5  EC_I_FL_L1  EC_I_FL_L2  EC_I_FL_L3  EC_I_FL_L4   EC_I_FL_L5
 EC_R_TIME1
     0.0000     48.5000     48.7000     49.5000     49.8000
 0.0000      1.0000

 EC_R_TIME2  EC_R_TIME3  EC_R_TIME4  EC_R_TIME5  EC_R_TIME6   EC_R_TIME7
 EC_R_TIME8
     0.0000      0.0000      0.0000      0.0000      0.1000
 1.0000      0.1000

 EC_R_TIME9 EC_R_TIME10  EC_I_TIME1  EC_I_TIME2  EC_I_TIME3   EC_I_TIME4
 EC_I_TIME5
     0.1000      0.0000      1.0000      0.0000      0.0000
 0.0000      0.0000

 EC_I_TIME6  EC_I_TIME7  EC_I_TIME8  EC_I_TIME9 EC_I_TIME10     EC_R_PS1
```

```
   EC_R_PS2
     0.1000      1.0000      0.1000      0.1000      0.0000    100.0000
     0.0000

   EC_R_PS3    EC_R_PS4    EC_R_PS5    EC_R_PS6    EC_R_PS7    EC_R_PS8
   EC_R_PS9
     0.0000      0.0000      0.0000     50.0000     50.0000
50.0000     50.0000

  EC_R_PS10    EC_I_PS1    EC_I_PS2    EC_I_PS3    EC_I_PS4    EC_I_PS5
   EC_I_PS6
     0.0000    100.0000      0.0000      0.0000      0.0000
 0.0000     50.0000

   EC_I_PS7    EC_I_PS8    EC_I_PS9   EC_I_PS10       KP_VC
  TI_VC   DALF_MX_VC
    55.0000     50.0000     50.0000      0.0000      0.5000
 0.8000     12.0000

 DALF_MN_VC                                           DCCUR
  KVDCR        KVDCI
   -12.0000                                       1500.0000    400.0000
   396.8500

      ALF/GAM   MIN     MAX     PAC      QAC   NB   EBASE    RC
XC     TR      TAP
   R:  13.11  13.00  17.00   602.7   261.5   2   400.0  0.296  9.250
0.4100 1.0325
   I:  15.24  15.00  19.00  -592.6   273.1   2   400.0  0.296  9.125
0.4100 1.0400
```

Chapter 20
Transmission Line and Other Relay Models

20.1. Principles

The model library includes a group of detailed branch relay models. These models, as described in this section, are intended to represent the general principles of relays that are sensitive primarily to apparent impedance. The models are not intended to exactly represent any particular product of any relay manufacturer. Rather, they model the effects of actual relays given properly specified data and proper interpretation by the engineer. The detailed relay models, which are demanding in terms of data, are constructed from a set of basic elements described below. The relay models themselves are best understood on the basis of a good understanding of these elements.

20.2. Relay Elements

20.2.1. Impedance Detection Unit

The basic element of these relay models is the impedance detection unit. This unit accepts the positive-sequence current flowing into the terminals of a transmission line and the positive-sequence voltage at the same terminals. It derives an apparent impedance by dividing the voltage by the current. This apparent impedance is compared to a relay characteristic and, if it is within the zone of the R-X (Figure 20.1, "Setting and Resetting of Zone Flags") plane defined by the characteristic, a zone flag is set.

All relays are reset by activity STRT, and this resets all zone flags. The flag for a zone is set when the apparent impedance enters the zone and reset when it leaves the zone. The relay zones are delineated by the logical product of the basic relay zone and the restrictive zone defined by any blinders that are in effect. The picking up and resetting of the zone flag for one relay zone is illustrated in Figure 20.1, "Setting and Resetting of Zone Flags". The apparent resistance and reactance detected by the unit are available in VARs for placement in output channels so that the user can plot loci of apparent impedance.

20.2.2. Zone Timer

The zone timer has a clock, two inputs, and a single output. The output is zero until the clock times out. The first input to the zone timer is the zone flag, the second is a reset signal. The reset input instantaneously initializes the clock but does not start it. The start input starts the clock; when the clock times out the output has a value of 1. After the clock has been started, additional start signals are ignored unless a reset signal has been given. The timer delay setting may be zero in which case the output is enabled instantaneously. The action of the timer is depicted in Figure 20.2, "Operation of Zone Timer". If the delay time specified is not a multiple of the time step, action will take place at the nearest time.

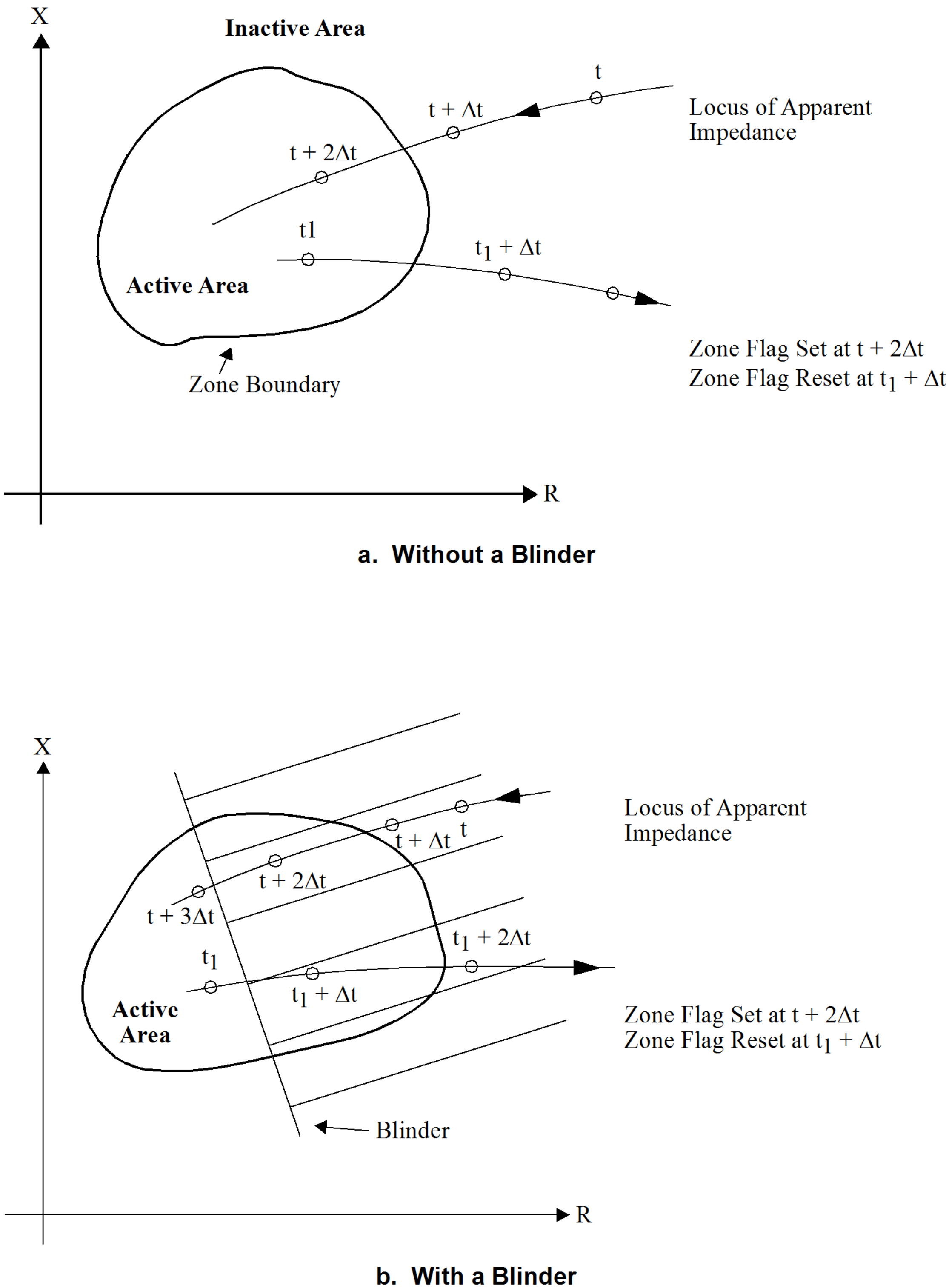
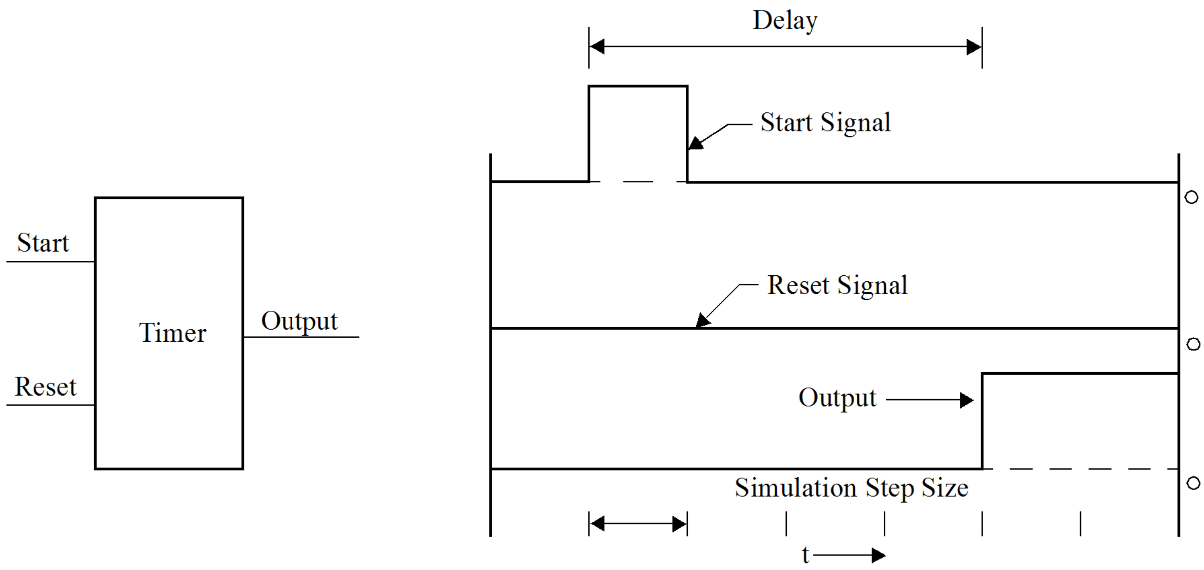
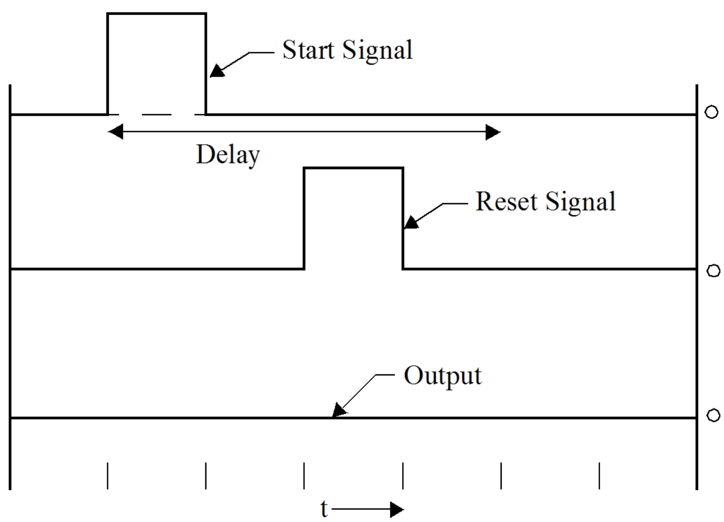


Figure 20.1. Setting and Resetting of Zone Flags



a. Times Out Before Reset



b. Resets Before Times Out

Figure 20.2. Operation of Zone Timer

20.2.3. Circuit Breaker Timer

The inherent opening delay of each circuit breaker to which a relay sends a trip signal is modeled by a circuit breaker timer. The action of these timers is similar to that of the zone timer.

20.2.4. Circuit Breaker

The circuit breaker model (Figure 20.3, "Logic for Breaker") has three signals that combine to provide the start input to the circuit breaker timer: a trip signal, normally the output of the zone timer; a permissive flag, which must be set for the breaker to respond to the trip signal; and a force trip signal that always produces a trip when set. The circuit breaker opens (i.e., current goes to zero), when the circuit breaker timer times out. No action is taken if the line has already been tripped (or reclosed) when the trip (or reclosure) timer times out.

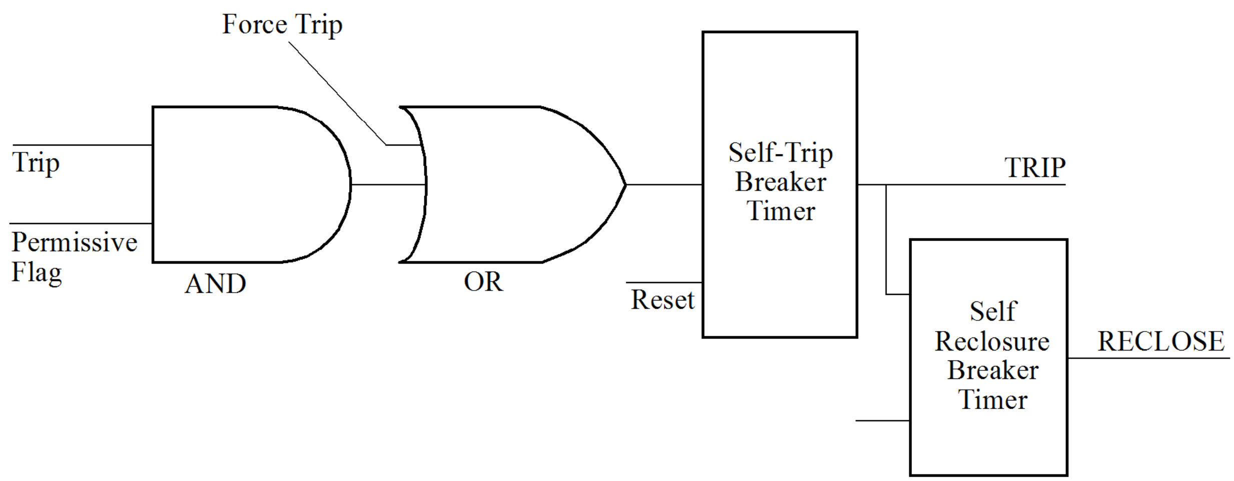


Figure 20.3. Logic for Breaker

20.2.5. Reclosure Timer

The reclosure timer is started when the breaker timer times out (i.e., when the line is tripped). When the reclosure timer times out, a reclose signal is sent to the breaker.

20.2.6. Minimum Current Detector

Several relays incorporate a minimum current detector. This unit sets a low-current flag if the absolute value of the current input to the impedance detection unit is below a threshold. This flag blocks action (i.e., current must be above threshold to permit action) in several places in the relays. (See overall relay logic diagrams.) This threshold current should be entered as per unit on system base.

20.2.7. Supervisory Input - Permissive Flag

The relay models have supervisory inputs. These take the form of permissive flags, one affecting tripping of the relay's own circuit breaker, and one that has a common effect on all of the relay's transfer trip actions. The permissive flag may have the value of 1 (tripping is blocked), 0 (tripping is permitted), or –1 (tripping is forced immediately, regardless of condition of the supervised relay.)

The permissive flags are initialized by activity DYRE to a value of 0 and are not affected by STRT. Their values may be changed manually via activity ALTR when the relay to which they apply is not supervised by another relay such as CIROS1 or SLNOS1. Use of the supervisory capability of CIROS1 or SLNOS1 automates the setting of the permissive flags and hence they should not be changed by ALTR when they are used as communication between relay models. Supervision is achieved by specifying the ICON number of the supervised relay's permissive flag in the supervisory ICON number. This can be done via the relay editors or activity ALTR.

20.2.8. Blinders

The relays are provided with blinders that form a straight-line boundary to restrict the extent of their otherwise circular zones. The characteristic of each blinder is a straight line separating the R-X plane into a trip-permitted zone on one side and a trip-prohibited zone on the other, as shown in Figure 20.4, "Straight-Line Relay Blinders" (top). The blinder's effective zone is logically and-ed with all basic zones of the relay in which the blinder is incorporated to produce a restricted effective zone as shown in Figure 20.4, "Straight-Line Relay Blinders"(bottom).

20.2.9. Relay Time-Gating Unit

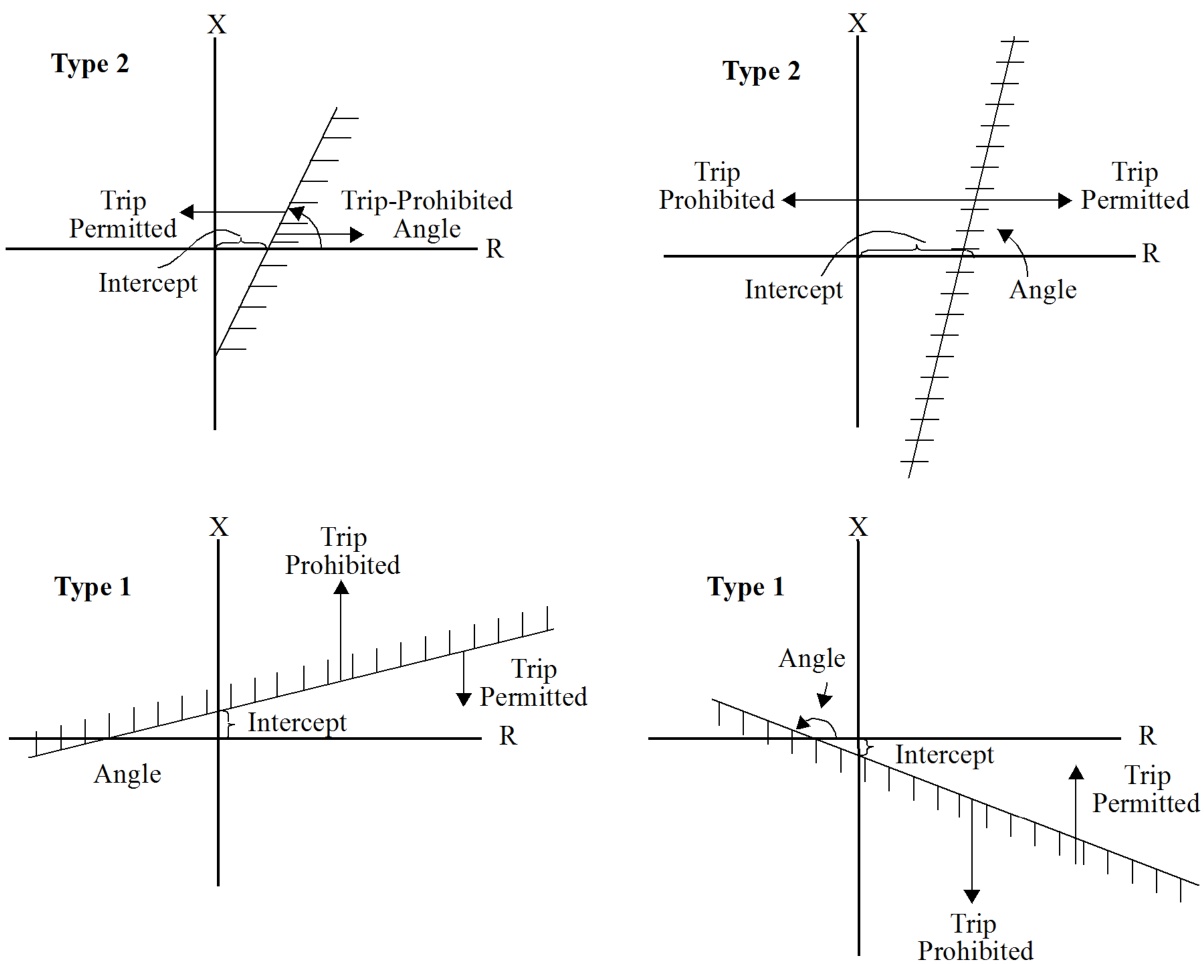
PSS®E applies a time-gating logic to some of the detailed relay models. This logic causes the relay model to be executed every n time steps, instead of every time step, which is the normal practice. Use of the time-gating logic with a value of n = 5, for example, would be appropriate in special situations, i.e., a particularly small time step is used to accommodate a short time constant in a model like GENDCO or SHAF25. The time-gating logic is overridden to force execution of all relay models at all pauses or internal switching operations within the execution of activity RUN (Figure 20.5, "Operation Time Gating Logic").

As indicated by Figure 20.1, "Setting and Resetting of Zone Flags"a, zone timers are started and stopped when the apparent impedance locus enters and leaves the effective trip zone and not when the locus crosses the basic circular zone boundary. That is, the blinder characteristic line becomes a part of the zone boundary and the excluded arc of the circle disappears.

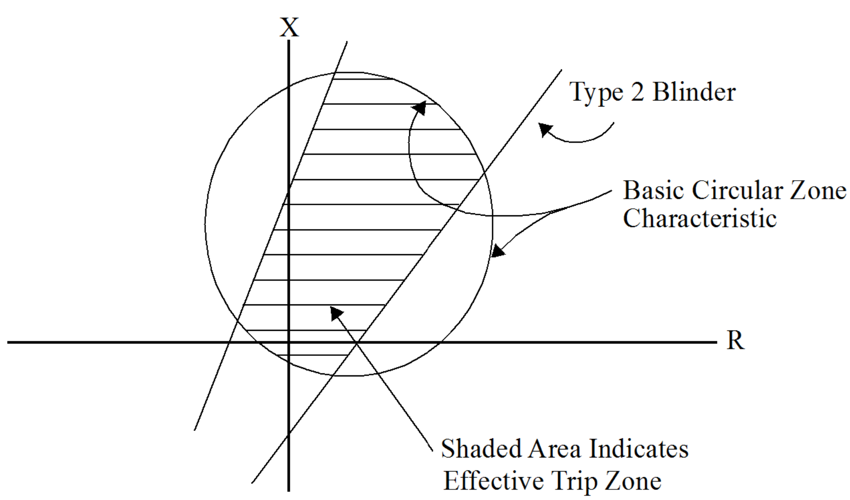
20.3. Bases for Relay Data

All impedance relay models in Chapter 11 of the PSS®E Model Library (DISTR1, CIROS1, SLNOS1, and RXR1) use common bases for data:

1. All angles are stated in degrees.
2. All impedance intercepts, zone center distances, and zone diameters, expressed with respect to the R-X plane, are stated in terms of impedance per-unit on system base.
3. All time delays are stated in cycles.
4. All currents, voltages, and detected impedances are stated per unit with respect to system MVA base.



a. Blinder Types



b. Type 2 Blinder Application

Figure 20.4. Straight-Line Relay Blinders

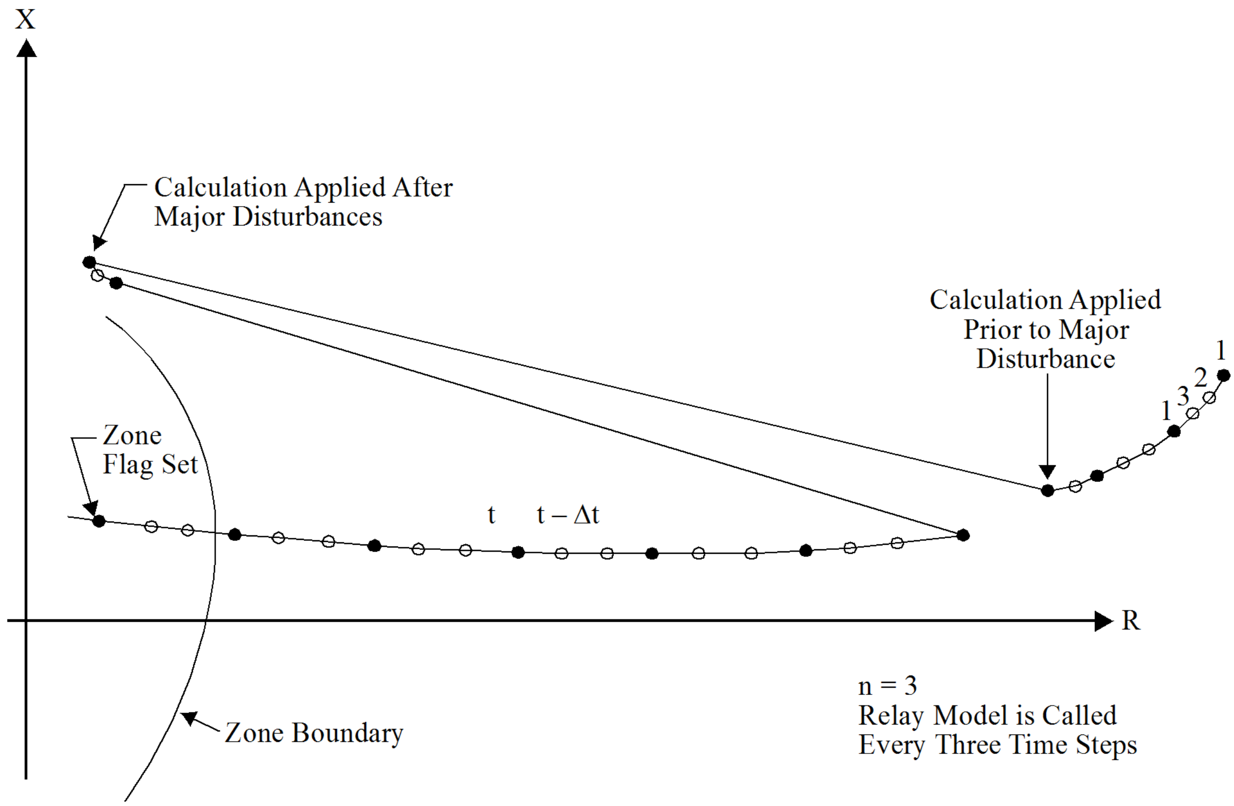


Figure 20.5. Operation Time Gating Logic

20.4. Model DISTR1

20.4.1. General Characteristics

The features of the distance relay model (DISTR1) follow. Its overall logic diagram is shown in Figure 20.6, "Overall Logic Diagram".

- Mho, impedance, or reactance characteristic with up to three independent (separately specified diameter and center offset) circles for mho or impedance units.
- Trip of up to three remote lines (transfer trips) as well as monitored line (self trip).
- Single attempt reclosure for self transfer trip for zone 1 faults.
- Supervisory signal input to prevent tripping or to force immediate tripping.
- Up to two straight-line blinders.
- Minimum pickup current logic.
- Model may be used in a monitoring only mode.

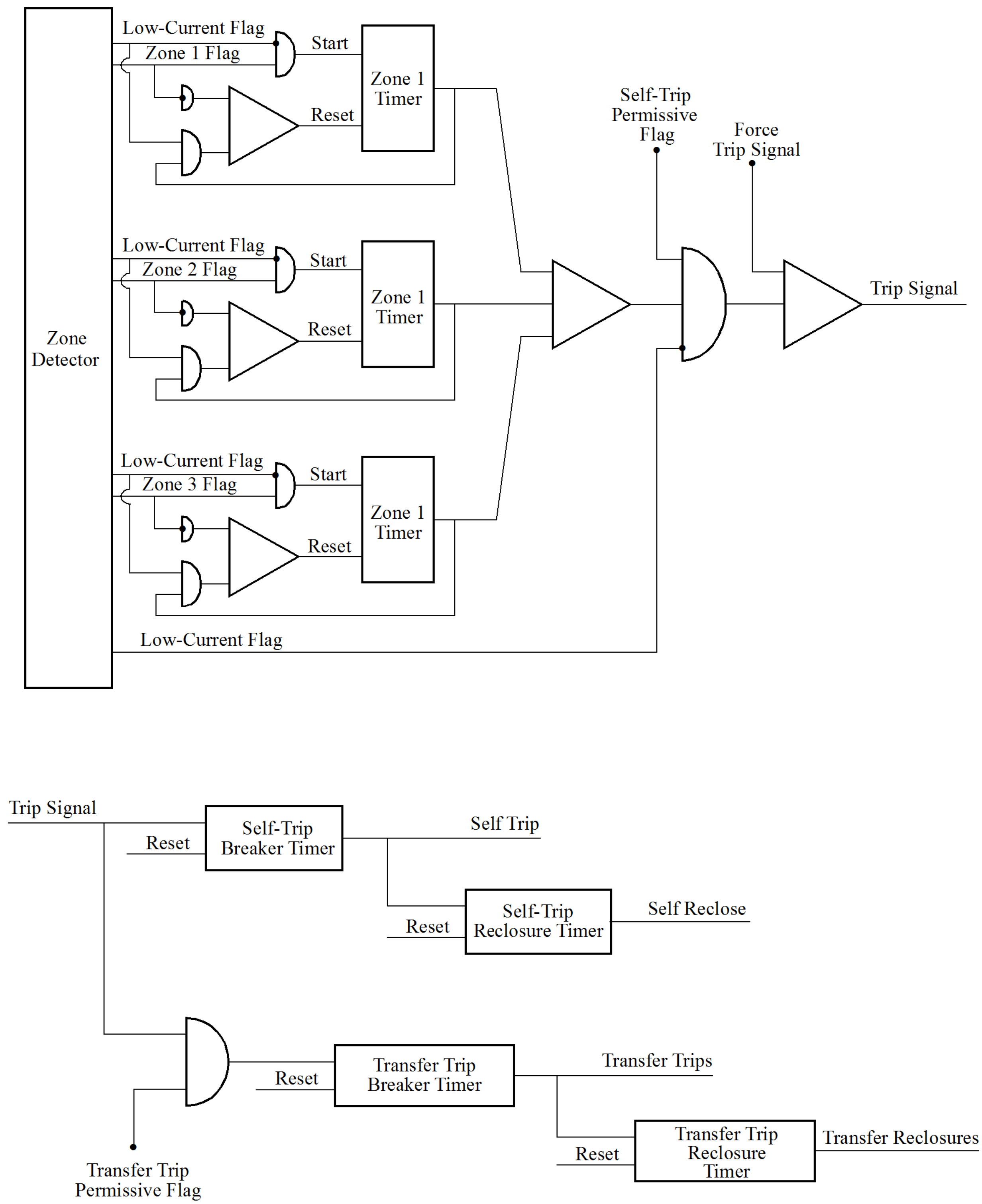


Figure 20.6. Overall Logic Diagram

20.4.2. Specific Characteristics

The following should be noted with respect to the DISTR1 model data sheet:

- A trip action caused by DISTR1 opens the circuit breakers at both ends of a line simultaneously.
- Relay is at the from bus looking toward the to bus.
- If invalid line data is specified, the appropriate message is printed out during initialization.
- DISTR1 requires certain ICONs and VARs for local storage. Do not reuse these storage locations in other models or user-written logic in CONEC and CONET subroutines.
- The first three VARs used by DISTR1 are the per-unit resistance, reactance, and current. These values may be put into output channels.
- All angles are specified in degrees from horizontal; anti-clockwise direction is positive.
- All timer settings are specified in cycles and includes all delays.
- Resetting of timers is assumed instantaneous.
- A from bus of 0 for a transfer trip bypasses the logic for that transfer trip. The permissive flags should be set to 1 in user input if tripping is desired.
- The permissive flags are not initialized by the program. The self-trip permissive flag of a supervised relay may be changed by a supervising relay during a simulation run.

20.4.3. Data

ICON(I)	The relay type is specified by this ICON. The zone shape associated with each type is shown on the data sheet.
ICON(I+1)	Specifying 0 disables all tripping actions of relay model, but allows detected impedance to be recorded as if model was active.
ICON(I+2,3,4)	Specify a line to be tripped by transfer-trip action from this relay. Setting these ICONs to zero deactivates transfer tripping.
ICON(I+5,6,7)	See above.
ICON(I+8,9,10)	See above.
ICON(I+11) (Note: ICON(I+11) through ICON(I+28) are *not* included in the data record for DYRE.)	Specify permissive flag supervising the relay's tripping of its own circuit breaker. Its value is initialized to 1 (permit tripping) by activity DYRE and is not affected by activity STRT. Supervising relays such as CIROS1, or the user activity ALTR, may change the value of this ICON during a simulation run. Supervising action by another relay is achieved by setting the supervisory ICON number of the supervising relay to

	(I+11). (See Section 20.6, "Model CIROS1" and Section 20.7, "Model SLNOS1".)
ICON(I+12)	Specify the permissive flag supervising all transfer tripping actions of the relay. Specification and/or control is the same as for ICON(I+11).
CON(J)	Set to the relay's basic operating time: the minimum time for the relay to see the apparent impedance in zone 1 in order to issue a trip signal. May be set to 0 to represent instantaneous tripping action.
CON(J+1,2,3)	Specify the size and position of the relays zone 1. Zone 1 must be the innermost of three zones specified.
CON(J+4)	Specify sum of the time delay setting of zone 2 and the relay's basic operating time.
CON(J+5,6,7)	Specify the size and position of zone 2.
CON(J+8)	Specify sum of the time delay setting of zone 3 and the relay's basic operating time.
CON(J+9,10,11)	Specify the size and position of zone 3.
CON(J+12)	Specify the angle of directional element in an impedance distance relay where three circular zones are centered at the origin. The angle is defined on the DISTR1 data sheet.
CON(J+13)	Specify current threshold of the minimum current detector. DISTR1 will neither start its zone timers nor issue trip signals if the current input to the apparent impedance detector is below this value.
CON(J+14)	Specify the operating time of the relay's own circuit breaker: the time elapsed between receipt of a trip signal at the circuit breaker and interruption of current.
CON(J+15)	Specify the reclosure delay for the relays own circuit breaker. The reclosing delay timer is started upon interruption of current. Reclosure occurs (i.e., contacts touch) when this timer times out.
CON(J+16,17)	Specify circuit breakers controlled by relay's transfer trip outputs.
CON(J+18,19,20)	Specify first of two blinders. (See Section 20.2.7, "Supervisory Input - Permissive Flag".) Set to zero if blinder not active.
CON(J+21,22,23)	Specify second of two blinders. Set to zero if blinder not active.

20.4.4. Example Application - DISTR1

The application of DISTR1 is illustrated by example. The example considers the sample system used in Section 15.4, "Generator Models" to illustrate the application of the CSVGN1 static var device model. Figure 20.7, "" shows a filled-in data sheet for an initial trial application of DISTR1. The example checks the effect of mho distance relays on the three 500-kV circuits from bus 1 to 2. The concern is with relays located at bus 1 looking toward bus 2 when a fault occurs on circuit 1 at the bus 1 (sending) end. The data shown in Figure 20.7, “” and Figure 20.10, “DOCU Output Corresponding to Figure 20.7, “”” is a first trial at relay settings.

Figure 20.11, “Dialog for Simulation with DISTR1 on Circuits 1 and 2 Between Buses 1 and 2 (Sheet 1 of 2)” shows the dialog and relay message output from a first simulation run in which a fault is simulated by the application of a 100 per-unit reactive admittance (i.e., 0.01 per-unit fault impedance) at the line reactor location of circuit 1. The fault must be applied by changing the value of the branch shunt admittance, rather than by changing the bus shunt admittance at bus 1, because the bus shunt would be behind the relays and would result in a contribution to line current in the wrong direction.

The second page of Figure 20.11, “Dialog for Simulation with DISTR1 on Circuits 1 and 2 Between Buses 1 and 2 (Sheet 1 of 2)” shows the use of activity RUN where DISTR1, rather than the user, handles the clearance of the fault. Because DISTR1 will handle fault clearance in this run, the initial run duration can be any convenient length, rather than the duration of the fault. An initial run to 0.2 sec, with the fault applied at t = 0.1, permits plotting and printing every time step while faults and switchings are causing rapid changes. (Output channel printing is deleted from Figure 20.11, “Dialog for Simulation with DISTR1 on Circuits 1 and 2 Between Buses 1 and 2 (Sheet 1 of 2)” after t = 0.133 to conserve space.) From t = 0.2, the run is extended to t = 5.0 with more economical printing and plotting intervals.

The simulation output shows messages from the two DISTR1 models. These messages indicate that the relay on circuit 1 sees the fault in its zone 1 and that this results in clearance by the 1.5 cycle breaker after 0.033 sec, or 2 cycles, as expected, given the 0.5 cycle zone 1 relay time. The messages from DISTR1 also indicate that the relay on circuit 2 sees the fault in its third zone from t = 0.117 seconds. This zone 3 timer times out as the message indicates at t = 0.25 seconds, which initiates the breaker tripping 1.5 cycles later. The voltage never recovers and appears to still be dropping.

Figure 20.13, “Locus of Apparent Z Seen by DISTR1 on Circuit 2” shows the locus of apparent impedance, Z, seen by DISTR1 on circuit 2 in relation to that relay’s impedance zones. Figure 20.14, “Time Plots of Simulation Result” shows the simulation result in more conventional time-domain terms and emphasizes the collapse of the system after the tripping of the second transmission circuit.

DISTR1

mho, Impedance, or Reactance Distance Relay

Relay is located from bus	#______	IBUS.	
to bus	#______	JBUS.	
circuit	#______	ID.	
relay slot (1 or 2)	#______	RS.	

ICONs	Value	Description	
I	1	Type 1 - mho distance Type 2 - impedance distance Type 3 - reactance distance	
I+1	1	0 - Monitor 1 - Monitor and operate	
I+2	0	From bus number	First transfer trip
I+3	0	To bus number	
I+4	0	Circuit ID	

ICONs	Value	Description	
I+5	0	From bus number	Second transfer trip
I+6	0	To bus number	
I+7	0	Circuit ID	
I+8	0	From bus number	Third transfer trip
I+9	0	To bus number	
I+10	0	Circuit ID	
I+11	X	Permissive flag for self trip [a]	
I+12	X	Permissive flag for transfer trip [b]	
I+13 . . . I+28	X	ICONs required for internal program logic	

[a]Set to 1 and -1 by supervisory relay to block trip and force trip, respectively.
[b]Set to 1 by supervisory relay to block trip.

VARs	Description
L	Apparent R
L+1	Apparent X
L+2	Current
L+3 . . . L+9	VARs required for internal program logic

Application of DISTR1 to Circuits 1 and 2

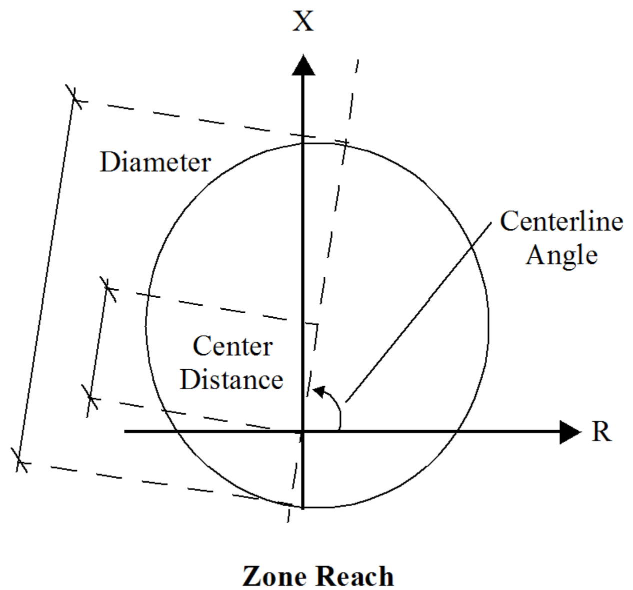


Figure 20.7.

IBUS, 'DISTR1', JBUS, ID, RS, first 11 ICONs, CON list /

Between Buses 1 and 2 of Sample System (Sheet 1 of 3)

CONs	Value	Description
J	.5	Zone 1 operating time (cycles)
J+1	.065	Zone 1 reach (diameter or reactance) (pu)
J+2	86	Zone 1 centerline angle in degrees (0 for reactance relay)
J+3	.03	Zone 1 center distance (0 for reactance relay)
J+4	.5	Zone 2 pickup time (cycles)
J+5	.085	Zone 2 reach (diameter or reactance) (pu)
J+6	86	Zone 2 centerline angle (0 for reactance relay)
J+7	.04	Zone 2 center distance (0 for reactance relay)
J+8	8	Zone 3 pickup time (cycles)
J+9	.11	Zone 3 reach (diameter)
J+10	86	Zone 3 centerline angle (degrees)
J+11	.055	Zone 3 center distance (pu)
J+12	0	Angle of directional unit (only for impedance relay)
J+13	1.0	Threshold current (pu)
J+14	1.5	Self trip breaker time (cycles)
J+15	1E6	Self trip reclosure time (cycles)
J+16	1.5	Transfer trip breaker time (cycles)
J+17	1E6	Transfer trip reclosure time (cycles)
J+18	0	1st blinder type (±1 or ±2)
J+19	0	1st blinder intercept (pu)
J+20	0	1st blinder rotation (degrees)
J+21	0	2nd blinder type (±1 or ±2)
J+22	0	2nd blinder intercept (pu)
J+23	0	2nd blinder rotation (degrees)

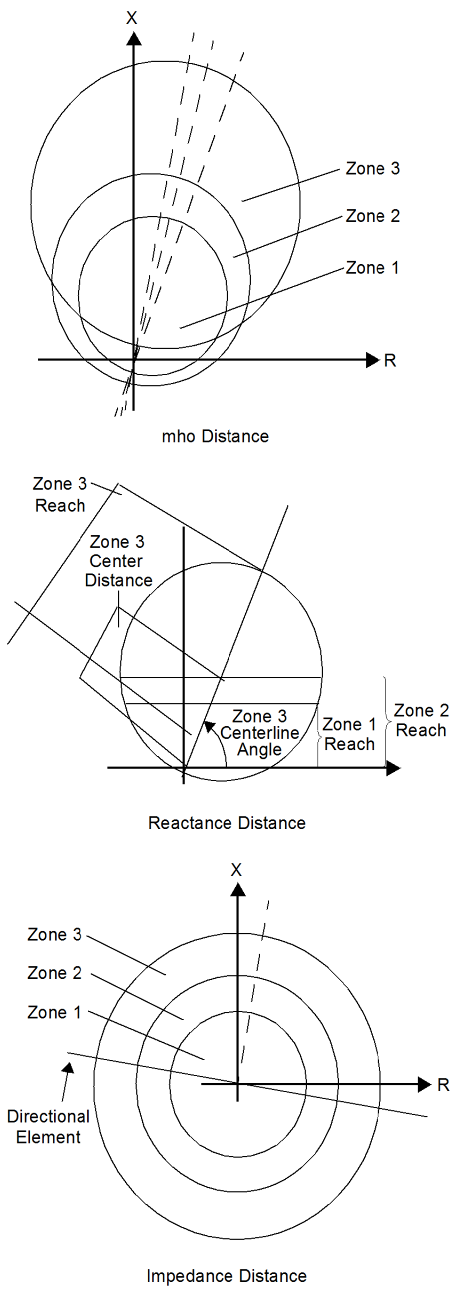
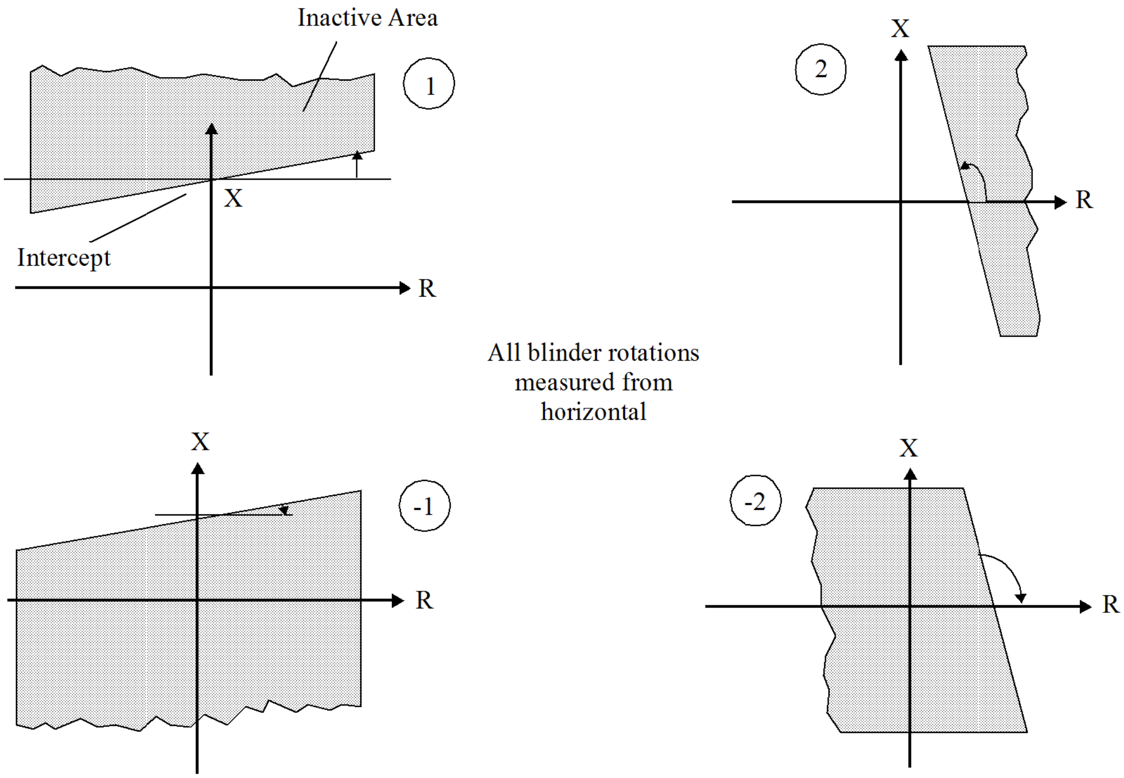
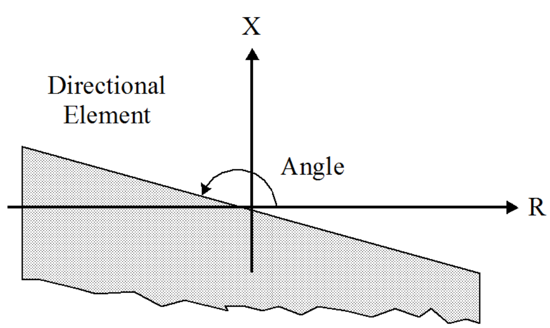


Figure 20.8. Application of DISTR1 to Circuits 1 and 2 Between Buses 1 and 2 of Sample System (Sheet 2 of 3)



Blinder Types



mho, Impedance, or Reactance Distance Relay

Figure 20.9. Application of DISTR1 to Circuits 1 and 2 Between Buses 1 and 2 of Sample System (Sheet 3 of 3)

```
                *** CALL DISTR(    4,    59,     4) ***

                   ICON'S     C O N ' S     V A R ' S
                  4-    39      59-    82      4-    13

  REF #    TYPE   MON/TRIP FLAG   RES      MONITORED LINE       TRANSFER TRIP    No transfer trip
      1       1             1       1              1      2  '1 '     0     0  '0 '

        TRANSFER TRIP        TRANSFER TRIP    SELF FLAG   TRANS FLAG          Supervisory flags
          0       0  '0 '      0       0  '0 '         1            1         initialized by STRT

    CY1    REACH1    ANGLE1     DIST1        CY2    REACH2    ANGLE2     DIST2
  0.500     0.065    86.000     0.030      5.000     0.085    86.000     0.040

    CY3    REACH3    ANGLE3     DIST3    DIR ANG    THRESH   SELF TB   SELF TR
  8.000     0.110    86.000     0.055      0.000     1.000     1.500*********    Large number
                                                                                 prevents reclosure
 TRAN TB   TRAN TR   BL1 TYP   BL1 INT   BL1 ROT   BL2 TYP   BL2 INT   BL2 ROT
       1.500*********     0.000     0.000     0.000     0.000     0.000     0.000

                *** CALL DISTR(   40,    83,    14) ***

                   ICON'S     C O N ' S     V A R ' S
                     40-    75     83-   106      14-    23

  REF #    TYPE   MON/TRIP FLAG   RES      MONITORED LINE       TRANSFER TRIP
      2       1             1       1              1      2  '2 '     0     0  '0 '

        TRANSFER TRIP        TRANSFER TRIP    SELF FLAG   TRANS FLAG
          0       0  '0 '      0       0  '0 '         1            1

    CY1    REACH1    ANGLE1     DIST1        CY2    REACH2    ANGLE2     DIST2
  0.500     0.065    86.000     0.030      5.000     0.085    86.000     0.040

    CY3    REACH3    ANGLE3     DIST3    DIR ANG    THRESH   SELF TB   SELF TR
  8.000     0.110    86.000     0.055      0.000     1.000     1.500*********

 TRAN TB   TRAN TR   BL1 TYP   BL1 INT   BL1 ROT   BL2 TYP   BL2 INT   BL2 ROT
  1.500*********     0.000     0.000     0.000     0.000     0.000     0.000
```

Figure 20.10. DOCU Output Corresponding to Figure 20.7, “”

```
Executing activity STRT

    PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      TUE, NOV 30 1999  12:02
LONG DISTANCE RADIAL TRANSMISSION WITH
STATIC VAR GENERATOR VOLTAGE SUPPORT

INITIAL CONDITION LOAD FLOW USED  1 ITERATIONS

-------------------------MACHINE INITIAL CONDITIONS--------------------------
X------ BUS -----X ID  ETERM  EFD    POWER    VARS   P.F.  ANGLE   ID     IQ
    1 HYDRO    500 1  1.0600 2.4913 2690.23 1029.58 0.9339  44.43 0.8729 0.4001
    3 LOAD     230 1  1.0252 2.4828  450.00  200.00 0.9138  -5.58 0.9334 0.4451
    4 TERT1   33.0 1  1.0000 0.0000    0.00  461.58 0.0000   0.00 0.6976-0.6046
    5 TERT2   33.0 1  1.0000 0.0000    0.00  461.58 0.0000   0.00 0.6976-0.6046

INITIAL CONDITIONS CHECK O.K.

CHANNEL OUTPUT FILE IS C:\pag\gp.out

   TIME X- VALUE --X X--------- IDENTIFIER ---------X X- VALUE --X X--------- IDENTIFIER ---------X
-0.0167  0.91666      VOLT     2 [RECEIVE 500.00]        44.435      ANGL     1 [HYDRO   500.00] [1 ]
    3    -5.5805      ANGL     3 [LOAD    230.00] [1 ]   26.902      POWR     1 [HYDRO   500.00] [1 ]
    5     4.5000      POWR     3 [LOAD    230.00] [1 ]   10.296      VARS     1 [HYDRO   500.00] [1 ]
    7    0.10219      R-1-2-1                          0.39110E-01 X-1-2-1
    9    0.10219      R-1-2-2                          0.39110E-01 X-1-2-2
```

R+jX as seen by DISTR1 for circuit 1

R+jX as seen by DISTR1 for circuit 2

```
 0.1000  0.91666      44.435      -5.5805       26.902       4.5000       10.296
    7    0.10219    0.39110E-01  0.10219      0.39110E-01

BRANCH DATA FOR CKT 1  FROM      1 [HYDRO   500.00] TO      2 [RECEIVE 500.00]:
 STATUS  LINE R     LINE X  CHARGING  RATE-A  RATE-B  RATE-C LENGTH
OLD 1    0.00500   0.07200   5.50000  2000.0  1000.0  2500.0     0.0 CHANGE IT?
LINE SHUNTS: BUS      1 [HYDRO    500.00]  BUS      2 [RECEIVE 500.00]
OLD                   0.00000  -2.00000             0.00000   0.00000 CHANGE IT?
NEW                   0.00000-100.00000             0.00000   0.00000
```

0+j.01 per unit impedance fault applied on circuit 1

```
METERED END IS BUS      1 [HYDRO   500.00]. ENTER 1 TO REVERSE:
    7 DIAGONAL AND      8 OFF-DIAGONAL ELEMENTS

CHANNEL OUTPUT FILE IS C:\pag\gp.out

RELAY DISTR1 # 1 CIRCUIT 1  FROM      1 TO      2 MESSAGES AT TIME =  0.100:
    APPARENT IMPEDANCE ENTERED ZONE(S) 1 2 3
    ZONE 1 2 3 TIMER(S) STARTED
```

DISTR1 on circuit 1 sees the fault

```
   TIME X- VALUE --X X--------- IDENTIFIER ---------X X- VALUE --X X--------- IDENTIFIER ---------X
 0.1000  0.38679      VOLT     2 [RECEIVE 500.00]        44.435      ANGL     1 [HYDRO   500.00] [1 ]
    3    -5.5805      ANGL     3 [LOAD    230.00] [1 ]   6.9294      POWR     1 [HYDRO   500.00] [1 ]
    5     3.0819      POWR     3 [LOAD    230.00] [1 ]   27.444      VARS     1 [HYDRO   500.00] [1 ]
    7    0.89754E-03 R-1-2-1                           0.94847E-02 X-1-2-1
    9    0.70637E-01 R-1-2-2                           0.46409E-01 X-1-2-2

RELAY DISTR1 # 1 CIRCUIT 1  FROM      1 TO      2 MESSAGES AT TIME =  0.108:
    ZONE 1      TIMER(S) TIMED OUT
    SELF TRIP BREAKER TIMER STARTED
```

End of ½ cycle zone 1 operating time of relay; circuit breaker receives trip signal

```
 0.1083  0.32616      44.435      -5.5805       5.5109       2.4114       22.557
    7    0.87426E-03  0.93942E-02  0.64095E-01  0.49172E-01

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  0.117:
    APPARENT IMPEDANCE ENTERED ZONE(S) 3
    ZONE 3      TIMER(S) STARTED
```

DISTR1 on circuit 2 sees fault on circuit 1 as voltage at bus 1 falls

```
 0.1167  0.27259      44.575      -5.5008       4.3274       1.7994       18.634
    7    0.83635E-03  0.93107E-02  0.58145E-01  0.51909E-01

 0.1250  0.25894      44.922      -5.2395       4.0101       1.6501       17.597
    7    0.82162E-03  0.92991E-02  0.57263E-01  0.52866E-01
```

Figure 20.11. Dialog for Simulation with DISTR1 on Circuits 1 and 2 Between Buses 1 and 2 (Sheet 1 of 2)

```
 RELAY DISTR1 # 1 CIRCUIT 1  FROM      1 TO      2 MESSAGES AT
TIME =  0.133:
   SELF TRIP BREAKER TIMER TIMED OUT
 *** CIRCUIT 1  FROM     1 [HYDRO    500] TO      2 [RECEIVE  500]
   TRIPPED AT TIME =  0.133
   SELF RECLOSURE TIMER STARTED

  0.1333  0.24418      45.401     -4.8232      3.7039      1.4822      16.601
    7    0.80582E-03  0.92773E-02  0.55627E-01  0.53776E-01

   7 DIAGONAL AND    8 OFF-DIAGONAL ELEMENTS

   TIME X- VALUE --X X--------- IDENTIFIER ---------X X- VALUE -
-X X--------- IDENTIFIER ---------X
 0.1333  0.38151    VOLT    2 [RECEIVE 500.00]      45.401    ANGL
1 [HYDRO   500.00] [1 ]
   3   -4.8232    ANGL    3 [LOAD    230.00] [1 ]  8.0012    POWR    1
[HYDRO   500.00] [1 ]
   5    2.0341    POWR    3 [LOAD    230.00] [1 ]  10.772    VARS    1
[HYDRO   500.00] [1 ]
    7    0.10000E+11 R-1-2-1                    0.10000E+11 X-1-2-1
    9    0.49250E-01 R-1-2-2                    0.66303E-01 X-1-2-2

  0.1417  0.38844      46.022     -4.2640      8.3022      1.9846      11.326
    7    0.10000E+11  0.10000E+11  0.49856E-01  0.68015E-01

  0.1500  0.40314      46.759     -3.5779      8.8965      1.9467      12.307
    7    0.10000E+11  0.10000E+11  0.50676E-01  0.70104E-01

  0.1583  0.40628      47.594     -2.7809      9.0824      1.8917      12.774
    7    0.10000E+11  0.10000E+11  0.50732E-01  0.71352E-01
```

Breakers interrupt current in circuit 1

Circuit 2 breakers receive trip signal

Breakers are open on circuit 2

Figure 20.12. Dialog for Simulation with DISTR1 on Circuits 1 and 2 Between Buses 1 and 2 (Sheet 2 of 2)

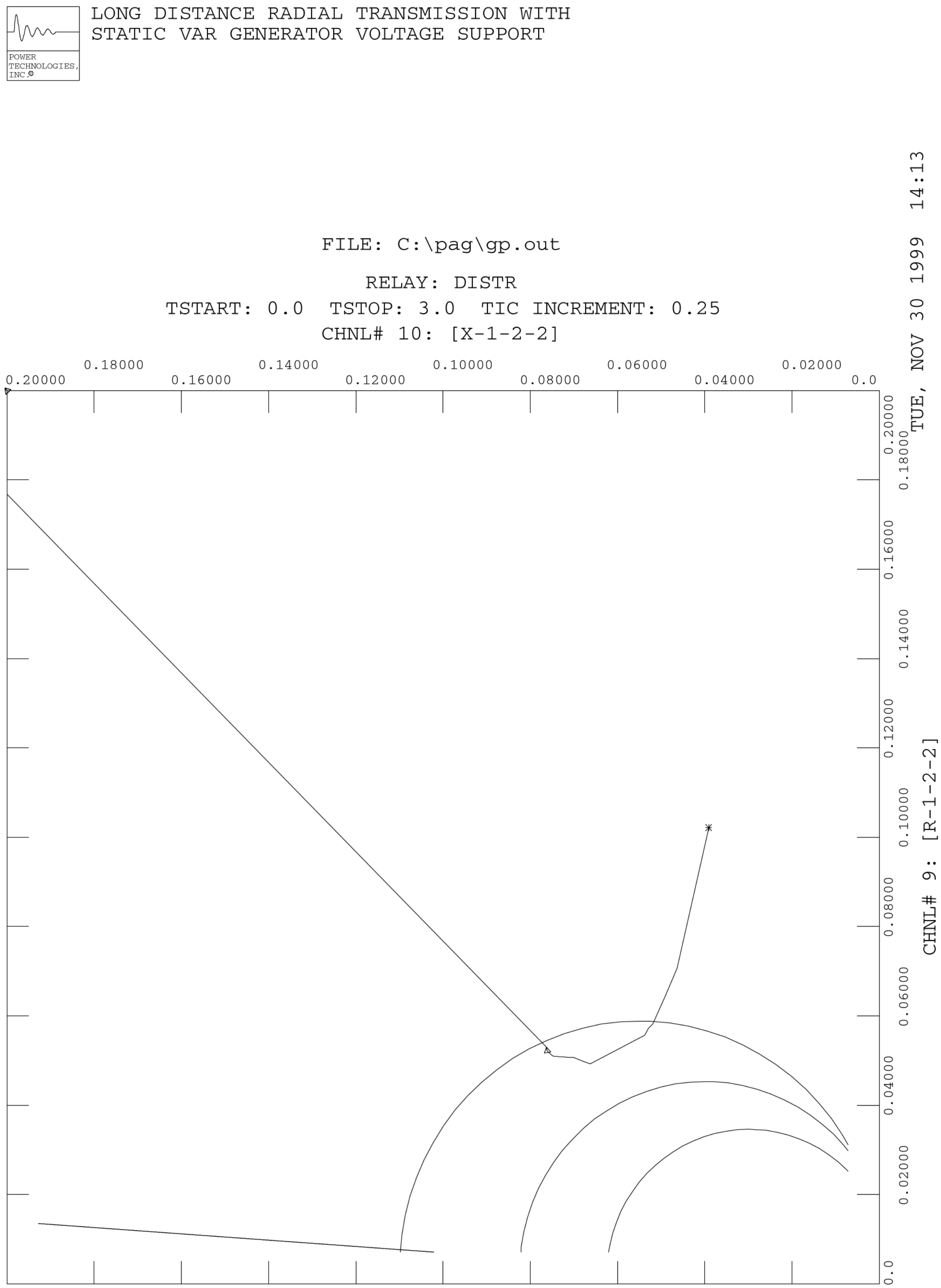


Figure 20.13. Locus of Apparent Z Seen by DISTR1 on Circuit 2

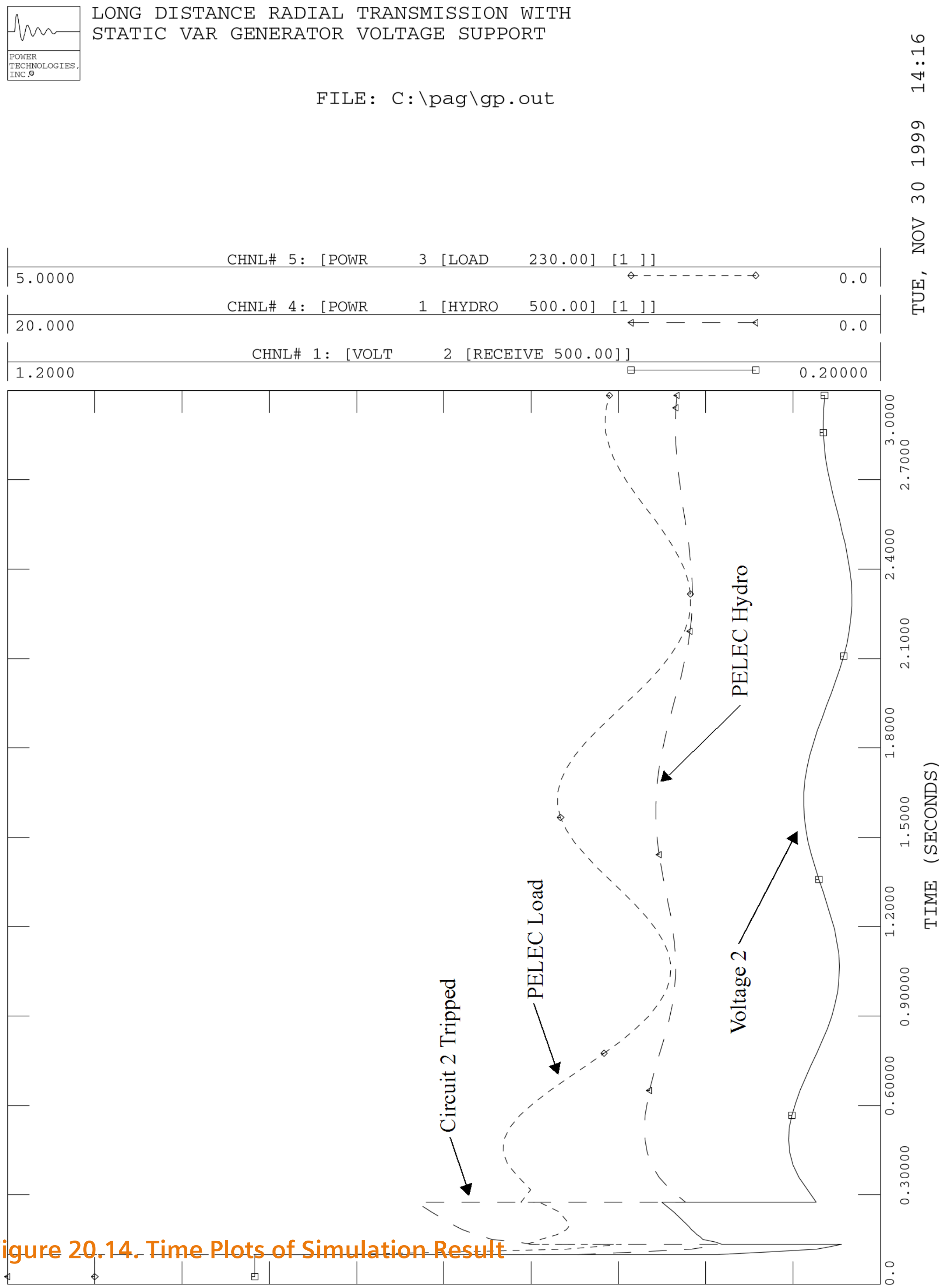


Figure 20.14. Time Plots of Simulation Result

The undesirable effect of the third zone of the distance relay on circuit 2 can be corrected in this example by the application of a blinder. The proper location of the blinder can be found by rerunning the simulation of Figure 20.11, "Dialog for Simulation with DISTR1 on Circuits 1 and 2 Between Buses 1 and 2 (Sheet 1 of 2)" with no changes except for setting the zone 3 time delay of the DISTR1 relay on circuit 2 to a large value. The result of this appears in the relay messages in Figure 20.15, "Relay Messages for Fault at Bus 1 End of Circuit 1 with Normal Clearing by DISTR1 but with Infinite Time Delay in DISTR1 on Circuit 2" and by the locus of apparent impedance seen by DISTR1 on circuit 2, shown in Figure 20.16, "Locus of Apparent Z Seen by DISTR1 on Circuit 2 Infinite Zone 3 Time". The messages and the plotted locus show that the apparent impedance seen by DISTR1 on circuit 2 hovers close to the edge of zone 3 and swings into and out of the zone. The time response shown in Figure 20.17, "Time Domain Response Corresponding to Figure 20.15, "Relay Messages for Fault at Bus 1 End of Circuit 1 with Normal Clearing by DISTR1 but with Infinite Time Delay in DISTR1 on Circuit 2" and Figure 20.16, "Locus of Apparent Z Seen by DISTR1 on Circuit 2 Infinite Zone 3 Time"" indicates that this low value of apparent Z is the result of severely depressed voltage and consequent high reactive power flow into the load area. The timings in Figure 20.15, "Relay Messages for Fault at Bus 1 End of Circuit 1 with Normal Clearing by DISTR1 but with Infinite Time Delay in DISTR1 on Circuit 2" indicate that the zone 3 time delay would have to be about 0.3 sec to avoid trips during the successive incursions of apparent Z into the third zone. This delay is too long and would prevent the relay from providing its intended backup protection for other relays.

Tripping due to the swings shown in Figure 20.15, "Relay Messages for Fault at Bus 1 End of Circuit 1 with Normal Clearing by DISTR1 but with Infinite Time Delay in DISTR1 on Circuit 2" can also, though, be prevented by use of a blinder to clip off the right-hand side of zone 3. Figure 20.18, "Relay Messages from Same Event as in Figure 20.11, "Dialog for Simulation with DISTR1 on Circuits 1 and 2 Between Buses 1 and 2 (Sheet 1 of 2)" and Figure 20.15, "Relay Messages for Fault at Bus 1 End of Circuit 1 with Normal Clearing by DISTR1 but with Infinite Time Delay in DISTR1 on Circuit 2", but with Normal Zone 3 Time and Blinder on DISTR1 of Circuit 2" through Figure 20.20, "Time Domain Response" show the DISTR1 data, messages, and simulation output involved when a blinder is placed at the right-hand side of the standard circular relay zones. The placement of the blinder is shown in Figure 20.19, "Locus of Apparent Z Seen by DISTR1 on Circuit 2", and the corresponding data are shown in Figure 20.18, "Relay Messages from Same Event as in Figure 20.11, "Dialog for Simulation with DISTR1 on Circuits 1 and 2 Between Buses 1 and 2 (Sheet 1 of 2)" and Figure 20.15, "Relay Messages for Fault at Bus 1 End of Circuit 1 with Normal Clearing by DISTR1 but with Infinite Time Delay in DISTR1 on Circuit 2", but with Normal Zone 3 Time and Blinder on DISTR1 of Circuit 2". This final simulation run includes a major load shedding action at t = 3.0 sec, after which system voltages recover strongly and continued satisfactory operation becomes possible.

```
RELAY DISTR1 # 1 CIRCUIT 1  FROM      1 TO      2 MESSAGES AT TIME =  0.100:
    APPARENT IMPEDANCE ENTERED ZONE(S) 1 2 3
    ZONE 1 2 3 TIMER(S) STARTED

RELAY DISTR1 # 1 CIRCUIT 1  FROM      1 TO      2 MESSAGES AT TIME =  0.108:
    ZONE 1     TIMER(S) TIMED OUT
    SELF TRIP BREAKER TIMER STARTED

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  0.117:   DISTR1 on
    APPARENT IMPEDANCE ENTERED ZONE(S) 3                                        circuit 2
    ZONE 3     TIMER(S) STARTED                                                 sees fault

RELAY DISTR1 # 1 CIRCUIT 1  FROM      1 TO      2 MESSAGES AT TIME =  0.133:
    SELF TRIP BREAKER TIMER TIMED OUT
*** CIRCUIT 1  FROM       1 [HYDRO     500] TO       2 [RECEIVE  500]
    TRIPPED AT TIME =   0.133
    SELF RECLOSURE TIMER STARTED

    7 DIAGONAL AND     8 OFF-DIAGONAL ELEMENTS

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  0.308:   Loses sight of it
    APPARENT IMPEDANCE OUTSIDE ZONES
    ZONE 3     TIMER(S) RESET

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  1.833:   Sees it again
    APPARENT IMPEDANCE ENTERED ZONE(S) 3
    ZONE 3     TIMER(S) STARTED

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  1.917:   Loses it
    APPARENT IMPEDANCE OUTSIDE ZONES
    ZONE 3     TIMER(S) RESET

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  2.550:   Sees it
    APPARENT IMPEDANCE ENTERED ZONE(S) 3
    ZONE 3     TIMER(S) STARTED

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  2.700:   Loses it
    APPARENT IMPEDANCE OUTSIDE ZONES
    ZONE 3     TIMER(S) RESET

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  3.283:   Sees it
    APPARENT IMPEDANCE ENTERED ZONE(S) 3
    ZONE 3     TIMER(S) STARTED

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  3.458:   Loses it
    APPARENT IMPEDANCE OUTSIDE ZONES
    ZONE 3     TIMER(S) RESET

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  4.017:   Sees it
    APPARENT IMPEDANCE ENTERED ZONE(S) 3
    ZONE 3     TIMER(S) STARTED

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  4.200:   Loses it
    APPARENT IMPEDANCE OUTSIDE ZONES
    ZONE 3     TIMER(S) RESET

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  4.767:   Sees it
    APPARENT IMPEDANCE ENTERED ZONE(S) 3
    ZONE 3     TIMER(S) STARTED

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  4.917:   Loses it
    APPARENT IMPEDANCE OUTSIDE ZONES
    ZONE 3     TIMER(S) RESET
```

Figure 20.15. Relay Messages for Fault at Bus 1 End of Circuit 1 with Normal Clearing by DISTR1 but with Infinite Time Delay in DISTR1 on Circuit 2

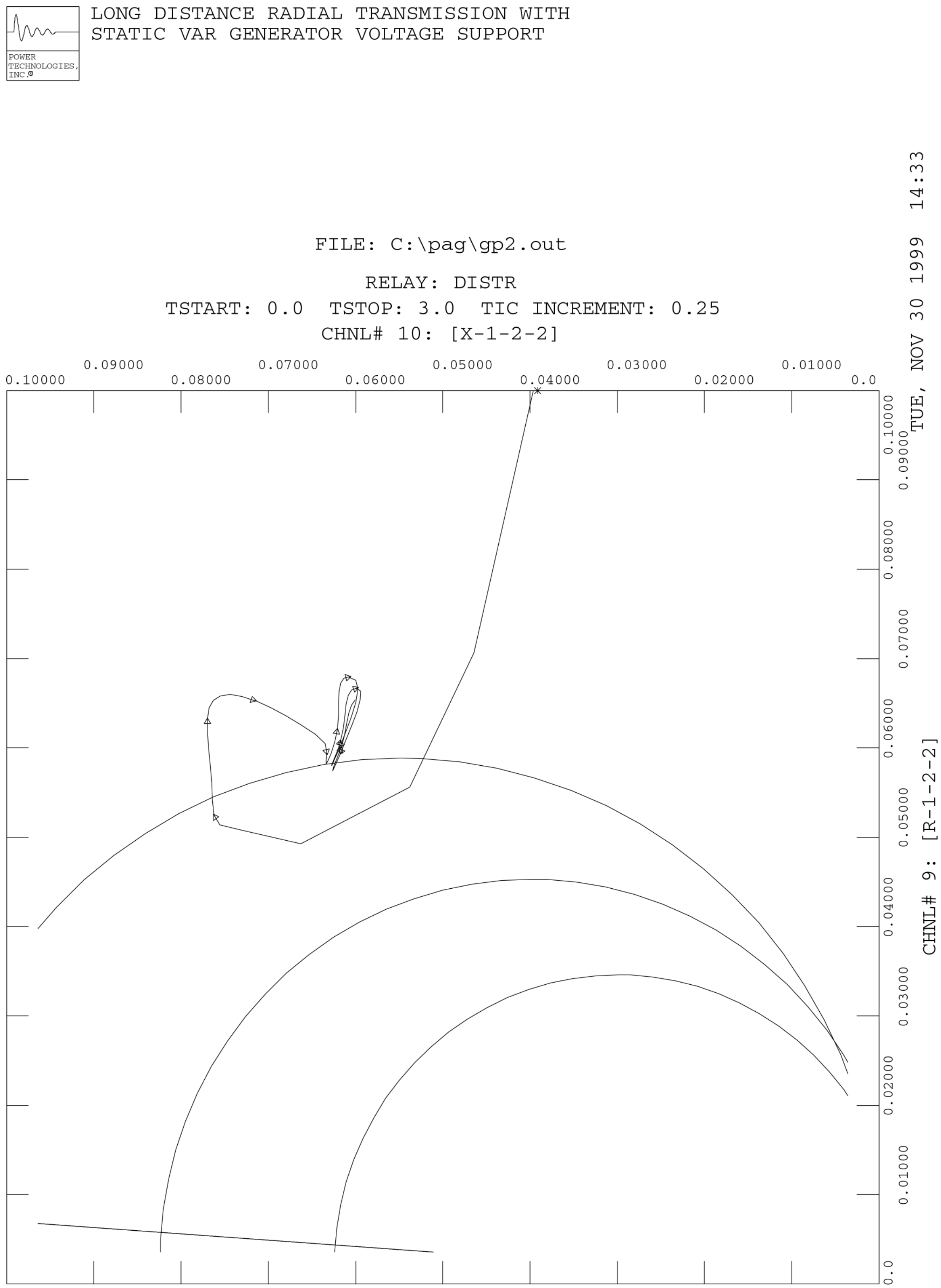


Figure 20.16. Locus of Apparent Z Seen by DISTR1 on Circuit 2 Infinite Zone 3 Time

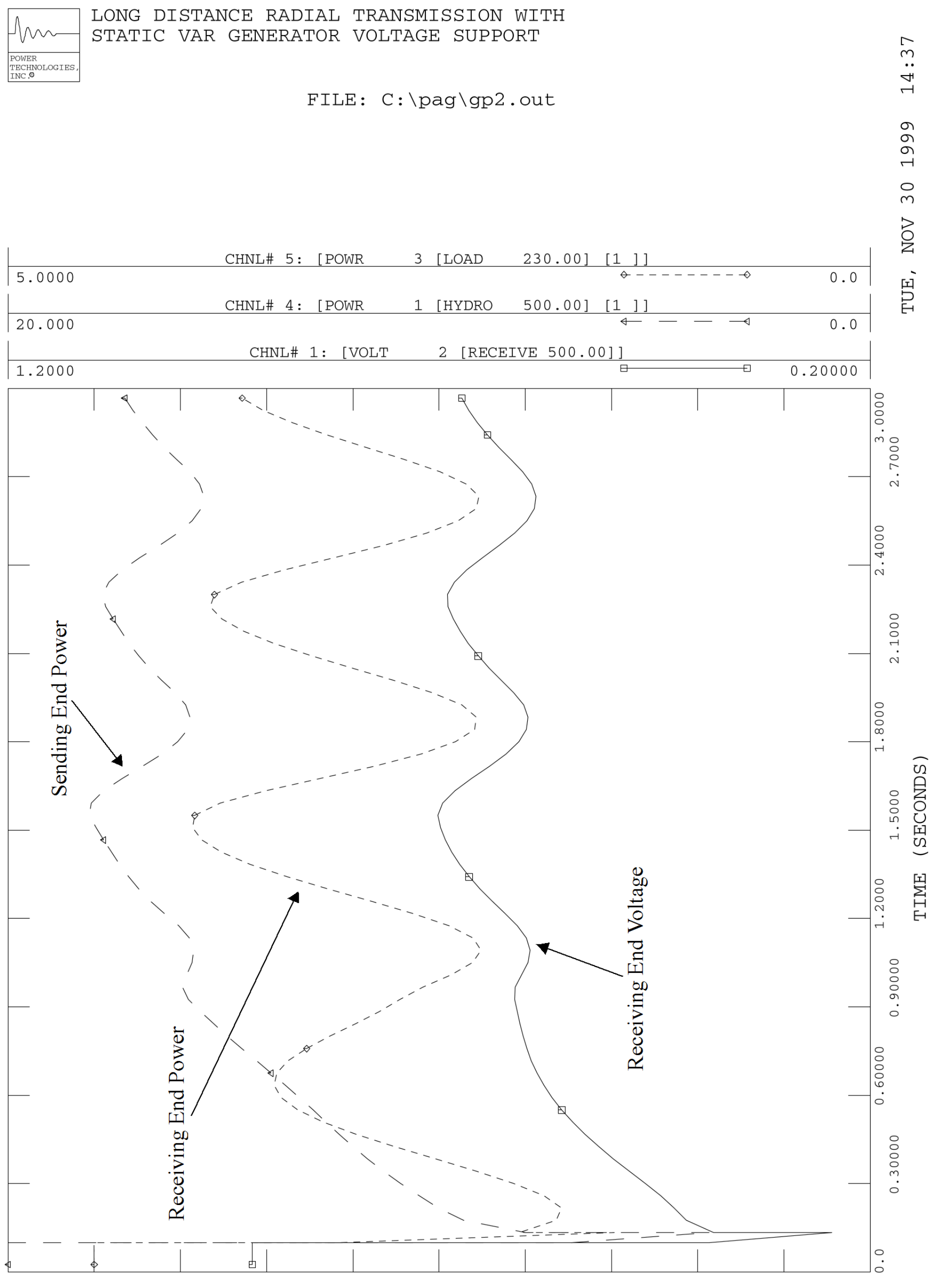


Figure 20.17. Time Domain Response Corresponding to Figure 20.15, "Relay Messages for Fault at Bus 1 End of Circuit 1 with Normal Clearing by DISTR1 but with Infinite Time Delay in DISTR1 on Circuit 2" and Figure 20.16, "Locus of Apparent Z Seen by DISTR1 on Circuit 2 Infinite Zone 3 Time"

```
** DISTR1 ** RELAY SLOT  FROM BUS   NAME  BSKV  TO BUS   NAME  BSKV  CKT ID
                  1             1 HYDRO   500        2 RECEIVE  500     2

                   I C O N S       C O N S       V A R S
                    32-60          83-106         13-22

                DISTANCE TYPE              MON/TRIP SETTING
                    1  (MHO)                       1

                TRANSFER TRIP 1:  FROM BUS   TO BUS  CKTID
                                      0          0    '0 '

                TRANSFER TRIP 2:  FROM BUS   TO BUS  CKTID
                                      0          0    '0 '

                TRANSFER TRIP 3:  FROM BUS   TO BUS  CKTID
                                      0          0    '0 '

               FLAG FOR SELF TRIP      FLAG FOR TRANSFER TRIP
                       0                         0

     CY1    REACH1   ANGLE1    DIST1      CY2   REACH2   ANGLE2    DIST2
   0.500     0.065   86.000    0.030    5.000    0.085   86.000    0.040

     CY3    REACH3   ANGLE3    DIST3  DIR ANG   THRESH  SELF TB  SELF TR
   8.000     0.110   86.000    0.055    0.000    1.000    1.500*********

 TRAN TB   TRAN TR  BL1 TYP  BL1 INT  BL1 ROT  BL2 TYP  BL2 INT  BL2 ROT
   1.500*********     2.000    0.035   86.000    0.000    0.000    0.000

RELAY DISTR1 # 1 CIRCUIT 1  FROM      1 TO      2 MESSAGES AT TIME =  0.100:
    APPARENT IMPEDANCE ENTERED ZONE(S)  1  2  3
    ZONE 1 2 3 TIMER(S)  STARTED

RELAY DISTR1 # 1 CIRCUIT 1  FROM      1 TO      2 MESSAGES AT TIME =  0.108:
    ZONE 1     TIMER(S) TIMED OUT
    SELF TRIP BREAKER TIMER STARTED

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  0.117:
    APPARENT IMPEDANCE ENTERED ZONE(S)  3    BEHIND BLINDER 1

RELAY DISTR1 # 1 CIRCUIT 1  FROM      1 TO      2 MESSAGES AT TIME =  0.133:
    SELF TRIP BREAKER TIMER TIMED OUT
*** CIRCUIT 1  FROM      1 [HYDRO    500] TO      2 [RECEIVE   500]
    TRIPPED AT TIME =   0.133
    SELF RECLOSURE TIMER STARTED

    7 DIAGONAL AND     8 OFF-DIAGONAL ELEMENTS

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  0.308:
    APPARENT IMPEDANCE OUTSIDE ZONES

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  1.833:
    APPARENT IMPEDANCE ENTERED ZONE(S)  3    BEHIND BLINDER 1

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  1.917:
    APPARENT IMPEDANCE OUTSIDE ZONES

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  2.550:
    APPARENT IMPEDANCE ENTERED ZONE(S)  3    BEHIND BLINDER 1

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  2.700:
    APPARENT IMPEDANCE OUTSIDE ZONES

RELAY DISTR1 # 1 CIRCUIT 2  FROM      1 TO      2 MESSAGES AT TIME =  3.283:
    APPARENT IMPEDANCE ENTERED ZONE(S)  3    BEHIND BLINDER 1
```

Blinder added to DISTR1 on circuit 2

Apparent Z seen by circuit 2 DISTR1 enter zone 3 circle, but does not cross blinder – timer not started

Circuit 2 DISTR1 loses sight of zone apparent Z

Sees it again but blinder prevents timer start

Figure 20.18. Relay Messages from Same Event as in Figure 20.11, “Dialog for Simulation with DISTR1 on Circuits 1 and 2 Between Buses 1 and 2 (Sheet 1 of 2)” and Figure 20.15, “Relay Messages for Fault at Bus 1 End of Circuit 1 with Normal Clearing by DISTR1 but with Infinite Time Delay in DISTR1 on Circuit 2”, but with Normal Zone 3 Time and Blinder on DISTR1 of Circuit 2

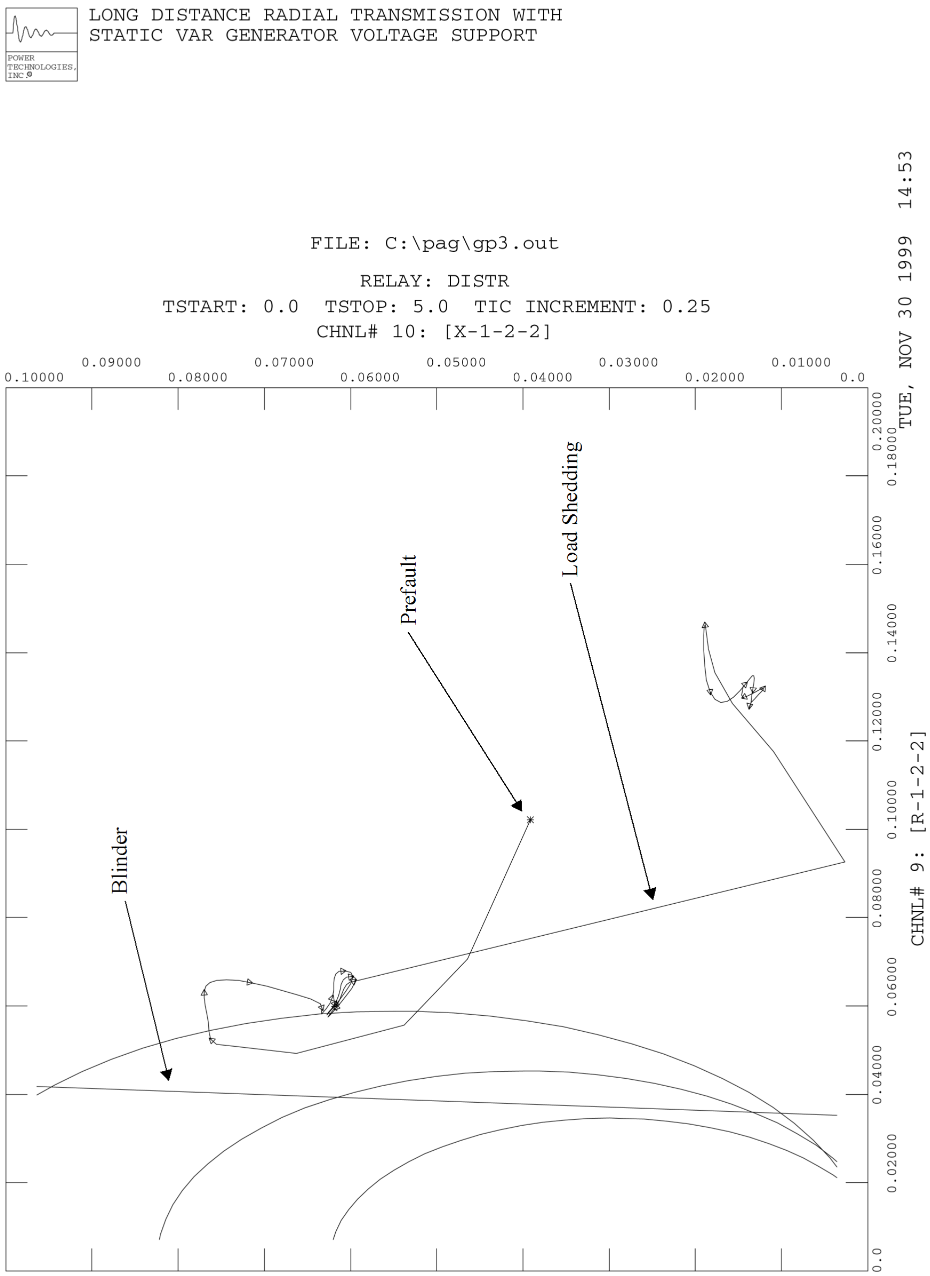


Figure 20.19. Locus of Apparent Z Seen by DISTR1 on Circuit 2

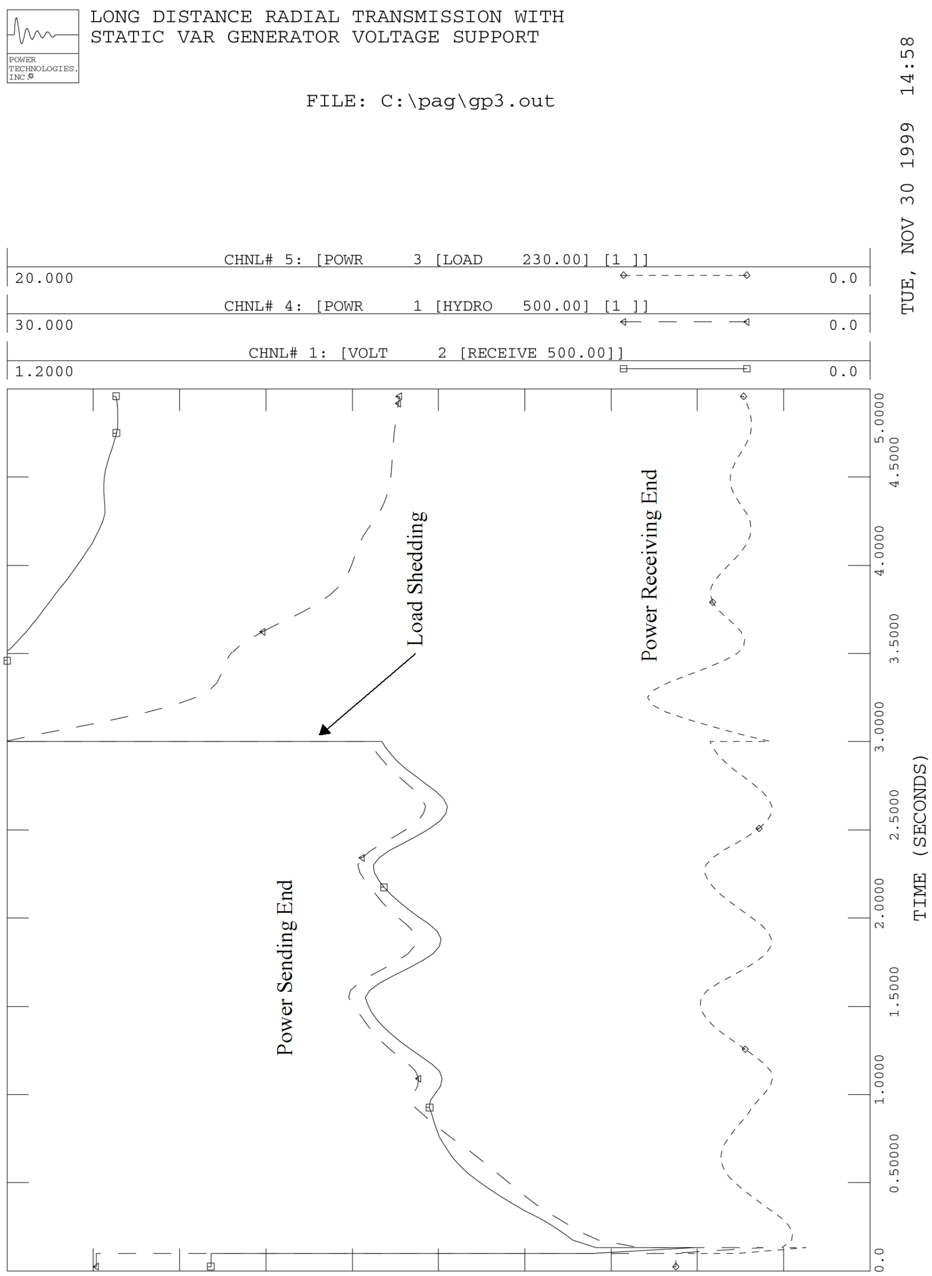


Figure 20.20. Time Domain Response

20.5. Model RXR1

The distance relay model (RXR1) represents a three-zone distance relay where logic characteristics are similar to those of DISTR1, but where zones are shaped as polygons rather than as blinded circles. The principal difference in logic between RXR1 and DISTR1 is that RXR1 starts all of its zone timers when the apparent impedance locus crosses into its outermost, or starting, zone. After timers are started, they continue to run until either one of them times out with the apparent impedance in its zone to send a trip signal, or the apparent impedance crosses back outside the starting zone. The timer for zone 1, 2, or 3 is not reset if the apparent impedance goes outside that zone but remains within the starting zone. The logic flow of RXR1 is shown in Figure 20.21, “Relay Model RXR1 Logic Diagram”.

20.6. Model CIROS1

20.6.1. Operation

The double circle or lens out-of-step relay model (CIROS1) detection is based on circular characteristics. CIROS1 may be used to trip its own line, transfer-trip up to three other lines, or control the supervisory flag of another relay. The purpose of the out-of-step relay is to detect the passage of the apparent impedance locus through zone 2. The arrangements of characteristics is shown in Figure 20.22, “Definition of Circular Zones in CIROS1”. Setting the type code, ICON(I+1), to +1 or -1 gives a pair of full-circle boundaries. Setting the type code to +2 or -2 gives a pair of lens-shaped boundaries. In both cases, the important thing is that the boundaries produce an inner zone, zone 1, surrounded by a second zone, zone 2. A rapid passage through zone 2 into zone 1 is interpreted as evidence of a fault. A passage taking more than a defined time, however, indicates a system swing or out-of-step situation. The detection logic of the relay is shown in Figure 20.23, “Conditions for Setting/Resetting Timers in CIROS1” and Figure 20.24, “CIROS1 Logic Diagram”.

A positive value of the type code, ICON(I+1), puts CIROS1 in tripping mode. In this mode it has no effect on the supervisory flag, if any, specified by its IFL argument; rather it establishes trip signals that are passed to its own and its transfer-trip circuit breakers, or are not passed, depending upon its own supervisory permissive flags, ICON(I+16) and ICON(I+17).

A negative value of type code, ICON(I+1), puts CIROS1 in its blocking mode, and it sends no trip signals to its own circuit breaker. Instead it sets the permissive flag of its supervised relay to zero on detection of an out-of-step condition. Transfer tripping actions of CIROS1 are the same in its tripping and blocking modes. CIROS1 is made to supervise another relay, a DISTR1 for example, by setting the calling argument, IFL, of CIROS1 to the ICON address of the supervised relay’s permissive flag. This cross referencing must be done via the relay editors or activity ALTR.

The supervisory, or permissive, flags of the supervised relay are set to 1 (permit tripping) by activity DYRE, and are not affected by activity STRT. CIROS1 affects the self-trip supervisory permissive flag of its supervised relay only on detection of the out-of-step condition, where upon CIROS1 sets this flag to zero. CIROS1 does not ever reset the permissive flag to 1.

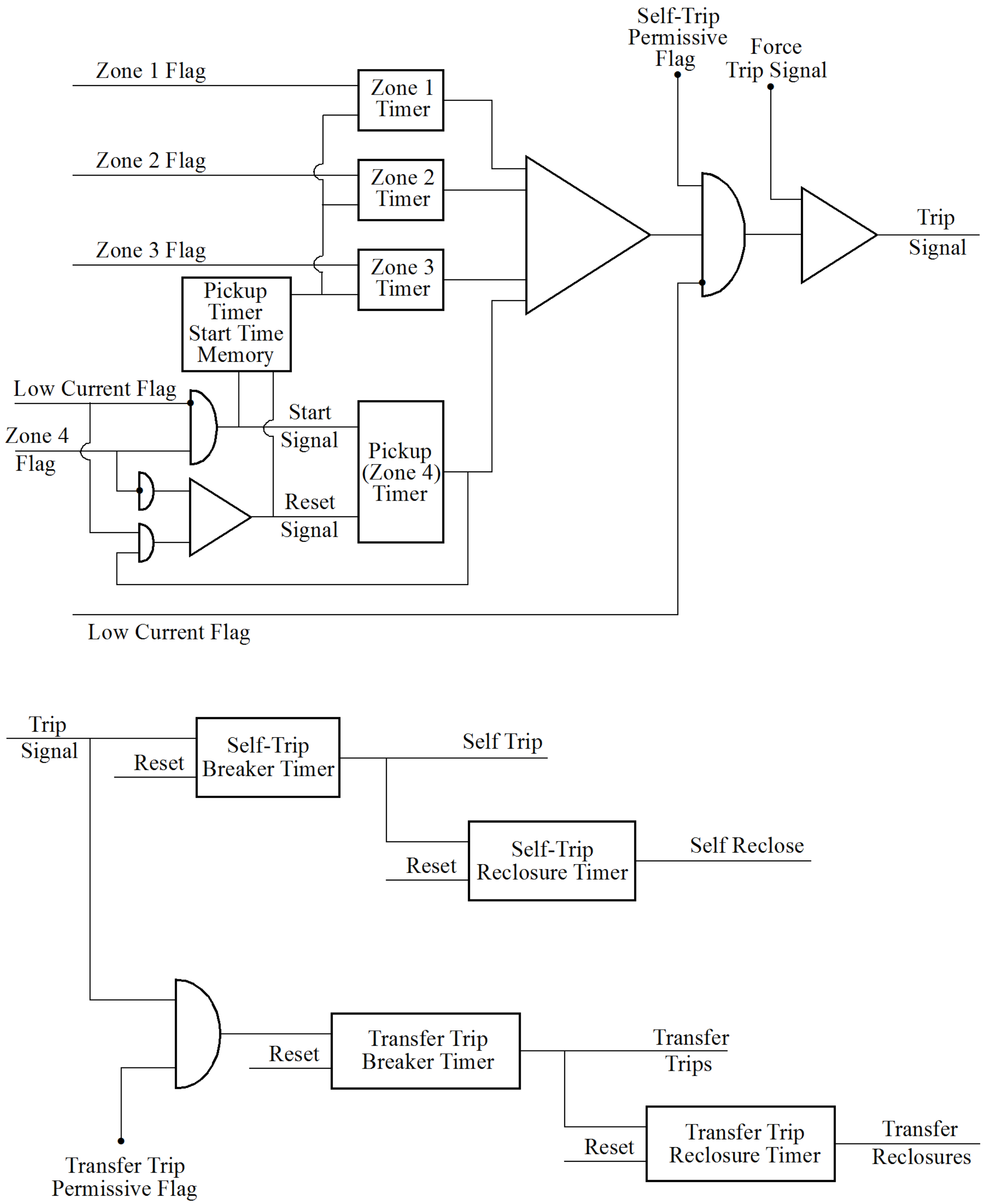


Figure 20.21. Relay Model RXR1 Logic Diagram

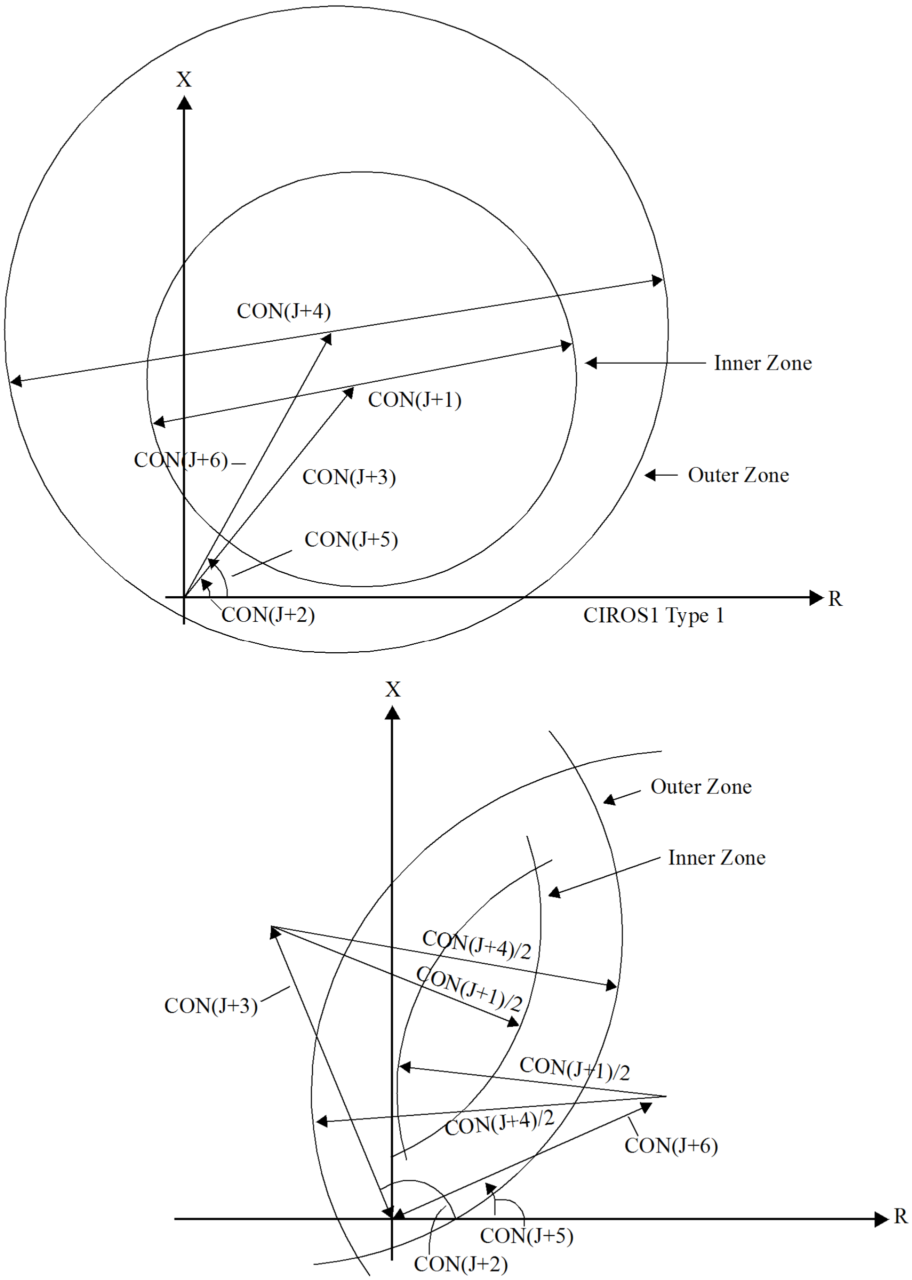
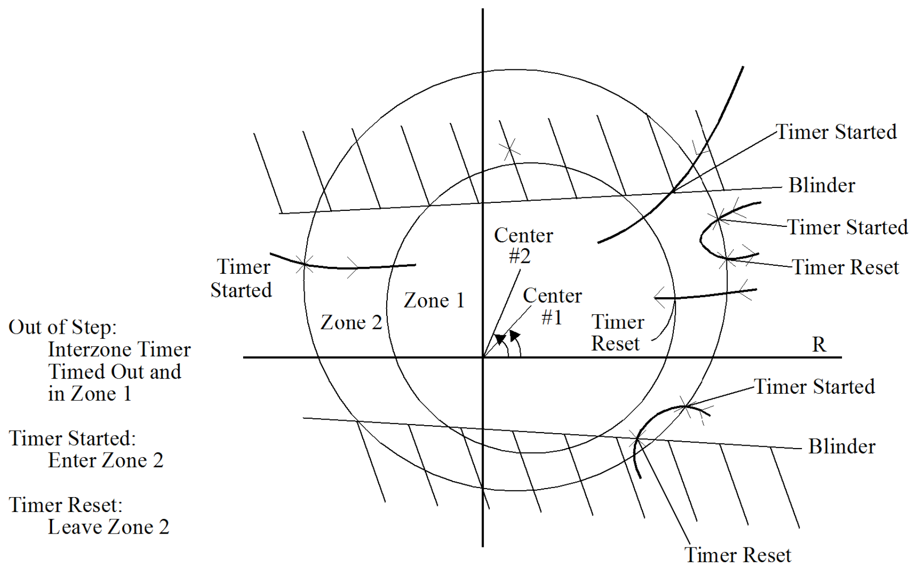
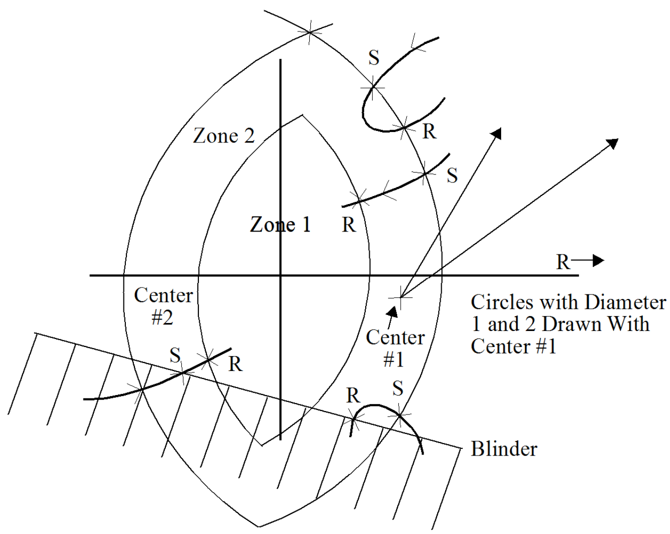


Figure 20.22. Definition of Circular Zones in CIROS1



a. Double Circle Geometry



b. Lens Geometry

Figure 20.23. Conditions for Setting/Resetting Timers in CIROS1

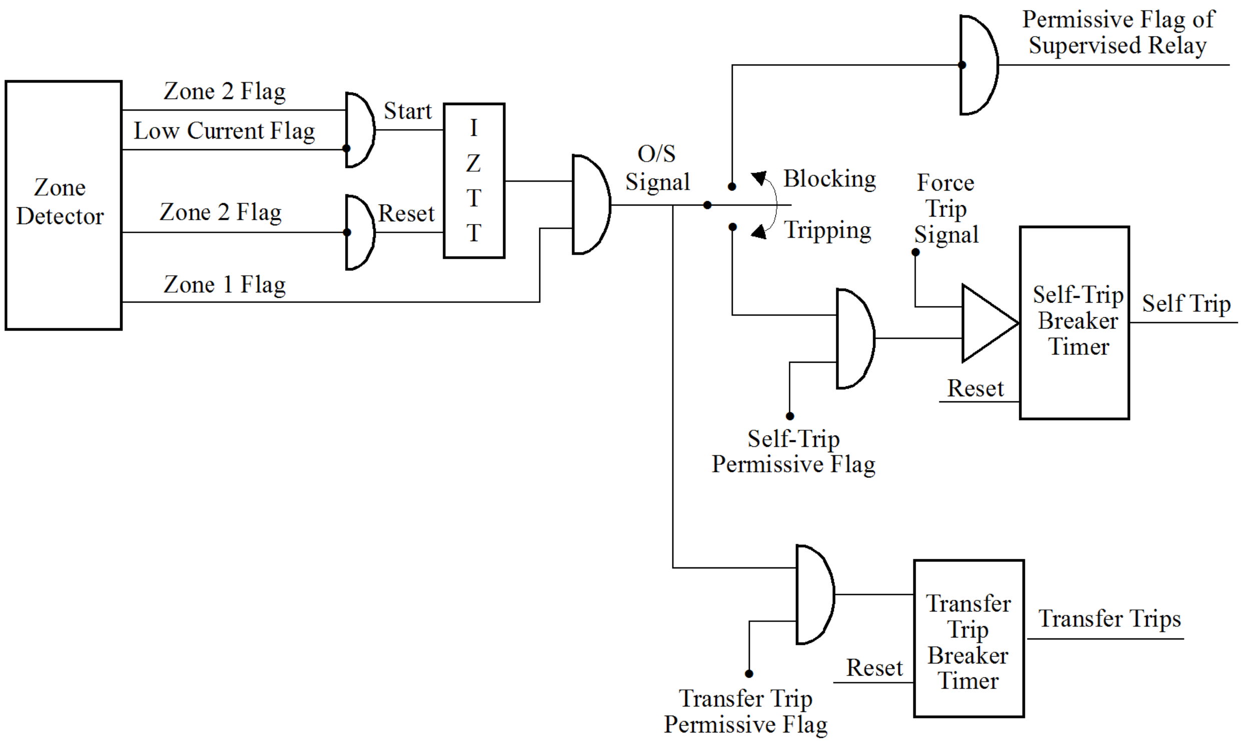


Figure 20.24. CIROS1 Logic Diagram

The following points should be noted in filling out the data sheet:

- The relay is at the from bus looking toward the to bus.
- If invalid line data is specified, the appropriate message is printed out during initialization.
- A from bus of 0 for a transfer trip bypasses the logic for that transfer trip.
- CIROS1's own permissive flags should be set to 1 by the user if tripping on out-of-step is required. The model does not initialize its own or any other permissive flags. Upon detection of an out-of-step, the permissive flag of a supervised relay contained in ICON(IFL) will be set to zero if CIROS1 is in the blocking mode.
- CIROS1 requires certain ICON and VAR locations for local storage of flags, etc. Care should be exercised not to overwrite these storage locations.
- The first three VARs used by CIROS1 are the per-unit resistance, reactance, and current. These values may be put into output channels. If the resolution of the relay is other than 1, the values will be constant between sample points.
- All angles are specified in degrees from the horizontal with anti-clockwise direction positive. Figure 20.22, "Definition of Circular Zones in CIROS1" specifies the geometrids.
- All timer settings are specified in cycles and include any delays.
- Resetting of timers is assumed instantaneous.

- If CIROS1 is used only for tripping on an out-of-step, the supervisory ICON can have a value of 0. If both tripping or blocking may be considered, it is recommended that the supervisory ICON be set to the address of the supervised relay’s permissive flag. The permissive flag of a supervised relay will be set to 0 only during the blocking mode upon detection of an out-of- step.
- The self-trip permissive flag of CIROS1 prohibits only self trip. All other operation is independent of the self-trip permissive flag.

20.7. Model SLNOS1

SLNOS1 is a generalized straight-line blinder out-of-step relay. SLNOS1 may be used to trip its own line, transfer-trip up to three other lines, or control the supervisory flag of another relay. A positive value of ICON(I +1) indicates that the model is used for tripping while a negative value indicates it is used for blocking. A magnitude of 1 for ICON(I+1) indicates the relay is the single blinder type while a magnitude of 2 indicates a double blinder type.

The purpose of the relay is to note an out-of-step situation through a system swing by measuring the time taken for the apparent impedance locus to pass through defined zones. The detection logic for the single blinder type relay is shown in Figure 20.25, "SLNOS1 Single-Line Blinders"; the zones are defined in Figure 20.26, "Zone Definition for Single Blinder of SLNOS1". An out-of-step signal will be sent when after spending a defined time in zone 1, the apparent impedance locus goes to zone 5 if it originated in zone 2 or to zone 2 if it originated in zone 5. Figure 20.27, "SLNOS1 Relay Logic After Receiving Out-of-Step Signal" diagrams the remaining relay logic after an out-of-step signal. The detection logic for the double blinder characteristic is shown in Figure 20.28, "SLNOS1 Double Line Blinders"; zones are defined in Figure 20.29, "Zone Definition for Double Blinder SLNOS1". This relay sends an out-of-step signal when in zone 2 only if the apparent impedance loci takes a minimum predefined time, the interzone travel time, to go from the outer zones (4 or 5) through the inner zones (3 and 1, respectively). The remaining logic upon receipt of an out-of-step signal is as for the single blinder shown in Figure 20.27, "SLNOS1 Relay Logic After Receiving Out-of-Step Signal". SLNOS1 has additional blinders to further restrict its sensitive zones. The blinder type can be set to zero to ignore the extra blinders.

In the tripping mode the supervisory ICON for this model remains unchanged. In the blocking mode the model can still be used for up to three transfer trips.

SLNOS1 is made to supervise another relay, a DISTR1 for example, by setting the supervisory ICON, of SLNOS1 to the ICON address of the supervised relay's permissive flag. This cross-referencing can be done via the relay editors or activity ALTR.

The supervisory, or permissive, flags of the supervised relay are set to 1 (permit tripping) by activity DYRE, and are not affected by activity STRT. SLNOS1 affects the self trip supervisory permissive flag of its supervised relay only on detection of the out-of-step condition, whereupon SLNOS1 sets this flag to zero. SLNOS1 does not ever reset the permissive flag to 1.

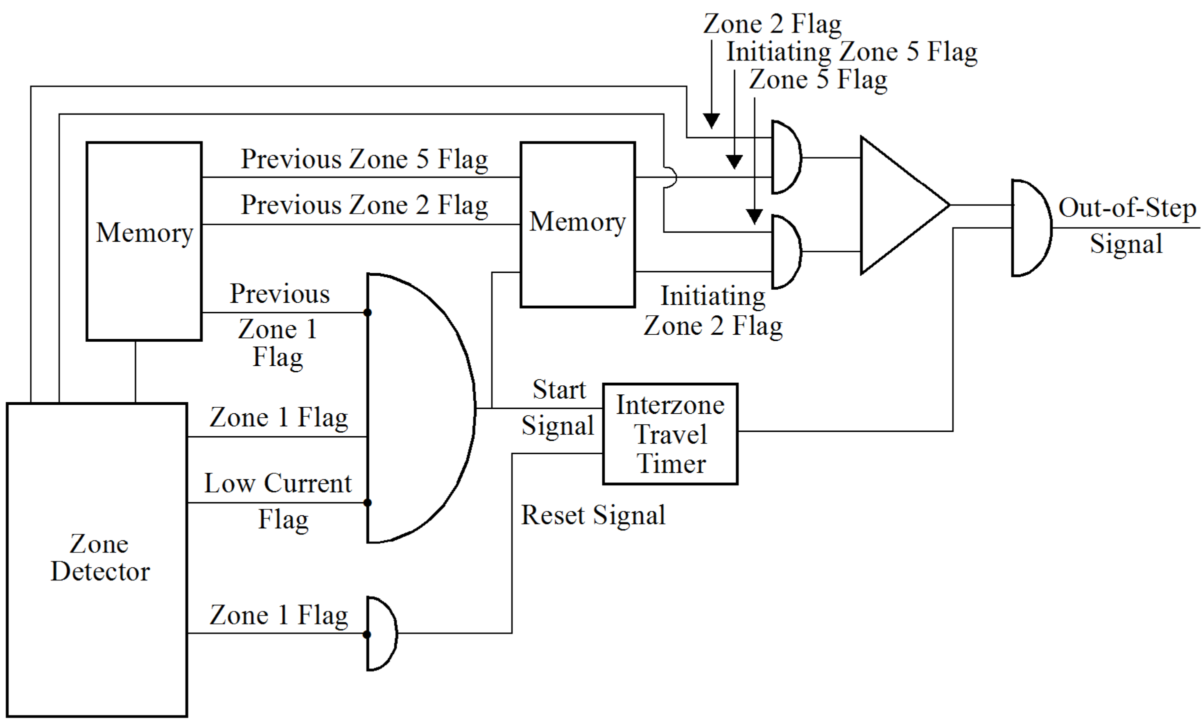


Figure 20.25. SLNOS1 Single-Line Blinders

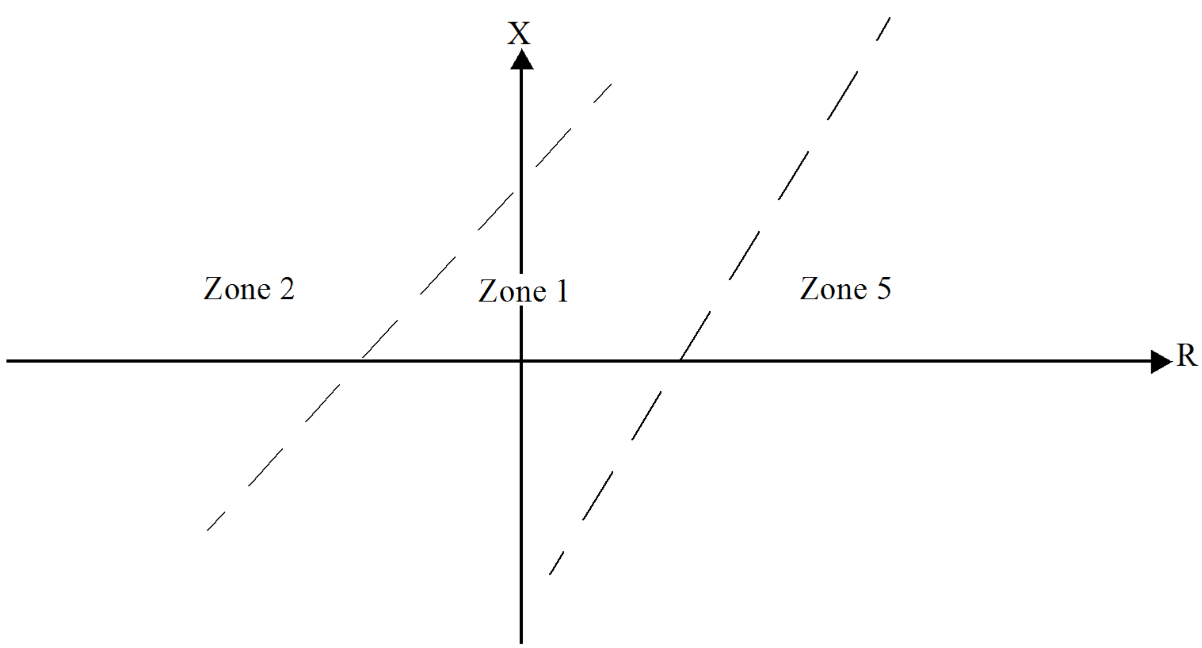


Figure 20.26. Zone Definition for Single Blinder of SLNOS1

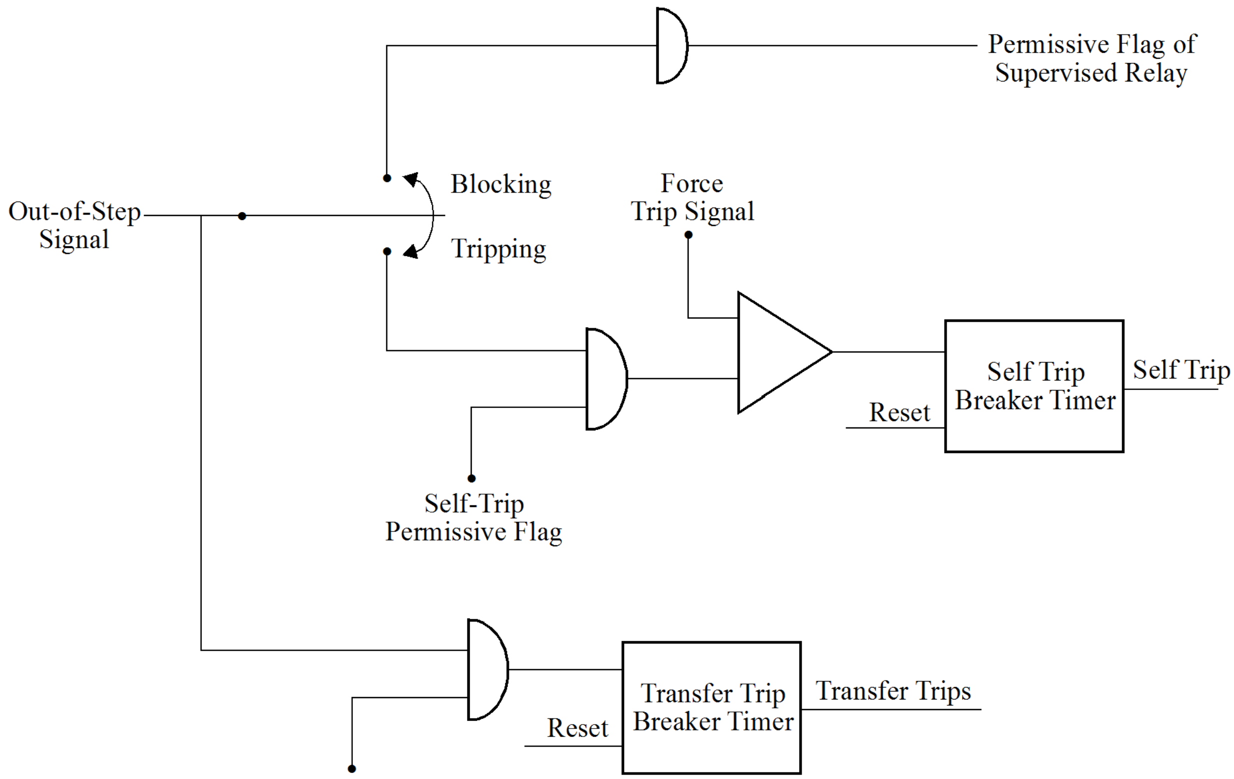


Figure 20.27. SLNOS1 Relay Logic After Receiving Out-of-Step Signal

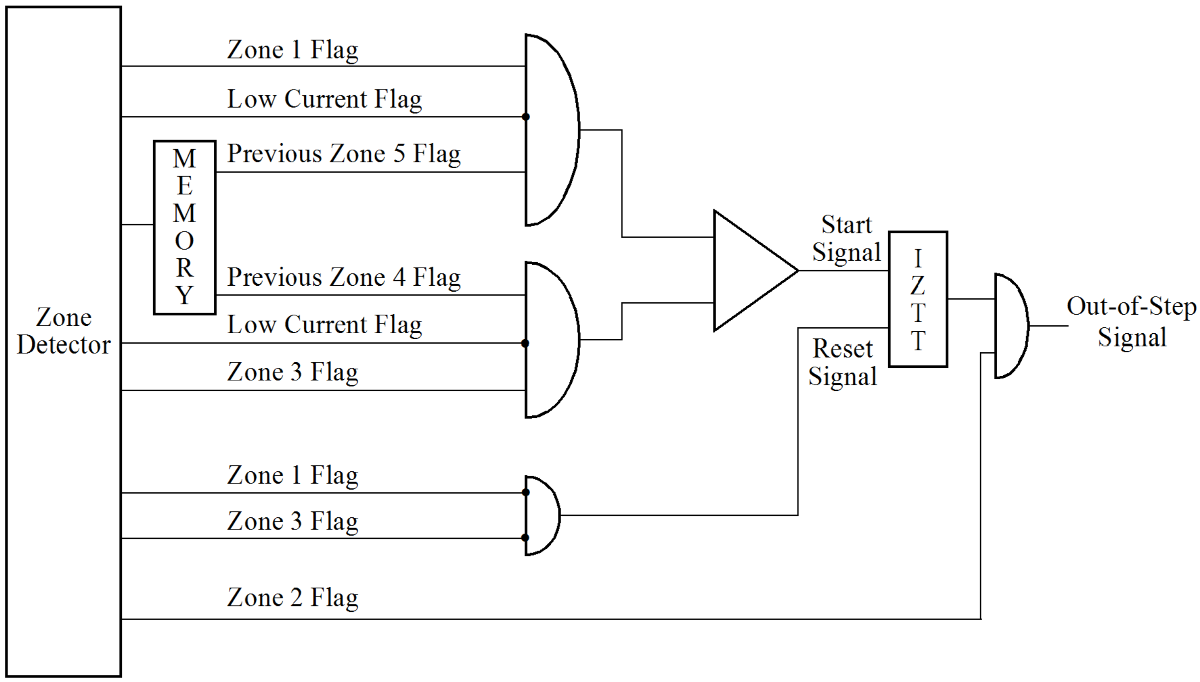


Figure 20.28. SLNOS1 Double Line Blinders

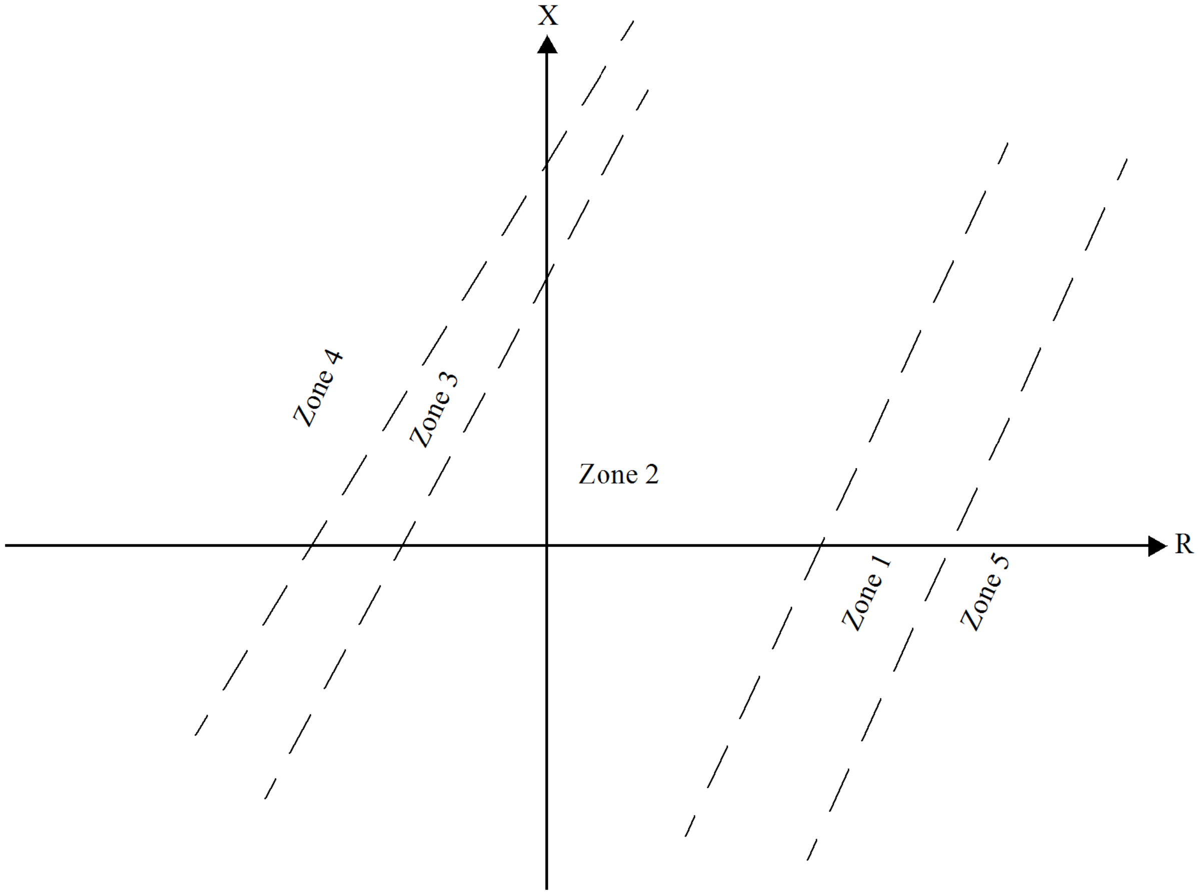


Figure 20.29. Zone Definition for Double Blinder SLNOS1

The following points should be noted in filling out the data sheet:

- The relay is at the from bus looking toward the to bus.
- If invalid line data is specified, the appropriate message is printed out during initialization.
- A from bus of 0 for a transfer trip bypasses the logic for that transfer trip.
- SLNOS1's own permissive flags should be set to 1 by the user if tripping on out-of-step is required. The model does not initialize its own or any other permissive flags. Upon detection of an out-of-step, the permissive flag of a supervised relay contained in the supervisory ICON will be set to zero if SLNOS1 is in the blocking mode.
- SLNOS1 requires certain ICON and VAR locations for local storage of flags, etc. Care should be exercised not to overwrite these storage locations.
- The first three VARs used by SLNOS1 are the per-unit resistance, reactance, and current. These values may be put into output channels. If the resolution of the relay is other than 1, the values will be constant between sample points.

- Angles are specified in degrees from the horizontal with anti-clockwise direction positive.
- All timer settings are specified in cycles and include any delays.
- Resetting of timers is assumed instantaneous.
- If SLNOS1 is used only for tripping on an out-of-step, the supervisory ICON can have a value of 0. However, if both tripping or blocking is considered, this ICON should be set to the address of the supervised relay's permissive flag. This permissive flag will be set to 0 only during the blocking mode after detecting an out-of-step.
- The self-trip permissive flag of SLNOS1 prohibits only self trip. All other operation is independent of the self-trip permissive flag.

20.8. Model DPDTR1

Model DPDTR1 represents a power relay rate of change. The logic diagram for this relay is shown in Figure 20.30, “DPDTR1 Logic Diagram”. For this relay, both the derivative of the power and the power itself must be above their individual thresholds to start the timer. The timer is reset, after the delay time, if either of these thresholds is not met. If both thresholds are met after the delay time, the line to which it is applied will trip after the breaker time.

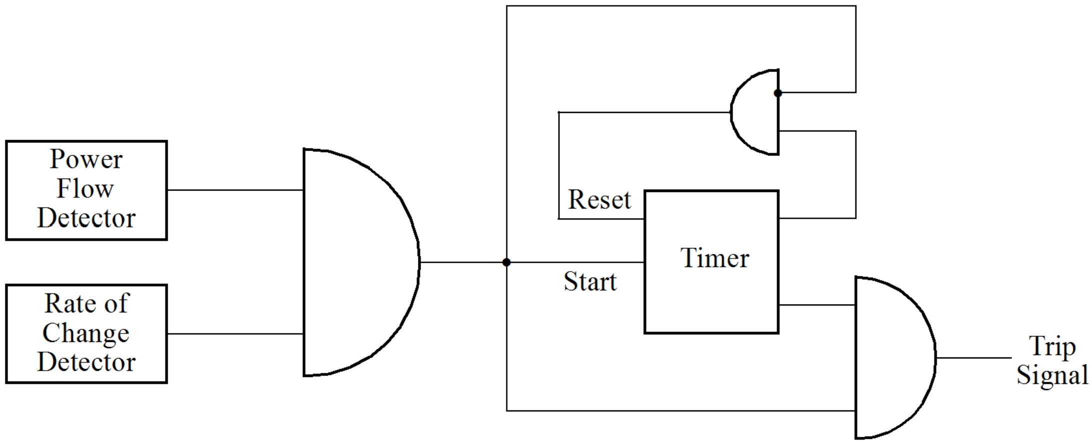


Figure 20.30. DPDTR1 Logic Diagram

The following should be noted about this model:

- The relay is at the from bus looking toward the to bus.
- If invalid line data is specified, the appropriate message is printed out during initialization.
- A from bus of 0 for the transfer trip bypasses the logic for it.
- Timers are specified in sec.

20.9. Model TIOCR1

Model TIOCR1 is an overcurrent relay with an inverse-time characteristic as defined in Figure 20.31, "Time-Inverse Operating Characteristic of TIOCR1". The four current points and the saturation or largest current point are all entered as CONs and should be entered as a multiple of the pickup or threshold current that is entered on system base, usually 100 MVA. The time-to-close relay for each point is the time that the relay would take to close its trip contact if presented with a constant input current. The actual time to close the trip contact in response to a varying input current is given by the integral of the rate of motion of the sensitive element, as defined in Figure 20.31, "Time-Inverse Operating Characteristic of TIOCR1". The movement occurs for any value of current exceeding the threshold current.

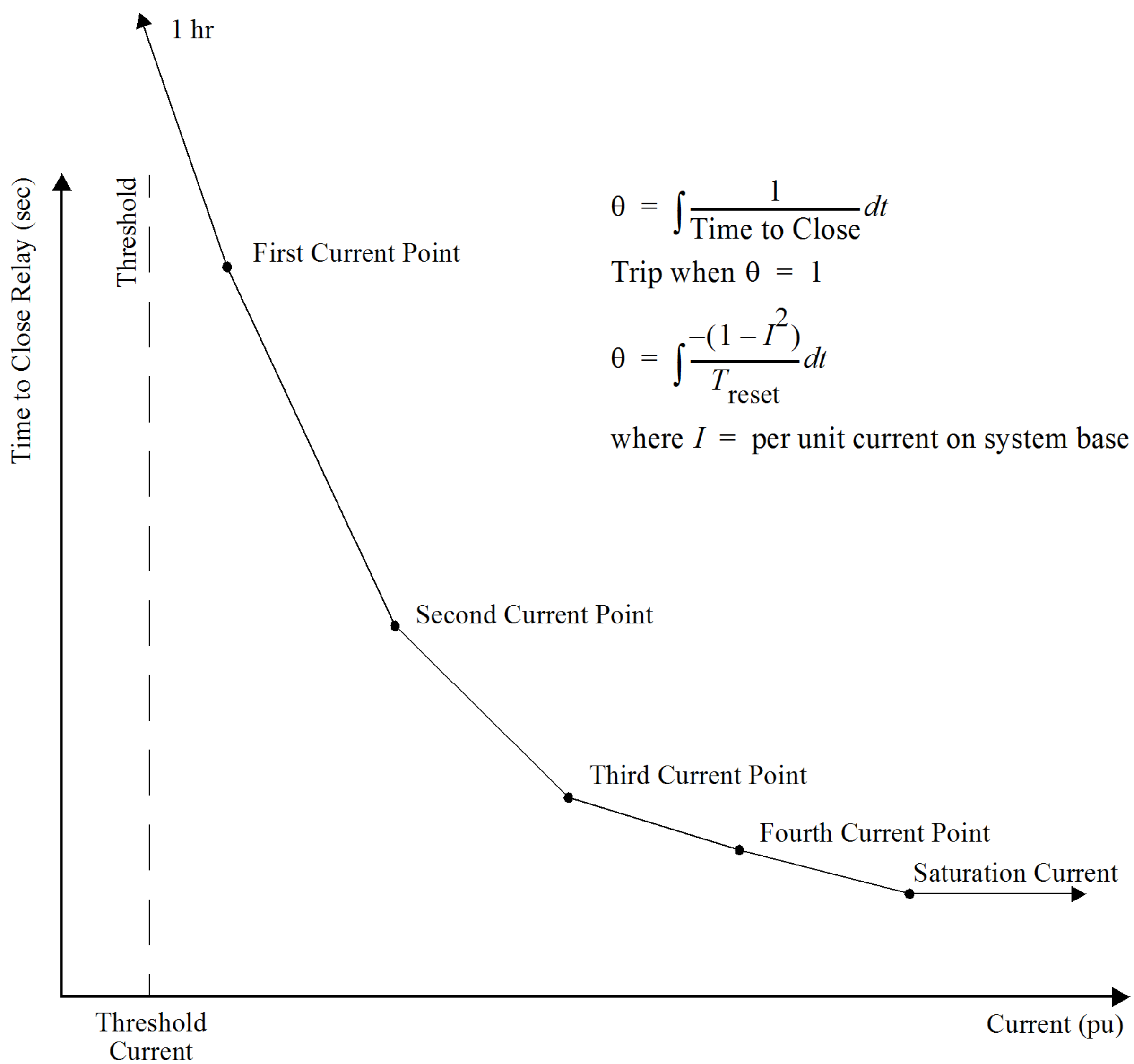


Figure 20.31. Time-Inverse Operating Characteristic of TIOCR1

The model assumes that at constant threshold current it would take one hour for the contact to close. The relay does not reset immediately if current goes below the threshold; it resets in a linear fashion at a rate proportional to the square of the deviation of current from the threshold. With zero current, it would take T_{reset} sec to reset, while with a current just at the threshold it would never reset. If the current goes above the pickup threshold current during the resetting process, the relay commences integrating toward its trip contact closure from its partially reset condition.

This model allows for the remote (transfer) trip of up to three lines and allows for the disconnection (shedding) of load at any bus. The model can self-trip if specified as one of the transfer-trip lines. A from bus of 0 for a transfer-trip bypasses logic for that transfer-trip. Also, specifying a bus number of 0 for the load shedding bypasses that logic. When load on a bus is shed, the relay model operates identically on constant MVA load, constant current load, and constant admittance load.

20.10. Advanced Uses of Branch Relay Models

The user may want to add information to subroutine CONET to run a more exotic coordination of relays than the simple supervisory logic built into the models. This section describes how specific ICONs are set by the relays. An assumed breaker time greater than zero for all the models achieved the ICON summarizations that follow.

20.10.1. DPDTR1 Flags

When the timer has timed out and the relay is still in the active zone of relay DPDTR1, ICON I+6 is set to 2. ICON I+6 is set to 3 when the breaker has timed out.

20.10.2. TIOCR1 Flags

ICON I+12 is set to −1 when the timer has timed out for relay TIOCR1. When it is time for the breaker to trip, ICON I+14 is set to 1.

20.10.3. DISTR1 Flags

The ICONs, which are set to 1 when zone 1, 2, and 3 time out for relay DISTR1, are I+16, I+18, and I+20, respectively. ICON I+22 is set to 1 when the breaker opens.

20.10.4. RXR1 Flags

If any timer times out for relay RXR1, ICON I+14 is set to 1. Breaker opening occurs when ICON I+16 is set to 1.

20.10.5. CIROS1 Flags

Both ICON I+17 and I+18 are set to 1 when an out-of-step condition is detected by CIROS1. If it is tripping, ICON I+21 is set to 1 at breaker opening.

20.10.6. SLNOS1 Flags

SLNOS1 sets ICON I+17 to 1 when it detects an out-of-step condition. If a breaker is to open, ICON I+21 is set to 1.

20.10.7. SLLP1 Flags

SLLP1 sets ICON I+19 to 2 when it detects an out-of-step condition. To open a breaker, ICON I+16 is set to 1.

20.10.8. LOEXR1 Flags

LOEXR1 sets ICONs M+2, M+4, and M+6 to 1 when it detects loss of excitation on zones 1, 2, and 3, respectively, and the corresponding zone timer has timed out. At breaker opening, ICON M+8 is set to 1.

20.11. Model SLLP1

The out-of-step relay model (SLLP1) detection is based on three lenses. There are two philosophies that are used for out-of-step tripping with SLLP1: (1) tripping on the way in and (2) tripping on the way out. For tripping on the way in, a passage of time greater than T1 through zone 1 and a passage time greater than T2 through zone 2 must occur consecutively before the apparent impedance enters zone 3. Figure 20.32, "Tripping on Way In" shows the tripping sequence in this mode. For tripping on the way out, in addition to the passage times on the way in, the apparent impedance must stay in zone 3 for T3 cycles and exiting passage time T4 through zones 2 and 1 must also be satisfied. The relay will then send an out-of-step signal upon exiting all lenses. Figure 20.33, "Tripping on Way Out" shows the tripping sequence in this mode. Both T3 and T4 must be greater than zero to force SLLP1 to assume tripping on the way out.

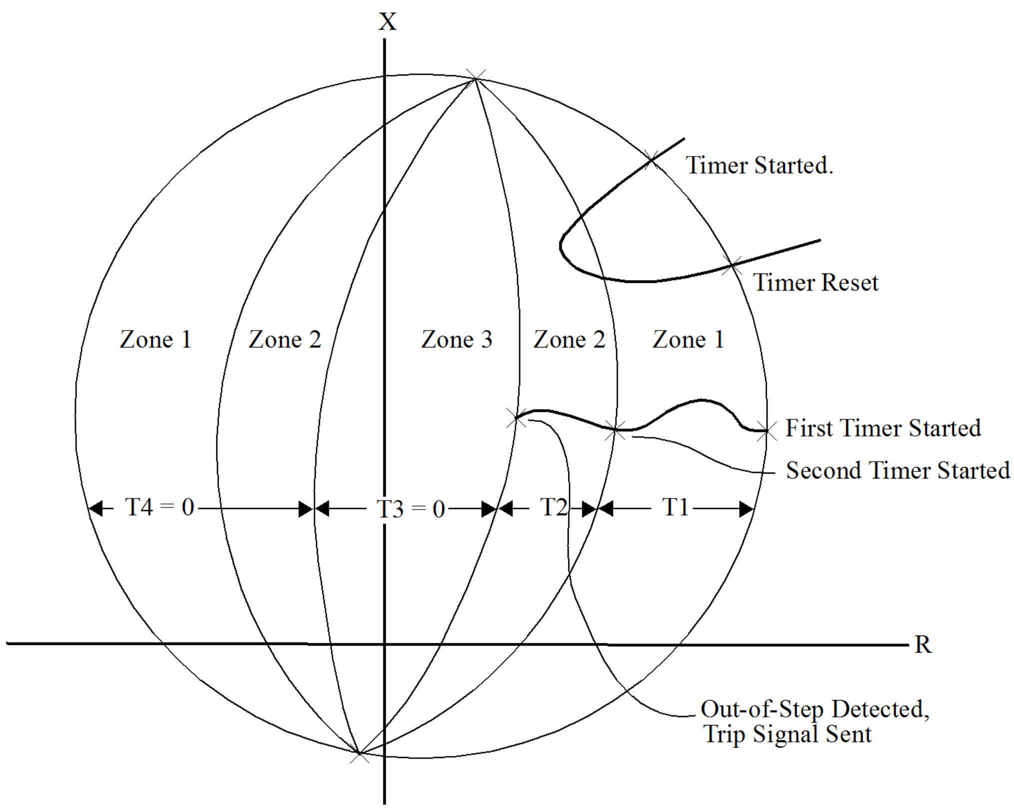


Figure 20.32. Tripping on Way In

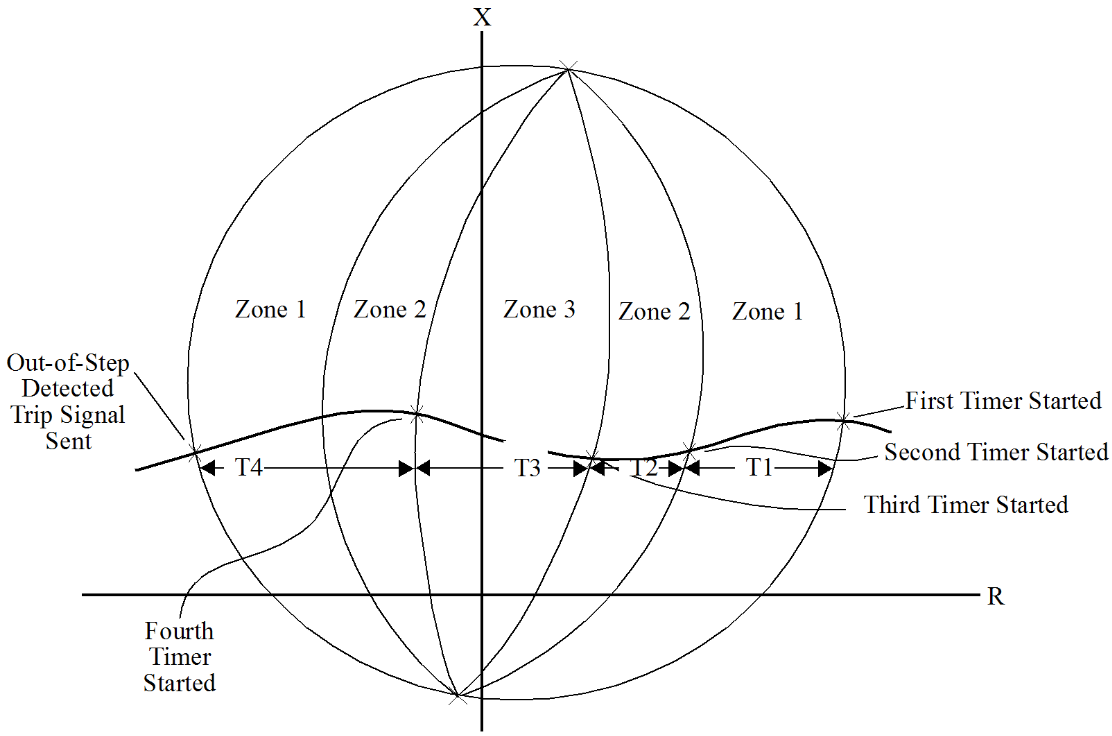


Figure 20.33. Tripping on Way Out

Rapid passage through any zone signifies that an out-of-step has not occurred. The apparent loci must subsequently leave all zones and reenter to restart the timers. The model will print messages based on zone changes even though timers are not active. SLLP1 may be used to trip its own line and to transfer-trip up to three other lines. The following points should be noted in filling out the data sheet:

- The relay is at the from bus looking toward the to bus.
- If invalid line data is specified, the appropriate message is printed out during initialization.
- A from bus of 0 for a transfer trip bypasses the logic for that transfer trip.
- SLLP1's own permissive flags should be set to 1 if tripping an out-of-step is required.
- SLLP1 requires certain ICON and VAR locations for local storage of flags, etc. Care should be exercised not to overwrite these storage locations.
- The first three VARs used by SLLP1 are per-unit resistance, reactance, and current. These values may be put in output channels.
- All time settings are specified in cycles.
- Resetting of timers is assumed to be instantaneous.

20.12. Model LOEXR1

Model LOEXR1 detects loss of excitation that can lead to armature core-end heating (end-turn heating) or rotor overheating due to operation as an induction generator, and may be detrimental to system performance due to the var drain imposed on the system. End-turn heating is more often associated with under-excitation operation and forms a part of the generator capability curve. Rotor heating due to induced rotor currents may cause dangerous over-temperatures in just several minutes. Stator over-heating may also occur due to combination of the power being delivered by the generator and the large var flow into the generator, but the rate of heat buildup will generally be considerably less than that occurring in the rotor. In many cases, the effect of the loss of var supply and the var drain on the system may be paramount to other effects and result in instability and severe low-voltage conditions in the vicinity of the failed generator.

The loss of excitation condition is generally detected by under-current or under-voltage relays in the field circuit, or by directional distance relays looking into the generator from the generator terminals and modeled by LOEXR1. Operation of the current and voltage relays in the field circuit is fairly obvious, and operation of the distance relay can be most readily visualized by use of the RX diagram shown in Figure 20.34, “Loss of Field Trajectory and Protective Relay”.

As the generator field is lost, rotor direct axis flux will decay, and the machine will speed up and go out-of-step with the rest of the system. The shock to the system as the machine goes out-of-step will not be severe because the generator rotor flux level (or machine internal voltage) will be low.

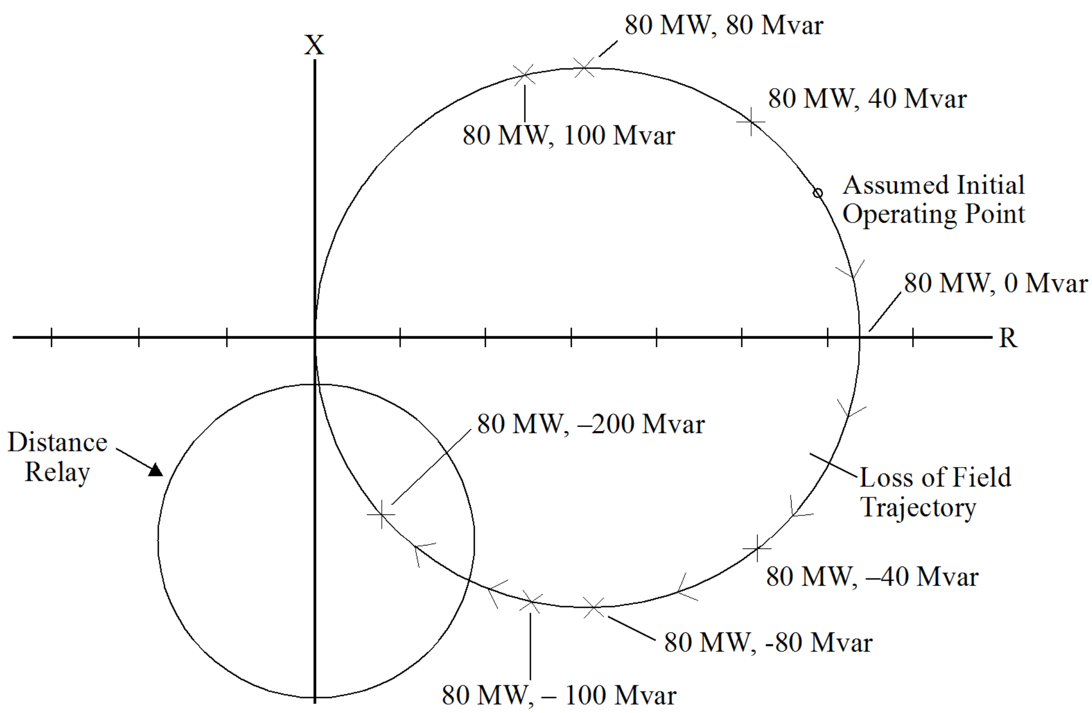


Figure 20.34. Loss of Field Trajectory and Protective Relay

Neglecting any power swings, due to flux in the rotor, the machine will make the transition from synchronous generator to induction generator including a period of increased rotor speed with approximately constant power output. During the transition, however, var output will decrease to zero and go negative, to a value two to four times machine rated var output. Figure 20.34, “Loss of Field Trajectory and Protective Relay” indicates the trace or locus that would be scribed by a 100-MVA generator (0.8 pf) initially operating at rated output and for which excitation is lost. Holding the power flow at the relay CT and PT locations constant and varying var flow from plus infinity to minus infinity allows a circle to be scribed on the RX diagram as indicated in Figure 20.34, “Loss of Field Trajectory and Protective Relay”.

The LOEXR1 model has been written to accommodate up to three zones, though usually only one or two are used. The zone reach (diameter) should be set to zero to disable a zone. The model has also be supplied with a voltage pickup point, VOLPIC. On some relay units, the voltage must drop below this value for the relay to trip. VOLPIC should be set to a large number if voltage is to be ignored.

Distances and reaches (diameters) should be entered on the machine base, MBASE of the unit being protected. The center distances are normally negative values based on the assumption that relays are set looking into the generator from its terminals, typically at a 90° angle.

20.13. Model SLYPN1

SLYPN1 models a positive-sequence distance relay, such as the GE solid-state types SLYP51B and SLYP51D used for directional comparison relaying. This model also represents, as an option, overcurrent relays such as the GE SLCN51D, which is often provided with the above mentioned units.

Directional comparison relaying often requires an additional distance relay at each terminal; this model was written so that identical units with different setpoints are assumed to be located at both line ends. These units are first made up with underreaching positive-sequence directional mho tripping functions for zone 1 protection. Either unit can send a trip signal to the breaker. This first zone protection is not sensitive (i.e., it ignores) to the relay unit looking away from the line or any optional blocking schemes provided with this relay. Figure 20.35, "Directional Comparison Scheme Assumed" indicates the method of directional comparison relaying assumed in this model. This model has included in it two directional units at each terminal, one unit looking through the protected line, like a normal second zone unit, and one unit looking away from the line. These two units are indicated as Z_2 and Z_b in Figure 20.35, "Directional Comparison Scheme Assumed". At each terminal the Z_2 unit is connected to trip through a normally closed pair of contacts operated by a receiver. The Z_b unit is connected only to operate the transmitter, which in turn picks up the receiver at each terminal. The Z_b unit is arranged to have faster operating time (instantaneous) then the Z_2 unit so that when an external fault occurs the Z_b unit can successfully block tripping by the Z_2 unit.

Operation then occurs as follows. Fault F1 (anywhere on the protected line) will cause both the Z_2 units to pickup and trip with high-speed. Faults F3 and F4 will cause the Z_b unit of relay R1 and the Z_2 unit of relay R2 to pickup. However, the Z_b unit will pick up first and transmit a block signal that will prevent tripping by the Z_2 unit. Fault F5 will pickup only the relay R1 Z_b unit with no consequence. Fault F6 will prompt no action from the directional comparison relaying.

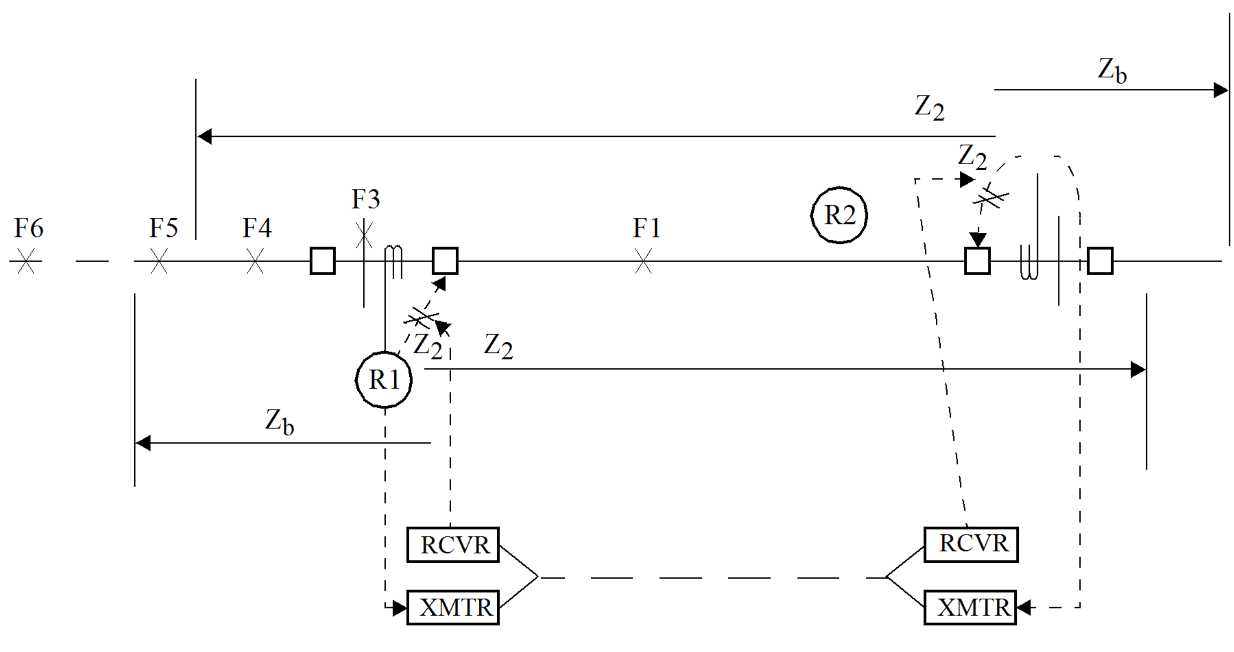


Figure 20.35. Directional Comparison Scheme Assumed

The zone 2 unit has a lens shape; the blocking relay has a standard circular mho shape. The model reports that the apparent impedance has entered zone 4 when the reverse reaching relay looking away from the terminal has picked up. When the reverse looking relay blocks, this model assumes the zone 2 timer is reset.

As an option, the SLYP51X relays may have a positive-sequence out-of-step distance function with a characteristic concentric with the zone 2 lens. The model flags the apparent impedance as being in zone 3 when it is in the area between the lens and its concentric circle. A slow passage through zone 3 thus indicates a swing or out-of-step situation. If the loci passages takes longer than the interzone travel time specified by the user, this optional function will block subsequent zone 2 tripping by this model. When blocked, the zone 2 timer will reset. The zone 3 timer only resets when the apparent impedance goes outside the outer circle.

The model also has an optional overcurrent supervisory function provided with it. If the supervisory function is set for blocking, current above the user specified supervisory level will cause zone 2 tripping to be blocked and the zone 2 timer to be reset. When the supervisory function is set for tripping, current above the user specified supervisory level will cause a trip signal to be sent instantaneously to the breaker regardless of any blocking signals or if the apparent impedance falls in the R-X plane. The model is also assumed to have single attempt reclosure for zone 1 trips only. The model assumes all distances and reaches are entered as positive values, and angles are between 0 and 90°. As for all PSS®E relays, all times should be specified in cycles.

This relay has one additional feature that other PSS®E relays do not have: the capability to disconnect one phase. As part of the input data for the model, the user can place equivalent positive-sequence data to model the protected line while one phase is opened. This equivalent may be obtained from activity SPCB or by other means. If the user inputs a X_{equiv} greater than 1000, the model assumes that all three phases are to be tripped.

The user should be careful, when using this model to trip a single phase, to ensure that no other relays are present on the line because the apparent impedance values and currents the other relays will see while one phase is opened will be calculated on the basis of the equivalent.

20.14. Model SCGAP2

The series capacitor gap relay model (SCGAP2) represents a current-induced relay that shorts out a series capacitor (flashes the gap) and can also be used to protect series inductors. SCGAP2 allows the user to specify first a monitored element and then the branch to be bypassed; they may be the same. When current in the monitored branch exceeds the gap firing current, a signal is sent to bypass the series capacitor branch. It bypasses after a communication delay, which can be specified as zero.

When the capacitor has flashed, a shorting switch timer starts. If the current does not go below the reinsertion current and satisfy the reinsertion duration, this switch permanently closes and does not allow capacitor reinsertion. The user specifies the number of allowable reinsertion attempts.

The model will transfer-trip up to three lines. Transfer-tripping can be initiated either the first time the capacitor bypasses or when the shorting switch closes.

Chapter 21
Load Modeling

21.1. Introduction to Application of Load Models

Load characteristic and load relay models may be introduced by subsystem. Subsystems can be designated as bus, owner, zone, area, or all. Each load model is available as a family of models; one for each subsystem type. For example, the IEEE load characteristic model is available in five forms:

Subsystem Type	Model Name
Bus	IEELBL
Owner	IEELOW
Zone	IEELZN
Area	IEELAR
All	IEELAL

These models are collectively referred to as the IEEL type models or as the IEELBL family of models. The last two characters of the model name refer to the subsystem type. This convention is applied throughout the load model library.

The presentation of a single data record for a subsystem model can generate multiple instances of the model's application. For example, presenting a bus-specific model with a wildcard element identifier (e.g., load-related model with IL='*') will generate an instance of the model for every load connected to the bus. Also, presenting an area specific subsystem model with a specific identifier (e.g., load-related model with IL='1') will generate as many instances of the model as there are loads within the area that are assigned that identifier.

Precedence is an issue unique to subsystem models. The data presentation for subsystem models may involve intersection among the subsystems. The data may contain a presentation for both a bus-specific model and an area-specific model, and the bus associated with the first model may belong to the area associated with the second. Therefore, a precedence order is provided to accommodate subsystem models. The decreasing order of precedence for resolving conflicts is from the most specific to most general subsystem; bus, owner, zone, area, and all. A model applied to a bus will take precedence over all conflicting models applied to any other subsystem in which the bus exists. A model applied to an owner will take precedence over any conflicting model applied to a zone, area, or to all buses.

A precedence order is provided to accommodate conflicts in element identifier as well. A data record that introduces a subsystem model with a specific element identifier will take precedence over a subsystem model with a wildcard ('*') identifier.

Load-type models employ data sharing among the loads for which a model is applied. That is, one set of CON and ICON data is used for all applications of the model. However, if required, VAR, STATE, and reserved ICON space is allocated for each load to which the model is applied. In other words, VAR, STATE, and reserved ICON data is unique for each instance of the model's application. For example, if the user enters one CIM5BL model data record (induction motor model) with a wildcard load identifier, specified for a bus with three loads, then the model will be applied to all three loads. Space will be reserved for only one set of CON and ICON data, as that data is shared among all applications of the model. However, space will be reserved for three sets of VARs, STATEs, and reserved ICONs (one for each application of the model).

For each load, there is one available slot for a load characteristic model and one available slot for a load relay model. That is to say, it is not permissible to apply more than one load characteristics model or more than one load relay model to the same load.

When DYRE is being run and a load record is encountered in which the subsystem is not found (for example, load on a bus), this record is ignored and no message is printed. This is consistent with how machine models are handled if the machine does not exist.

Further discussion of subsystem models can be found in the *PSS®E Program Operation Manual*, Subsystem Models

21.2. Load Characteristic Models

21.2.1. Basic Considerations

The PSS®E package recognizes three basic algebraic load versus voltage characteristics in its power flow database (see Load Voltage Characteristics). These characteristics: constant MVA, constant current, and constant admittance, are carried through to dynamic simulation. Activity CONL may be used either in power flow work prior to initialization of a dynamic simulation, or during dynamic simulation work, to change the mix of the three basic components in the loads. These components, while useful in the absence of better information, do not always give an adequate characterization of a system's load versus voltage characteristic. They cannot recognize the dependence of load components, other than constant admittance, on bus frequency.

More detailed load versus voltage and bus frequency characteristics are handled by a set of load models that participate directly in the network solution at each time step. All of these models determine values of load current on the basis of local bus frequency, voltage, and the algebraic or dynamic characteristics of the model.

All models, with the exception of the LDFR type models, will replace the characteristics of ALL components of load (constant MVA, current, and admittance), at loads for which the models are applied. The model's initial load level is determined by first reconverting all load components to constant MVA.

The effective value of load, as the models influence it, may be monitored during the simulation by assigning the desired loads to output channels in activities CHSB or CHAN. The user should be aware that the models convert the effective loads to current injections during the simulation. Therefore, while assigned output channels will show the correct effective loads, the power flow listing and reporting activities available through activity LOFL will not recognize the effective load.

21.2.2. Algebraic Characteristic Models

LDFR Type Models (LDFRBL, LDFROW, LDFRZN, LDFRAR, LDFRAL)

The LDFR family of models (LDFRBL, LDFROW, LDFRZN, LDFRAR, LDFRAL) make the constant current and MVA components of all loads to which the model is applied dependent on bus frequency. These models make load dependent on frequency in accordance with:

$$P = P_o\left(\frac{\omega}{\omega_o}\right)^m$$

$$Q = Q_o\left(\frac{\omega}{\omega_o}\right)^n$$

$$I_p = I_{po}\left(\frac{\omega}{\omega_o}\right)^r$$

$$I_q = I_{qo}\left(\frac{\omega}{\omega_o}\right)^s$$

where the constants m, n, r, and s are given by CON(J) through CON(J+3). These indices are not necessarily integers, may be negative (if meaningful), and may be zero if the corresponding load components are independent of frequency.

The models have no effect on constant admittance load or shunt devices as specified by line or bus shunt data. Frequency dependence of all shunts is always represented in accordance with the inductive or capacitive sign of the shunt admittance.

IEEL Type Models (IEELBL, IEELOW, IEELZN, IEELAR, IEELAL)

All constant MVA, current and admittance load for which the models are applied is replaced by a new load component defined by:

$$P = P_{load}\left(a_1 v^{n1} + a_2 v^{n2} + a_3 v^{n3}\right)(1 + a_7 \Delta f)$$

$$Q = Q_{load}\left(a_4 v^{n4} + a_5 v^{n5} + a_6 v^{n6}\right)(1 + a_8 \Delta f)$$

where P_{load} and Q_{load} are the real and reactive power loads that would be drawn at nominal frequency and one per unit voltage.

The a and n constants in the model need not be an integer, maybe negative, and may be zero.

The effective value of load as it varies during the simulation may be tracked by assigning the load to an output channel in activities CHSB or CHAN. The effective load is treated as a current injection from a fixed portion of load and a variable portion of load. Therefore, while the output channel will show the correct effective load, the power flow listing and reporting activities available through activity LOFL, will only show the fixed portion.

Compatibility note: The obsolete models IEELCB, IEELCZ, and IEELCA only recognized, and operated on, the constant MVA component at loads for which these models were applied.

21.2.3. Complex Models

CLOD Type Models (CLODBL, CLODOW, CLODZN, CLODAR, CLODAL)

The CLOD type models (CLODBL, CLODOW, CLODZN, CLODAR, CLODAL) replace all constant MVA, current, and admittance load with a composite load consisting of induction motors, lighting, and other types of equipment such as would be fed from many typical substations. The models may represent a composite load of induction motors, lighting, and other types of equipment such as would be fed from many typical substations. It is intended for use in situations where it is desirable to represent loads at the dynamic level, as distinct from the algebraic characteristic level used in power flow, but where detailed dynamics data is not available. The models allow the user to specify a minimum amount of data stating the general character of the composite load. It uses this data internally to establish the relative sizes of motors modeled in dynamic detail and to establish typical values for the detailed parameter lists required in the detailed modeling.

The models assume that all load components are connected at 0.98 per-unit voltage. At initialization, a tap is calculated to obtain that voltage based on the load and voltage shown on the bus at which it is connected. By entering R and X values in the appropriate CONs, a user may add some distribution transformer impedance or distribution line impedance. The load on the bus is then split according to the percentages the user inputs. The performance curves and data used for typical large motors is shown in Figure 21.1, "Large Motor Performance Curve (H = 1.0, Load Damping Factor = 1.0, Initial Slip = -0.00837)". The small motor curves are shown in Figure 21.2, "Small Motor Performance Curve (H = 0.6, Load Damping Factor = 1.0, Initial Slip = -0.02149)".

The distribution network between the supply point and the load is not modeled explicitly in the power flow. The CLOD type models permit representation of transformer current, if the user wants to represent the saturation effects of distribution transformers. The curve shown in Figure 21.3, "Voltage versus Magnetizing Current" (SAT2 model) handles the transformer saturation. The discharge lighting part of the load is handled as follows:

1. Real part of load as constant current.

2. Imaginary part of load as the voltage raised to the 4.5 power.

3. For voltage between 0.65 and 0.75 per unit, as 1) and 2) times a linear reduction.

4. For voltage below 0.65 per unit, the lighting is assumed to be extinguished (i.e., no load).

During initialization the discharge lighting is assumed to have approximately a 0.9 power factor.

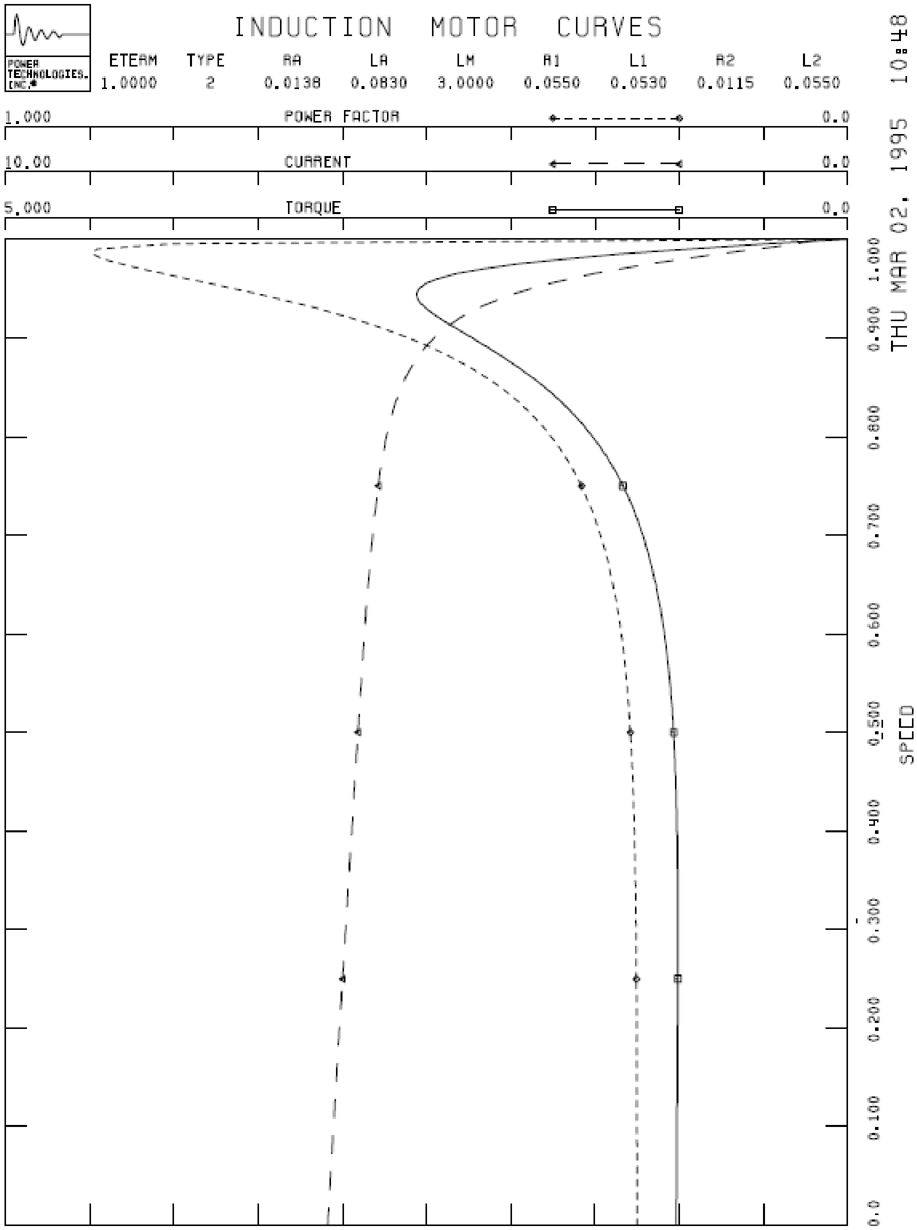


Figure 21.1. Large Motor Performance Curve (H = 1.0, Load Damping Factor = 1.0, Initial Slip = -0.00837)

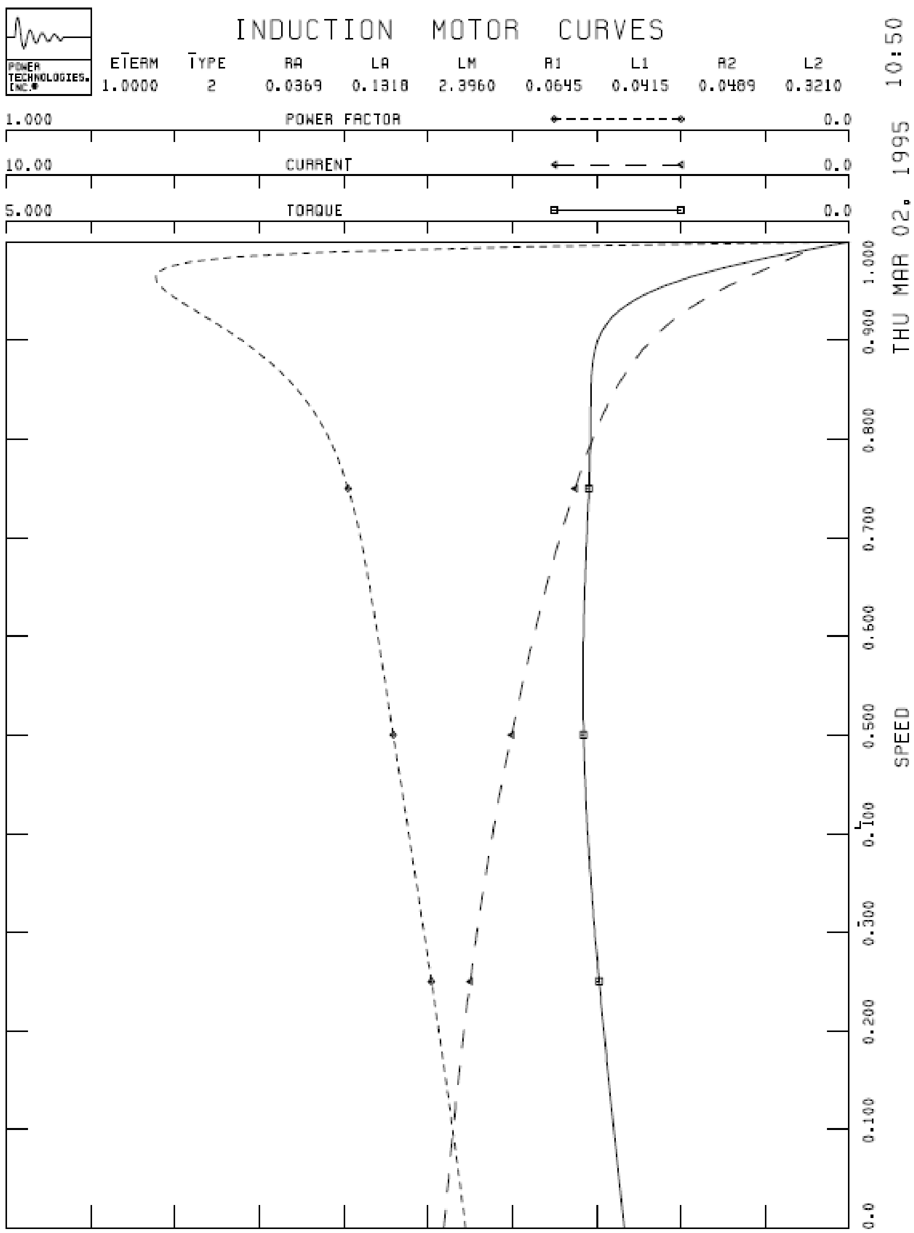


Figure 21.2. Small Motor Performance Curve (H = 0.6, Load Damping Factor = 1.0, Initial Slip = -0.02149)

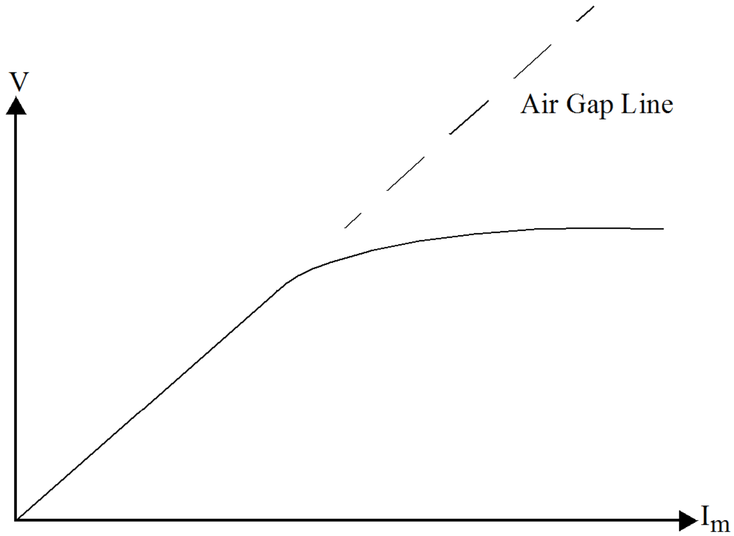


Figure 21.3. Voltage versus Magnetizing Current

The make-up of the composite load is specified by CON(J) through CON(J+4) of CLOAD. These CONs specify the percentage of the total load (as shown in the power flow case) that is due to large motors, small motors, magnetizing current, discharge lighting, constant MVA devices, and voltage sensitive load. The percentages may be specified arbitrarily on the basis of the user's knowledge of the nature of the particular plant, feeder, or substation.

The value of CON(J+2) stating the percentage of load current due to magnetizing should not exceed about 10%. All real load remaining on the bus after applying the specified percentages varies as the voltage is raised to the KP power. The reactive power left to balance the case varies as the voltage is raised to the second power.

Compatibility note: The obsolete model, CLOAD, only recognized, and operated on, the constant MVA component at loads for which this model was applied.

21.2.4. Induction Motor Models

Level of Detail

Induction motors and their driven loads, while not affected by rotor angle dynamics, are sensitive to changing frequency and voltage. The driven loads usually consume increased power at increased speed and hence contribute to system damping. Induction motor loads may be modeled in three levels of detail:

1. By the standard single-valued voltage/load characteristics provided by activity CONL and by the voltage/frequency/load characteristics provided by models such as LDFRBL.

2. With the dynamics of the rotating load represented by the inertial differential equation, and with the motor's steady-state electrical characteristic represented in detail, but with the electromagnetic dynamics of the motor neglected. This level of detail is handled by model CMOTOR. [1]

3. With both rotating load dynamics and motor electromagnetic dynamics represented in detail. This model is handled by the family of CIM5BL, CIM6BL and CIMWBL models, as well as CIMTR2 and CIMTR4.

Approach 1 is reasonable for many of the loads in a large-scale system-wide study because the details of individual loads are often not known and the provision of detailed motor/load data for thousands of loads may be a difficult task. Approach one is not adequate for studies of events where the transient behavior of motor loads has a critical effect on bus voltages and hence on their own, and other, loads in the system. It is also, of course, unusable where the induction motors themselves are of specific interest.

Approach 2 only recognizes flux linkages for which time variation consists of an equilibrium component corresponding to operation at fixed slip and voltage influence the rotor of the induction motor. This component is a unidirectional when the reference axes are synchronized with supply frequency. This approach neglects the synchronizing action provided by the induction machine during transients and as well as flux and voltage decay following tripping.

Approach 3 models a transient component that is zero in the steady state but takes the form required to change rotor flux linkages when the machine is subjected to a sudden change of supply frequency or voltage. The magnitude of this component is determined by the disturbance applied to the machine, and its decay is governed by the transient and subtransient time constants of the rotor winding.

Principal Time Constants

Unlike synchronous generators where principal time constants, both inertial and electromagnetic, are relatively long and comfortably compatible with the 0 to 30 rad/sec bandwidth of PSS®E; induction motor dynamics usually have time constants that correspond to the upper end of the PSS®E bandwidth.

The transfer function relating motor speed to electrical torque is:

$$\Delta n = \frac{\Delta T_e}{D_m + 2H_m s}$$

$$= \frac{1}{D_m}\left(\frac{\Delta T_e}{1 + \left(\frac{2H_m}{D_m}\right)s}\right)$$

where:

Dm =

$$\frac{\partial T_e}{\partial n} + \frac{\partial T_1}{\partial n}$$

$$\frac{\partial T_e}{\partial n}$$

[1]At PSS®E-26, CMOTOR is obsolete and has been superseded by the model CIM5BL. Discussions concerning CMOTOR have been provided for backward compatibility with pre-PSS®E-26 dynamic simulation setups. The user should refer to the *PSS® E Compatibility Reference* for more information.

= Slope of motor torque-speed characteristic.

$$\frac{\partial T_1}{\partial n}$$

= Slope of load torque-speed characteristic.

H_m = Rotational inertia of motor and load.

A typical large motor might develop full-load torque at a slip of about 0.005 pu, which corresponds to:

$$\frac{\partial T_e}{\partial n} \cong \frac{1.0}{0.005} = 200$$

A typical centrifugal pump or fan load might have a characteristic corresponding to:

$$\frac{\partial T_1}{\partial n} \cong 2$$

A typical motor plus load inertia for a centrifugal pump or similar load might be 1.0 sec. These data give the time constant governing speed changes as

$$T = \frac{2H_m}{D_m} = \frac{2 \times 1}{200} = 0.01 \text{ sec}$$

This time constant corresponds to the outer edge of the PSS®E bandwidth and may require the integration step to be reduced from the standard value of 0.00833 sec. The short induction motor inertial time constant has a direct effect on the electrical dynamics of the motor because the electrical slip, and hence shaft speed, has a direct effect on the electrical equivalent circuit. As a result, system simulations including induction motors should be checked carefully and repeatedly for evidence of numerical instability.

Motor Equivalent Circuit and Data (IMD)

Induction motor models require data either as the parameters of the equivalent circuit shown in Figure 21.4, "Circuit for Type 2 Specification in Program IMD" or as the standard parameters L_s, L'_s, L''_s, T'_{so}, T''_{so}, and R_a, the apparent stator reactances, time constants, and resistance of the motor. Induction motor data is seldom given in these forms, however. The more usual set of motor data gives:

- Rated torque and slip.
- Rated power and power factor.
- Starting torque and current.
- Starting power factor.
- Peak torque.

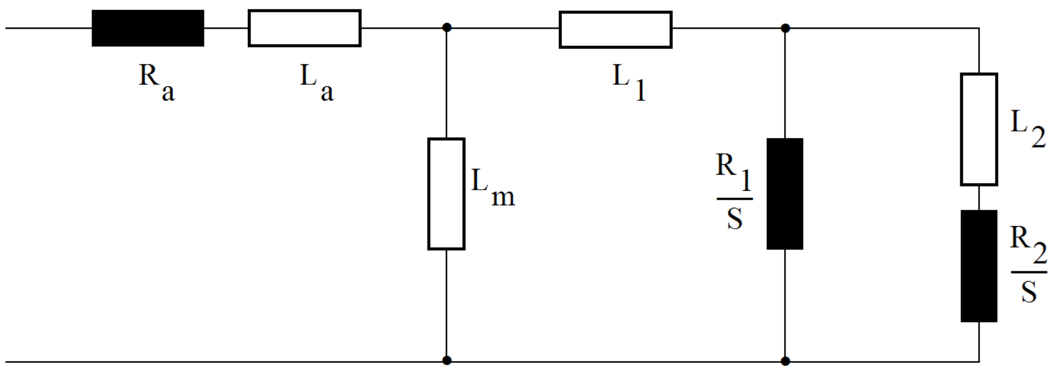


Figure 21.4. Circuit for Type 2 Specification in Program IMD

The required equivalent circuit data must be estimated from the nameplate and other available data. The estimation of equivalent circuit data can be handled quite effectively in many cases by the use of the support program, IMD, which allows the user to propose trial equivalent circuit data and calculates the corresponding motor performance curves. The operating procedure for IMD is provided below, and a sample dialog from a run of IMD is shown in Figure 21.5, "Use of IMD to Estimate Induction Motor Equivalent Circuit Parameters to Match Given Nameplate Data (Sheet 1 of 3)" and Figure 21.8, "Plotted Induction Motor Performance from IMD".

1. Start the program by typing the command IMD.

2. Enter INITIAL SELECTIONS for program setup.

   Terminal voltage should match power flow voltage at motor bus. Use Type 2 for equivalent circuit in Figure 21.4, "Circuit for Type 2 Specification in Program IMD", Type 1 for equivalent circuit of Figure 21.16, "Induction Motor Equivalent Circuit for Type 1 Specification in Program IMD".

3. Enter EQUIVALENT CIRCUIT PARAMETERS for motor definition.

   Values are entered per-unit on motor base. Specify $R_2 = L_2 = 999$ for single-cage motor.

4. Enter INDIVIDUAL CURVE POINTS for checking performance at specified motor speeds.

5. Enter SCALES for setting speed, current, torque and power factor scales prior to plotting and printing.

6. Select OUTPUTTING DYRE if desired.

7. Enter PRINTING DEVICE to redirect tabular output, e.g., hard copy output.

```
$ imd

 PSS®E Version 20.0
 Copyright (c) 1992 Power Technologies, Inc.
 This program is a confidential unpublished work created and first
 licensed in 1976. It is a trade secret which is the property of
 Power Technologies Inc. All use, disclosure, and/or reproduction
 not specifically authorized by Power Technologies Inc. is prohibited.
 This program is protected under the copyright laws of non-U.S.
 countries and by application of international treaties. All Rights
 Reserved Under The Copyright Laws.


 ENTER OUTPUT DEVICE CODE:
  0 FOR NO OUTPUT     1 FOR CRT TERMINAL
  2 FOR A FILE        3 FOR QMS PS2000
  4 FOR QMS_PS800     5 FOR HARD COPY TERMINAL
  6 FOR ALTERNATE SPOOL DEVICE: 1

 ENTER DESIRED CATEGORY:

      0 FOR EXIT,
      1 FOR INITIAL SELECTIONS,
      2 FOR EQUIVALENT CIRCUIT PARAMETERS,
      3 FOR PRINTING DEVICE,
      4 FOR SCALES,
      5 FOR TABULAR OUTPUT,
      6 FOR GRAPHICAL OUTPUT,
      7 FOR FLUX MODEL PARAMETERS,
      8 FOR INDIVIDUAL CURVE POINTS: 1

 CURRENT INDEPENDENT VARIABLE IS 'SPEED',
 ENTER 0 FOR 'SPEED', 1 FOR 'SLIP':

 CURRENT VALUE OF ETERM = 1.000, FREQ = 60.00,
 ENTER NEW TERMINAL VOLTAGE, FREQUENCY :

 SYSTEM BASE = 100.0, MOTOR BASE = 100.0,
 ENTER NEW SYSTEM BASE AND MOTOR BASE : ,3

 CURRENT MOTOR TYPE =  2
 ENTER 1 FOR TYPE 1, 2 FOR TYPE 2 MOTOR (USE TYPE 2 FOR CMOTOR) :

 ENTER DESIRED CATEGORY:

      0 FOR EXIT,
      1 FOR INITIAL SELECTIONS,
      2 FOR EQUIVALENT CIRCUIT PARAMETERS,
      3 FOR PRINTING DEVICE,
      4 FOR SCALES,
      5 FOR TABULAR OUTPUT,
      6 FOR GRAPHICAL OUTPUT,
      7 FOR FLUX MODEL PARAMETERS,
      8 FOR INDIVIDUAL CURVE POINTS: 2

 CURRENT MACHINE PARAMETERS ARE:
 RA      LA      LM      R1      L1      R2      L2       <------ Default motor parameters
 0.0380  0.0830  3.0000  0.0550  0.0280  0.0110  0.0550
 ENTER NEW RA, LA, LM, R1, L1, R2, L2: .01 .09 4.2 .035 .09 .012 .04

 NEW MACHINE PARAMETERS ARE:
 RA      LA      LM      R1      L1      R2      L2       <---- Initial estimate of motor parameters
 0.0100  0.0900  4.2000  0.0350  0.0900  0.0120  0.0400
```

Figure 21.5. Use of IMD to Estimate Induction Motor Equivalent Circuit Parameters to Match Given Nameplate Data (Sheet 1 of 3)

```
ENTER DESIRED CATEGORY:

    0 FOR EXIT,
    1 FOR INITIAL SELECTIONS,
    2 FOR EQUIVALENT CIRCUIT PARAMETERS,
    3 FOR PRINTING DEVICE,
    4 FOR SCALES,
    5 FOR TABULAR OUTPUT,
    6 FOR GRAPHICAL OUTPUT,
    7 FOR FLUX MODEL PARAMETERS,
    8 FOR INDIVIDUAL CURVE POINTS: 8
ENTER SPEED : .9915
```

Rated speed

```
 MOTOR BASE MVA     =    3.00000
 SYSTEM BASE MVA    =  100.00000
 AT PU SPEED OF          0.99150
 AND PU VOLTAGE OF       1.00000
 TORQUE             =    0.86435
 CURRENT (MAG.)     =    0.95815
 POWER FACTOR       =    0.91168
 P + JQ (P.U.)      =    0.87353 +J    0.39370
 YMOTOR (MOT BASE) =     0.87353 +J   -0.39370
 YMOTOR (SYS BASE) =     0.02621 +J   -0.01181
ENTER SPEED : 0
```

Motor at rated speed with initial estimate: current too low, power factor too high

```
 MOTOR BASE MVA     =    3.00000
 SYSTEM BASE MVA    =  100.00000
 AT PU SPEED OF          0.00000
 AND PU VOLTAGE OF       1.00000
 TORQUE             =    0.51029
 CURRENT (MAG.)     =    5.18997
 POWER FACTOR       =    0.15022
 P + JQ (P.U.)      =    0.77965 +J    5.13108
 YMOTOR (MOT BASE) =     0.77965 +J   -5.13108
 YMOTOR (SYS BASE) =     0.02339 +J   -0.15393
ENTER SPEED :
```

Motor at zero speed with initial estimate: torque too low, current too low

Several iterations are needed to refine motor parameters

```
ENTER DESIRED CATEGORY:

    0 FOR EXIT,
    1 FOR INITIAL SELECTIONS,
    2 FOR EQUIVALENT CIRCUIT PARAMETERS,
    3 FOR PRINTING DEVICE,
    4 FOR SCALES,
    5 FOR TABULAR OUTPUT,
    6 FOR GRAPHICAL OUTPUT,
    7 FOR FLUX MODEL PARAMETERS,
    8 FOR INDIVIDUAL CURVE POINTS: 2

CURRENT MACHINE PARAMETERS ARE:
RA      LA      LM      R1      L1      R2      L2
0.0100  0.0900  4.2000  0.0350  0.0900  0.0120  0.0400
ENTER NEW RA, LA, LM, R1, L1, R2, L2: .004 .083 4.0 .04 .08 .011 .05

NEW MACHINE PARAMETERS ARE:
RA      LA      LM      R1      L1      R2      L2
0.0040  0.0830  4.0000  0.0400  0.0800  0.0110  0.0500
```

Final selection of motor parameters

```
ENTER DESIRED CATEGORY:

    0 FOR EXIT,
    1 FOR INITIAL SELECTIONS,
    2 FOR EQUIVALENT CIRCUIT PARAMETERS,
    3 FOR PRINTING DEVICE,
    4 FOR SCALES,
    5 FOR TABULAR OUTPUT,
    6 FOR GRAPHICAL OUTPUT,
    7 FOR FLUX MODEL PARAMETERS,
    8 FOR INDIVIDUAL CURVE POINTS: 8
```

Figure 21.6. Use of IMD to Estimate Induction Motor Equivalent Circuit Parameters to Match Given Nameplate Data (Sheet 2 of 3)

```
ENTER SPEED : .9915

 MOTOR BASE MVA     =    3.00000
 SYSTEM BASE MVA    =  100.00000
 AT PU SPEED OF          0.99150
 AND PU VOLTAGE OF       1.00000
 TORQUE             =    0.90604
 CURRENT (MAG.)     =    1.00001
 POWER FACTOR       =    0.91003
 P + JQ (P.U.)      =    0.91004 +J    0.41455
 YMOTOR (MOT BASE)  =    0.91004 +J   -0.41455
 YMOTOR (SYS BASE)  =    0.02730 +J   -0.01244
ENTER SPEED : 0
```

Motor at rated speed with final parameters: current OK, power factor OK

```
 MOTOR BASE MVA     =    3.00000
 SYSTEM BASE MVA    =  100.00000
 AT PU SPEED OF          0.00000
 AND PU VOLTAGE OF       1.00000
 TORQUE             =    0.71758
 CURRENT (MAG.)     =    5.59853
 POWER FACTOR       =    0.15057
 P + JQ (P.U.)      =    0.84295 +J    5.53471
 YMOTOR (MOT BASE)  =    0.84295 +J   -5.53471
 YMOTOR (SYS BASE)  =    0.02529 +J   -0.16604
ENTER SPEED :
```

Motor at zero speed with final parameters: current OK, power factor OK, torque OK (0.718/0.906= 0.793 pu)

```
ENTER DESIRED CATEGORY:

    0 FOR EXIT,
    1 FOR INITIAL SELECTIONS,
    2 FOR EQUIVALENT CIRCUIT PARAMETERS,
    3 FOR PRINTING DEVICE,
    4 FOR SCALES,
    5 FOR TABULAR OUTPUT,
    6 FOR GRAPHICAL OUTPUT,
    7 FOR FLUX MODEL PARAMETERS,
    8 FOR INDIVIDUAL CURVE POINTS: 5

  ETERM TYPE    RA      LA      LM      R1      L1      R2      L2
  1.000    2  0.0040  0.0830  4.0000  0.0400  0.0800  0.0110  0.0500

     SPEED    SLIP    CURRENT  TORQUE  PWR FACT     Y - MOTOR
    0.0000   1.0000   5.5985   0.7176   0.1506   0.8430  -5.5347
    0.0200   0.9800   5.5886   0.7199   0.1512   0.8448  -5.5244
    0.0450   0.9550   5.5759   0.7227   0.1519   0.8471  -5.5112

    0.9700   0.0300   2.8856   2.2632   0.7959   2.2965  -1.7471
    0.9950   0.0050   0.6275   0.5470   0.8742   0.5485  -0.3047
    1.0000   0.0000   0.2449   0.0000   0.0010   0.0002  -0.2449
```

Abbreviated tabular output

```
ENTER DESIRED CATEGORY:

    0 FOR EXIT,
    1 FOR INITIAL SELECTIONS,
    2 FOR EQUIVALENT CIRCUIT PARAMETERS,
    3 FOR PRINTING DEVICE,
    4 FOR SCALES,
    5 FOR TABULAR OUTPUT,
    6 FOR GRAPHICAL OUTPUT,
    7 FOR FLUX MODEL PARAMETERS,
    8 FOR INDIVIDUAL CURVE POINTS: 0
$
```

Figure 21.7. Use of IMD to Estimate Induction Motor Equivalent Circuit Parameters to Match Given Nameplate Data (Sheet 3 of 3)

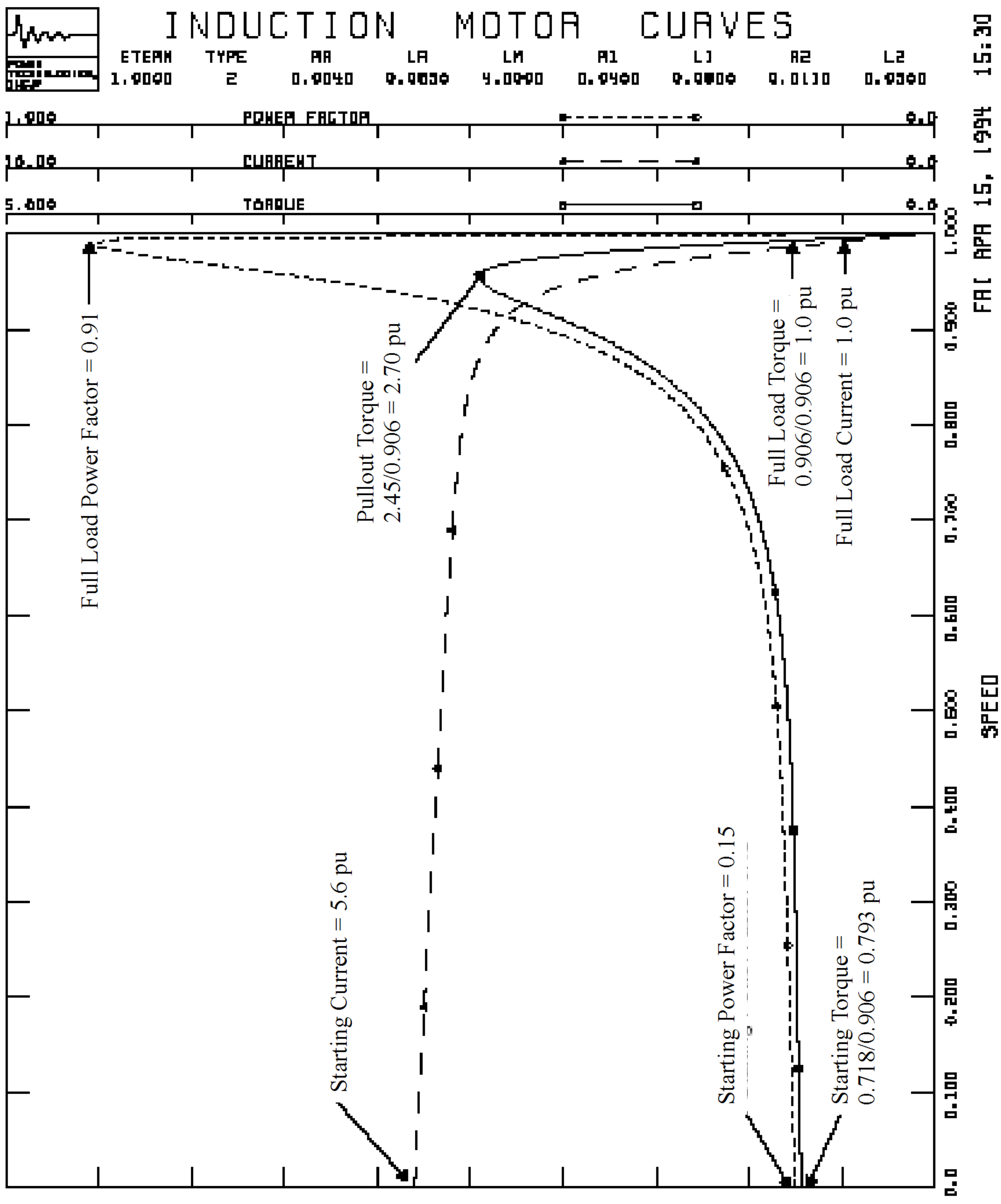


Figure 21.8. Plotted Induction Motor Performance from IMD

Establishing equivalent circuit parameters within IMD requires an iterative process of adjusting the values and checking how closely they match the given standstill and related conditions of the motor. The following guidelines relate to the equivalent circuit shown in Figure 21.4, “Circuit for Type 2 Specification in Program IMD”.

1. When executing IMD for rated conditions, current and voltage have to be 1.0 pu. The torque at rated conditions is less than 1.0 pu (see the section called “Definition and Setup”). If, for example, torque under rated conditions is 0.9 and the motor data set specifies 135% starting torque, starting torque from IMD should be $0.9 \times 1.35 = 1.215$.

2. Estimate L_a and L_1

   $L_a + L_1 \approx 1/(\text{per-unit locked rotor current})$

   assume initially that $L_a \approx L_1$.

3. Adjust L_m to set full-load power factor.

4. Set R_a initially to 0.01-0.02, then adjust to set starting power factor. The starting power factor is given roughly by $(R_a + R_1)/(L_a + L_1)$.

5. Adjust R_1 to set starting torque. For a single-cage motor the starting torque is given roughly by $I_s^2 R_1$, where I_s is the starting current. While increasing rotor resistances increases starting torque, it also increases slip at full load.

6. Set L_2 initially to 0.04-0.05. L_2 may have to be increased to get starting load current to flow into R_1 to set starting torque.

7. Adjust R_2 to set slip at full load. Initial value should be close to desired slip. L_2 may have to be adjusted in conjunction with R_2. Increasing rotor resistances decreases per unit pullout (peak) torque in relation to rated and starting torque.

As an example, consider an induction motor with the following data:

Voltage:	3.3 kV
Current:	525 A
Rating:	3500 hp
Speed:	3569 rpm
Inertia:	0.9 sec
Power Factor (running):	0.91
Locked rotor pf:	0.15
Locked rotor current:	5.6 pu
Locked rotor torque:	0.8 pu
Pullout torque:	2.7 pu

Using IMD and the procedure outlined in this section, it is possible to determine the equivalent motor circuit of the above data.

Representation of Rotor Flux Linkages in Induction Motors

The CIM5 type, CIM6 type and CIMW type family of induction motor models, as well as CIMTR2 and CIMTR4, fully recognize the rotor dynamic electromagnetic behavior. Their block diagrams are shown in Figure 21.9, “Induction Model With Rotor Flux Linkages Represents Both Type 1 and Type 2 Models in IMD”.

CIM5 Type Induction Motor Models (CIM5BL, CIM5OW, CIM5ZN, CIM5AR, CIM5AL)

The CIM5BL family of models (CIM5BL, CIM5OW, CIM5ZN, CIM5AR, CIM5AL) can be used to model either single-cage or double-cage induction motors including rotor flux dynamics. The motor is modeled in the power flow as a bus load where all of the load at a specific load id is taken as the steady-state motor load. These models may be applied to an individual load or a subsystem of loads. For example, the CIM5BL model can be applied to a specific load in order to model a specific induction motor. The CIM5AR model can be applied to all loads in a specific area in order to model generic motor load using typical data. The load composition can be any percentage of constant MVA, constant current or constant admittance.

The data input for the model are the equivalent circuit impedances for either a Type 1 or a Type 2 equivalent circuit model (Figure 21.10, "CIM5 Type Models"). The Model Type is specified in ICON(M+2). The CIM5 models translate the equivalent circuit parameters into transient parameters (flux linkage components) for use in the actual model calculations, according to the equations in the section called "Data Conversion From One Model Representation to Another".

The equivalent circuit impedances are specified in per unit on motor MVA base. The user has two choices for the specification of motor MVA base:

1. When CON(J+11) > 0., the motor MVA base is specified as CON(J+11).

2. When CON(J+11) = 0., the motor MVA base is specified as CON(J+12)*MW load.

Option 2 is incorporated to allow the motor size to be scaled along with the load at the bus.

The CIM5 type models use the following equation as its representation for mechanical load torque:

$T_{load} = T_{nom} (1 + \Delta \omega)^{D}$

where $\Delta \omega$ is the motor speed deviation from nominal (per unit slip), D is the load damping factor, CON(J +17), and T_{nom} is the motor load torque at synchronous speed.

At initialization, the CIM5 type models pick up the total power for the specified load id at the bus and together with the equivalent circuit data and the bus voltage, calculates the initial slip and reactive power consumption of the motor. The Mvar difference between the load and the actual motor reactive consumption, VAR(L+1), is accounted for automatically by the assignment of a hidden shunt at the bus, VAR(L). If the model is unable to resolve the load with the specified motor data, the user will be alarmed and the model will be disabled. Based on the motor load and the initial slip, the model then calculates the synchronous load torque (T_{nom}) in order to balance electrical and load torque in the steady state. The value for T_{nom} is stored in VAR(L+4). For online initialization, any value specified for T_{nom} in CON(J+18) will be ignored.

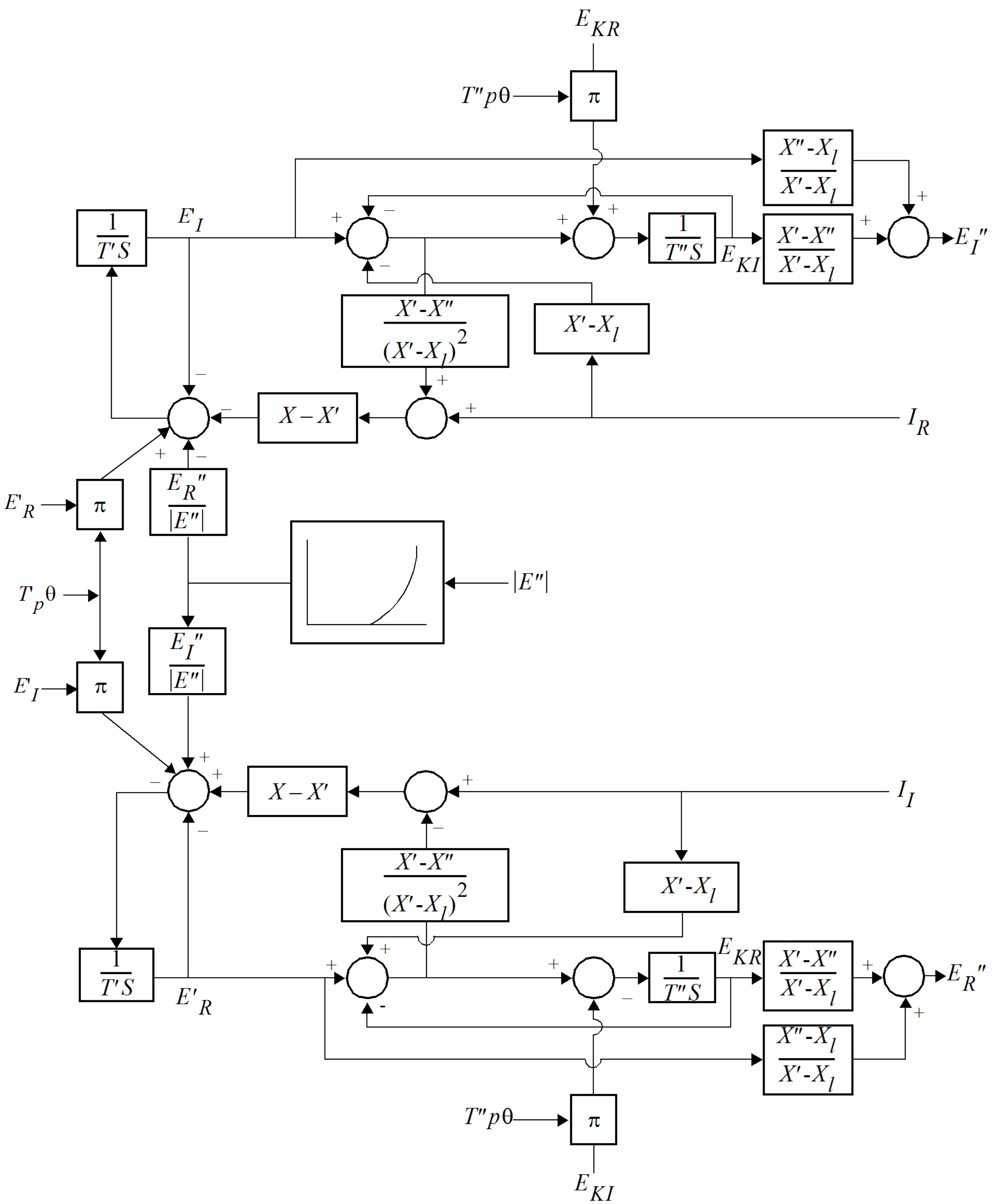


Figure 21.9. Induction Model With Rotor Flux Linkages Represents Both Type 1 and Type 2 Models in IMD

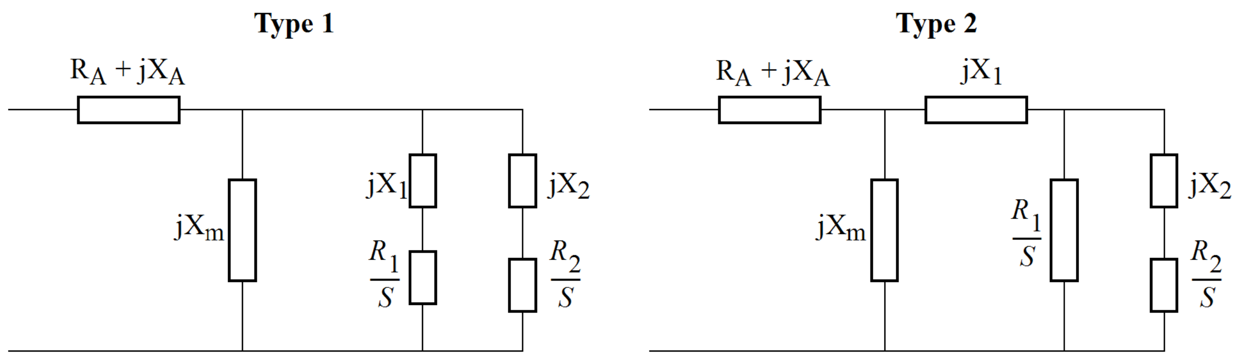


Figure 21.10. CIM5 Type Models

The models include a relay that can be used to trip the motor for an undervoltage condition. CON(J+14) is specified as the per unit voltage level (V_l) for which the relay will begin timing. CON(J+15) is the time in cycles (T_l) for which the voltage must remain below the threshold in order for the relay to trip. The breaker time delay (T_B) is specified in CON(J+16). The user may disable the relay by specifying CON(J+14) as zero.

Motor Starting Analysis

The CIM5 type models can be used for analyzing the start-up of a motor. In most cases, the CIM5BL model will be the most appropriate to use because of the need to specify a specific MBASE for motor starting. If the load status for the motor load in the power flow is specified as zero, the motor will be initialized as off-line by activity STRT. At any point in the simulation, the user may start the motor by toggling the load status to 1 (in-service) and supplying a *positive* per unit value for T_{nom} (synchronous load torque) in CON(J+18) to simulate the load on the motor. Any load for this bus/load ID that may be present at the time the status is toggled to one (in-service) will be ignored.

The value specified for T_{nom} will vary depending on the level of mechanical load it is intended for the motor to accelerate. In PSS®E, full mechanical load corresponds to the rated electrical torque for the motor, which is the torque developed at one per unit voltage and current. This value is typically in the range of 0.8 to 0.9 pu. The rated electrical torque (which must balance the load torque, T_{load}, in the steady state), together with the rated speed, enables the user to determine the value for T_{nom} corresponding to full mechanical load. Program IMD can be used to find the rated torque at rated speed, which can then be applied to the equation for load torque to find T_{nom}.

$$T_{nom} = \frac{T_{load}}{(1 + \Delta\omega)^D}$$

The value for T_{nom} can also be found through an online initialization of the motor model, where T_{nom} is determined (and stored in VAR(L+4)) from the power flow conditions and motor data.

For motor starting analysis, the user must ensure that CON(J+11), MBASE is used to specify the motor MVA base rather than CON(J+12), PMULT. Also, the simulation time step may need to be reduced to accommodate the very fast motor starting transients. It is recommended that the data for the motor always be tested first by running a simulation with the motor online.

CIMW Type Induction Motor Models (CIMWBL, CIMWOW, CIMWZN, CIMWAR, CIMWAL)

The CIMW type models (CIMWBL, CIMWOW, CIMWZN, CIMWAR, CIMWAL) are a special-purpose induction motor models created for compatibility with the WSCC Stability Program induction machine model.

The CIMW type models can be used to model either a single-cage or double-cage induction motors including rotor flux dynamics. The motor is modeled in the power flow as a positive load where *all* of the load at a specific load ID is taken as the steady-state motor load. The load composition can be any percentage of constant MVA, constant current or constant admittance. The CIMW type models cannot be used for induction generators (i.e., negative bus load). The PSS®E model CIMTR3, which is more appropriately modeled as a power flow generator, should be used.

The data input for the model are the equivalent circuit impedances for either a Type 1 or a Type 2 equivalent circuit model (Figure 21.11, "CIMW Type Models"). The model type is specified in ICON(M). The CIMW type models translate the equivalent circuit parameters into transient parameters (flux linkage components) for use in the actual model calculations, according to the equations in the section called "Data Conversion From One Model Representation to Another".

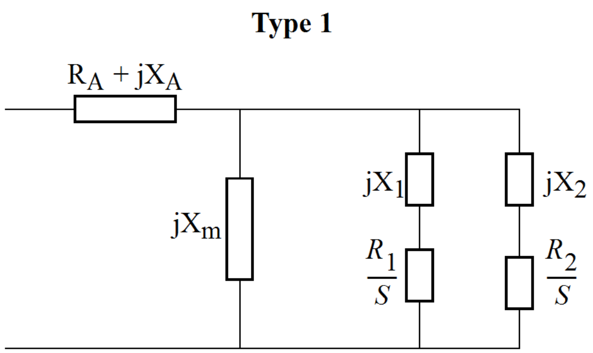


Figure 21.11. CIMW Type Models

The equivalent circuit impedances are specified in per unit on motor MVA base. The user has two choices for the specification of motor MVA base:

1. When CON(J+11) > 0., the motor MVA base is specified as CON(J+11).
2. When CON(J+11) = 0. the motor MVA base is specified as CON(J+12)*MW load.

Option 2 is incorporated to allow the motor size to be scaled along with the load at the bus.

The CIMW type models use the following equation as its representation for mechanical load torque:

$T_{load} = T_o(A\,\omega^2 + B\,\omega + C_o + D\,\omega\,\varepsilon)$

where:

$C_o = 1 - A\,\omega_o^2 - B\,\omega_o - D\,\omega_o\,\varepsilon$

$\omega_o = 1 + \Delta\omega_o$

To is the initial load torque, w is current motor speed, ω_o is the initial motor speed and $\Delta\omega_o$ is the speed deviation from synchronous (per unit slip).

At initialization, the CIMW type models pick up the total power at each load ID for which the model is applied, and together with the equivalent circuit data and the bus voltage, calculates the initial slip and reactive power consumption of the motor. The Mvar difference between the bus load and the actual motor reactive consumption, VAR(L+1), is accounted for automatically by the assignment of a hidden shunt at the bus, VAR(L). If the model is unable to resolve the bus load with the specified motor data, the user will be alarmed and the model will be disabled. Based on the motor load and the initial slip, the model then calculates the initial load torque (To) in order to balance electrical and load torque in the steady state. The value for T_o is stored in VAR(L+4).

The models include a relay that can be used to trip the motor for an undervoltage condition. CON(J+14) is specified as the per unit voltage level (V_I) for which the relay will begin timing. CON(J+15) is the time in cycles (T_I) for which the voltage must remain below the threshold in order for the relay to trip. The breaker time delay (T_B) is specified in CON(J+16). The user may disable the relay by specifying CON(J+14) as zero.

The CIMW type models are not valid for use in motor starting analysis.

CIM6 Type Induction Motor Models (CIM6BL, CIM6OW, CIM6ZN, CIM6AR, CIM6AL)

The CIM6 type models (CIM6BL, CIM6OW, CIM6ZN, CIM6AR, CIM6AL) have the detailed load torque representation of CIMW type models, and also have the motor starting capability of CIM5 type models. The data requirement for CIM6 type models are similar to those of CIMW type models, except that one extra CON has been added for entering the nominal torque for motor starting analysis.

Models CIMTR2 and CIMTR4 – Induction Motor Models

CIMTR2 and CIMTR4 model either a single-cage or double-cage induction motor including rotor flux dynamics. In the power flow, a generator with a negative electrical power should be used. To model a single cage machine, either T ″ or X ″ should be set to zero and ZSORCE in the power flow should be set equal to X′.

The last CON, D, for this model handles the effect of load on the motor according to the following:

$T_L = T_{nom}(1 + n)^D$

where n is the per-unit deviation of shaft speed from nominal and T_{nom} is synchronous load torque.

CIMTR4 uses one extra state variable but is more accurate than CIMTR2. It is recommended for large frequency deviations. CIMTR4 is similar to CIMTR3 for starting except that the user specifies the load torque at synchronous speed, a negative value. This model cannot be the only machine in an island when using the constant island frequency mode in extended term dynamics.

21.2.5. Single-Phase AC Motor Model

The ACMTBL model is meant to represent an aggregation of a large set of single-phase air-conditioners. It is a grid-level model suitable for studying the impact of residential air-conditioning loads on the dynamic performance of an interconnected power grid. The model is able to:

- determine the air-conditioner's real and reactive power and its power factor variation in response to voltage and frequency variations

- represent the air-conditioner's response to low frequency inter-area oscillations
- reasonably represent the stalling phenomenon, as well as accurately represent motor current, real and reactive power in the stalled state
- provide reasonable indication of air-conditioning load tripping by thermal protection

The characteristics of the ACMTBL model are consistent with the specifications for Performance Model for Representing Single-Phase Air-Conditioner Compressor Motors in Power System Studies, prepared by Western Electricity Coordination Council (WECC) Load Modeling Task Force (LMTF) [1]. The model structure and characteristics given in this document have been taken from [1].

This model includes the representation of:

- Compressor motor
- Compressor motor thermal relay
- Under-voltage relays
- Contactors

Compressor Motor Model

The compressor model represents the motors' behavior as a function of voltage and frequency in the "run" and "stall" states. The model uses an exponential function to represent the relationship between motor real and reactive powers versus motor voltage and frequency in the "run" state. The real and reactive power curves of the compressor motors, as obtained from voltage ramp test of the simulation model, are shown in . The model transitions from the "run" state to the "stall" state at a pre-defined voltage, V_{stall}. The motors in the "stall" state are represented by an equivalent impedance (R_{stall} + j X_{stall}).

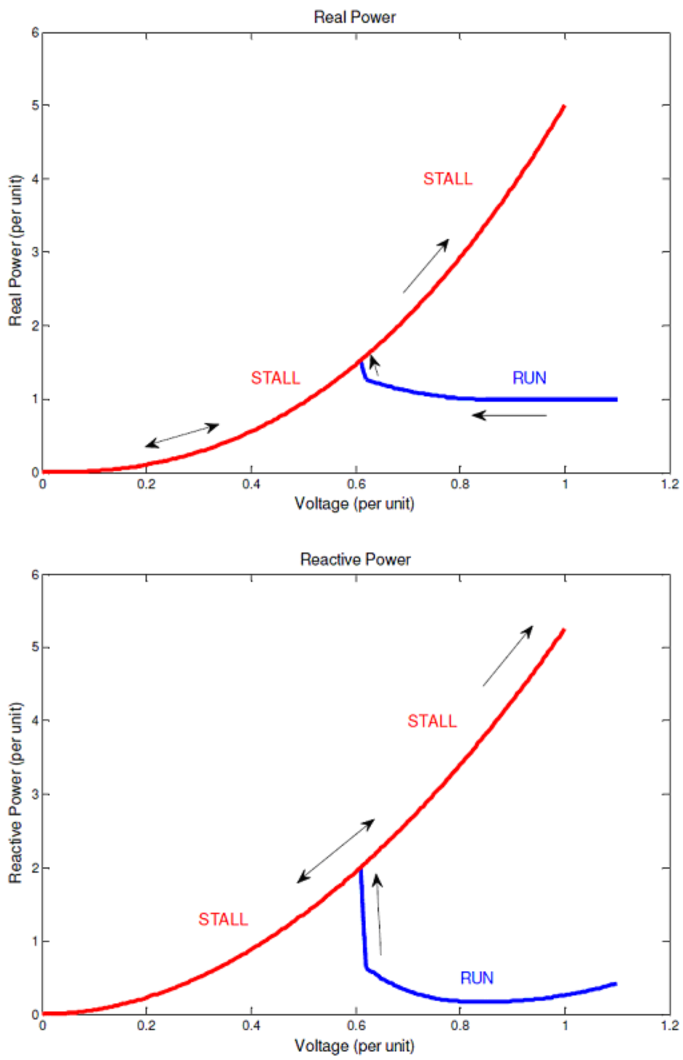


Figure 21.12. Performance Model Characteristics of Compressor Motors [2]

Compressor Motor Thermal Relay Model

The single-phase air-conditioner motors are protected against overheating by thermal relays. These over-current relays have an inverse time characteristic.

Figure 2 shows the model of the thermal relay, where:

I_c - compressor motor current

T_{th} - compressor motor heating time constant

R_{stall} - stall resistance

[2]"AC unit model specifications", WECC Load Modeling Task Force, April 2008.

Based on the computed winding temperature and the characteristics defined by the tripping temperatures, Th_{1t} and Th_{2t}, the model determines the fraction of compressor motors that are not tripped by thermal protection, K_{th}.

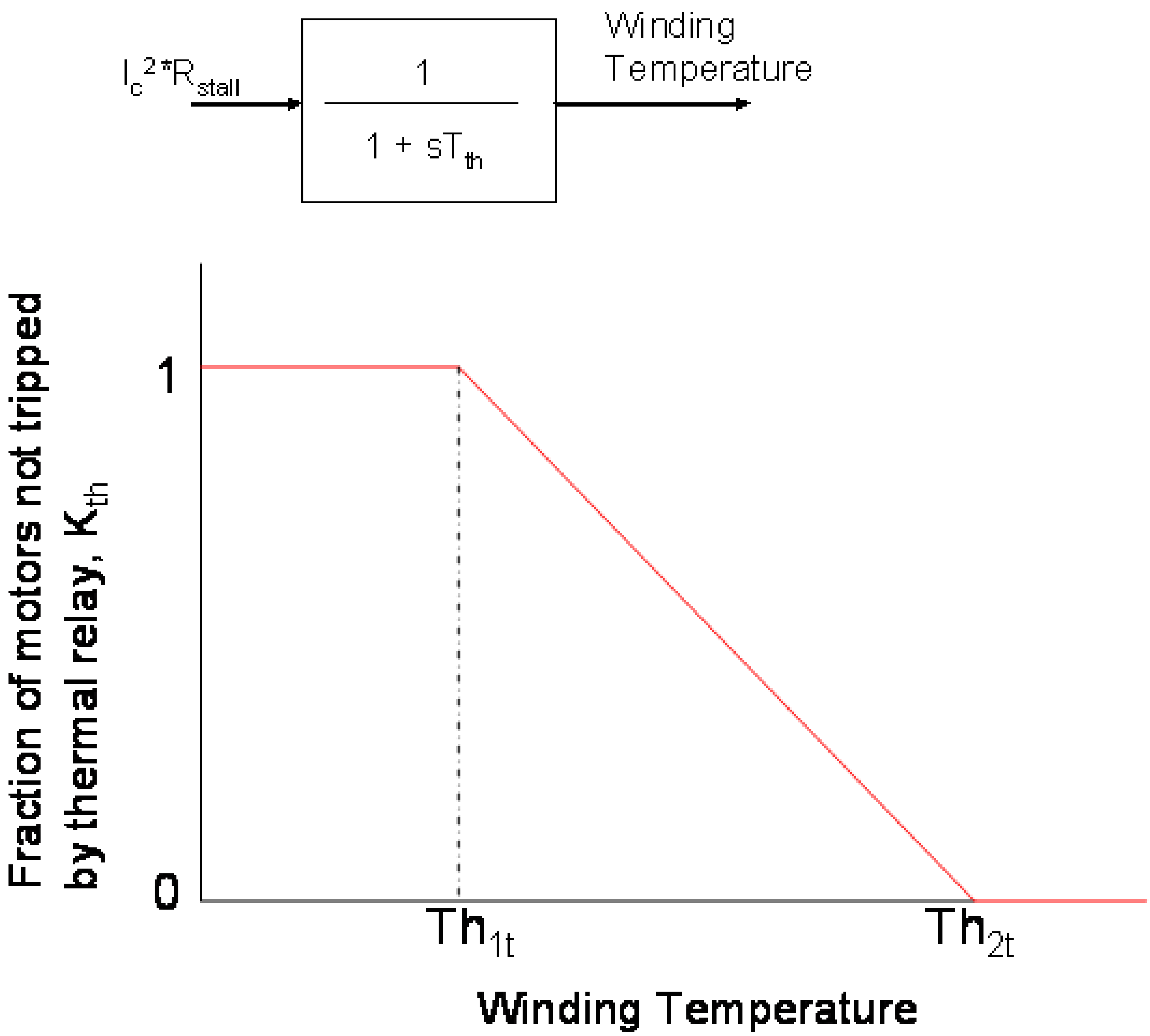


Figure 21.13. Compressor Motor Thermal Relay Model

Under-Voltage Relay Model

ACMTBL models the built-in protection of the compressor motors as a definite-time under-voltage relay with two thresholds. If the supply voltage stays below a threshold value for a specified period of time, the motors are tripped. Once the motors are tripped by the under-voltage relay, they are not reconnected during the simulation.

The following parameters are used to model the under-voltage relay:

Fuvr, fraction of compressor motors with under-voltage relays

UVtr1, 1st voltage pick-up (pu)

Ttr1, 1st definite time voltage pick-up (sec)

UVtr2, 2nd voltage pick-up (pu)

Ttr2, 2nd definite time voltage pick-up (sec)

The model determines the fraction of motors that are not tripped by under-voltage relay, Kuv.

Contactor Model

The compressor motors are energized through power contactors. The ON-OFF status of these contactors is affected by the fluctuations in supply voltage. The control circuit is typically supplied from the utility voltage through a transformer. Thus, a sag in supply voltage will be translated into a sag in control voltage. The contactors typically open when the control voltage drops to 40-45%, and re-close when the control voltage restores above 50-55% range. The model uses the following parameters to simulate the dropping and re-closing of contactors:

Vc1off, Control voltage 1 at which contactors start dropping out (pu)

Vc2off, Control voltage 2 at which all contactors drop out (pu)

Vc1on, Control voltage 1 at which all contactors reclose (pu)

Vc2on, Control voltage 2 at which contactors start reclosing (pu)

The model determines the fraction of motors that do not drop out, Kcon.

Compressor Unit Model Structure

The overall model structure of the single-phase air-conditioner is shown in Figure 21.14, "Model Structure of ACMTBL". The set of motors that are aggregated at a bus are categorized into two broad categories, namely Motor A and Motor B. Both Motor A and Motor B follow the same P vs V, Q vs V, P vs f, and Q vs f characteristics in the "run" and "stall" modes. Both Motor A and Motor B will stall when the voltage falls below Vstall. The main difference between these motors is in their capability to re-start. When the voltage recovers above the Vrst level, Motor B can restart, while Motor A will remain stalled. Frst is the fraction of motors that are capable of restart. Thus, Motor B are represented by fraction Frst and Motor A are represented by the balance fraction, i.e., 1-Frst. KthA and KthB represent the fractions of the Motor A and Motor B loads that are not tripped by thermal relay. Kuv and Kcon are the fractions of the motor load that are not tripped by under-voltage relay and contactors respectively.

The compressor model calculates the reactive power component of the motor load based on the voltage of the bus. The difference between the motor reactive power and the reactive component of the load connected at the bus during initialization is represented as a shunt at the bus.

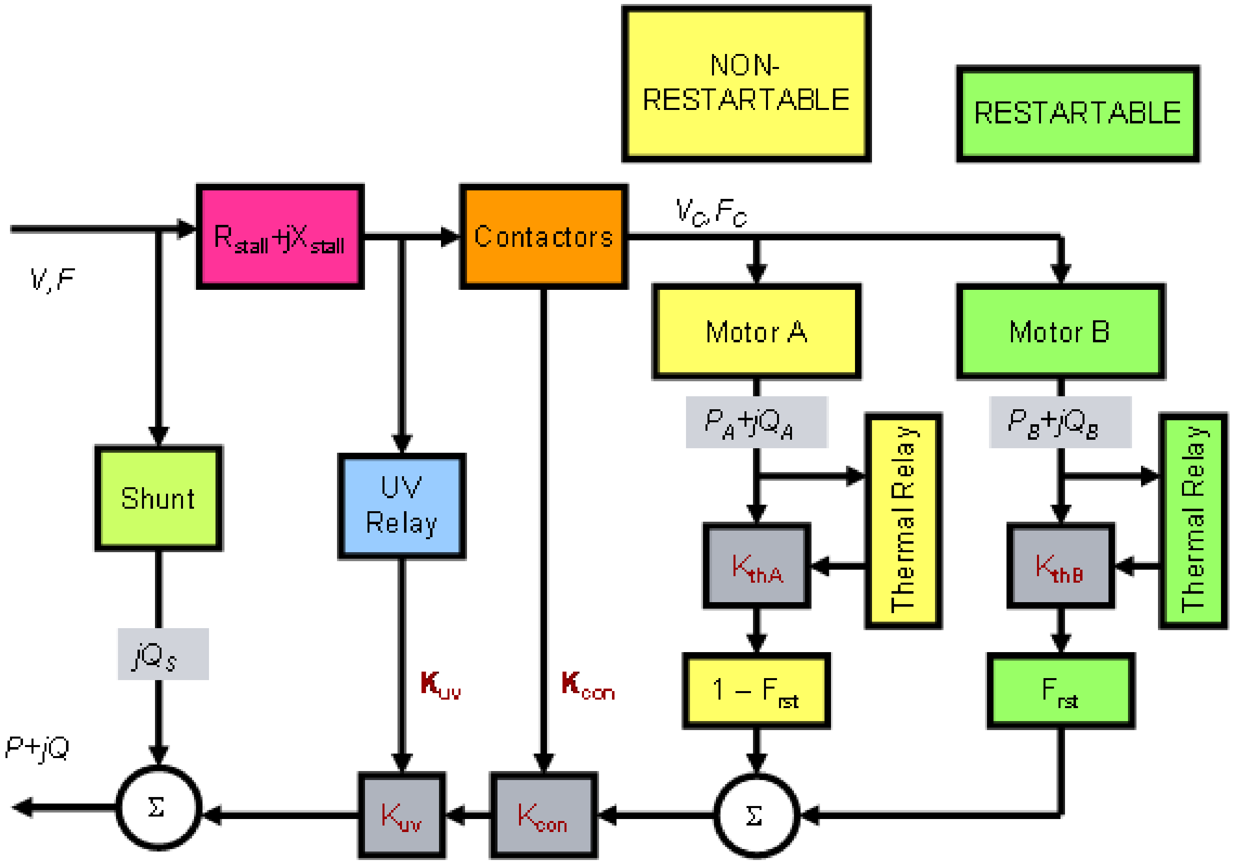


Figure 21.14. Model Structure of ACMTBL

Modeling of Time Delays

The ACMTBL models the following time delays from the instant of various threshold voltage levels:

- Stall delay: This is the time delay from the instant the voltage drops below the stall voltage to the instant the motor stalls. If the voltage recovers above the stall voltage before the completion of stall delay, the stall timer is reset.
- Restart delay: This is the time delay from the instant the voltage exceeds the restart voltage. This is applicable only for the set of Motor B. During the period of restart delay, the model assumes that the compressor motor thermal relay will not operate to trip the motors that are expected to restart.

ACMTBL Model Initialization

The single phase air-conditioner compressor load is represented in the power flow at a bus as a constant MVA, or constant current or constant admittance load.

During initialization of a dynamic simulation run, the ACMTBL model replaces all constant MVA, current, and admittance load at the defined bus with an aggregate single phase air-conditioner compressor load.

Similar models are available for defining the air-conditioning loads by owner (ACMTOW), zone (ACMTZN), area (ACMTAR) and the entire system (ACMTAL).

21.2.6. Composite Load Models

A new composite load, CMLDBL, has been developed for use in PSS®E to simulate the dynamic behavior of an aggregate of three-phase motors, a single-phase air conditioner motor, electronic loads and static loads connected to a low-voltage load bus. The dynamic response is reflected at the high-voltage system bus. In addition to representing the mix of loads at the low-voltage bus, this model includes also an equivalent circuit of distribution transformer, substation compensation, distribution feeder equivalent, and feeder compensation. The structure of the new composite load model CMLDBL is shown in Figure 21.15, "Composite Load Model Structure ".

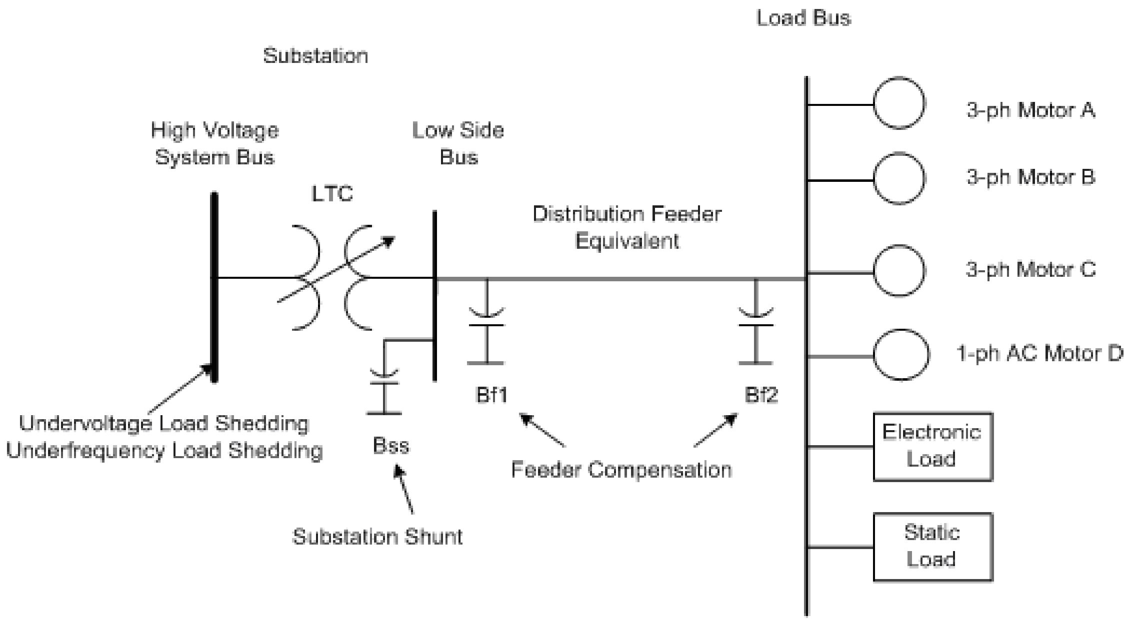


Figure 21.15. Composite Load Model Structure [3]

The main components of the composite load model CMLDBL are the following:

- Substation transformer with load tap changer (LTC) control
- Substation shunt
- Distribution feeder equivalent
- Feeder compensation
- Motor loads (up to four)
- Up to three different types of three-phase induction motors with built-in protection
- Single-phase air conditioner compressor motor with built in protection

[3]"Load Modeling",MMWG Report to TSS, August 2009.

- Electronic loads
- Static load
- Load shedding

Fractions of load components at Load Bus

- Motor A fraction, FmA
- Motor B fraction, FmB
- Motor C fraction, FmC
- Motor D fraction, FmD
- Electronic Load Fraction, Fel
- Static load fraction is computed as Fs = 1 - FmA - FmB - FmC - FmD - Fel

Static Load Component Model

The static load component model is defined by the following parameters

- Power Factor - PFs
- Voltage exponential parameters - P1e, P1c, P2e, P2c, etc.
- Frequency sensitivity parameters - Pfrq, Qfrq

The static load model uses the following equations;

P=P0* (P1c* V/V0P1e + P2c* V/V0P2e+P3)*(1+Pfrq * Df)

Q=Q0* (Q1c* V/V0Q1e + Q2c* V/V0Q2e + Q3)*(1+Qfrq * Df)

P0=Pload* (1.-FmA-FmB-FmC-FmD-Fel)

Q0=P0* tan(arc cos (PFs))

P3=1.-P1c-P2c

Q3=1-Q1c-Q2c

Electronic Load Component Model

The electronic load component model is defined by following parameters

- Power Factor, PFel
- Voltage drop out values, Vd1 and Vd2

The electronic load model varies the load as a function of voltage

Constant P, Q down to V=Vd1

P, Q reduces to zero linearly between Vd1 and Vd2

Three Phase Induction Motor Load Model

The composite load model has the capability to represent three different types of 3-phase induction motor loads. The various motor types are the following:

Three-phase motors driving constant torque loads, such as commercial/industrial air conditioner compressors and refrigerators

Three-phase motors driving torque speed-squared loads with high inertia, such as fans

Three-phase motors driving torque speed-squared loads with low inertia, such as pumps

Motor A, Motor B, and Motor C are 3-phase induction motors. These motors use the induction motor model CIM6BL from PSS®E standard model library. However, the input parameters for the 3-phase motor model are required in terms of impedances and time constants. The mechanical load torque is modeled as:

$TL=T0^{*}\ \omega^{Etrq}$

Where Etrq is torque speed exponent.

The 3-phase motor model has a built-in protection based on undervoltage trip settings.

Single Phase Air Conditioner Load Model

Motor D is the single phase air conditioner load. These motors stall when voltage drops below a set value and a portion of these motors restart when voltage recovers. It is represented by user-defined model ACMTBL. Following are some of the main features of the single-phase air conditioner load model:

Stall characteristics

- if V<Vstall for Tstall sec

Restart characteristics

- if V>Vrst for Trst sec, Frst fraction of motors restart

Undervoltage trip

- if V<Vtr1 for Tr1 sec, Fuvr fraction trips
- if V<Vtr2 for Tr2 sec, Fuvr fraction trips

Contactor

- trips linearly between Vc1off and Vc2off

- reconnects linearly between Vc2on and Vc1on

Thermal protection

- Trips linearly between Th1t and Th2t

Substation Transformer Model

The substation transformer is modeled by the following parameters:

- Transformer short circuit reactance
- Fixed taps on both sides
- Variable tap on the low side

There is an option to model the load tap change control in dynamic simulation. The model uses the online tap changer model OLTC1 from PSS®E standard model library to model the dynamics of load tap change function. The online tap changing model allows the modeling of transformer tap adjustments to help control low side voltage: it has two main components. The first is the voltage sensor, which compares the input voltage to the low side voltage control band defined by Vmin and Vmax. If the voltage input to the sensor is out of the control band, the control will operate after the time delay has been exceeded. Thus, the output of the regulator will be either raised or lowered until the voltage feedback into the sensor is again within the control band.

Load Shedding

The composite load model is responsive to load shedding signal from undervoltage and underfrequency relay connected at the system high voltage bus.

The undervoltage and underfrequency relay models disconnect a fraction of each of the component of the composite load namely static load, electronic load, three-phase induction motor load, single-phase air conditioner load based on the applicable undervoltage or underfrequency relay model setting. The relay model increases the feeder impedance in reverse proportion to the load shedding fraction and reduces the feeder compensation as a direction proportion of the load shedding fraction to simulate the tripping of an equivalent fraction of the feeder from the substation. The substation transformer and substation shunt values do not change due to load shedding.

CMLDBL Model Initialization

The composite load could be represented in the power flow at the system high voltage bus as a constant MVA, or constant current or constant admittance load.

During initialization of a dynamic simulation run, the CMLDBL model replaces all constant MVA, current, and admittance load at the defined bus with an aggregate single phase air conditioner compressor load.

Similar models are available for defining the composite loads by owner (CMLDOW), zone (CMLDZN), area CMLDAR and the entire system (CMLDAL).

During initialization, if the transformer reactance and / or feeder reactance are less than threshold values, the respective component is not represented in the composite load model. Furthermore, if the calculated far end load bus voltage is less than 0.95 pu, the feeder impedance, Rfdr and Xfdr are reduced to bring the voltage above 0.95 pu.

Data Conversion From One Model Representation to Another

Data describing induction machines will often come in the form of the steady-state equivalent. Program IMD also uses the data in this form. Figure 21.16, "Induction Motor Equivalent Circuit for Type 1 Specification in Program IMD" shows the model noted as type 1 in Program IMD.

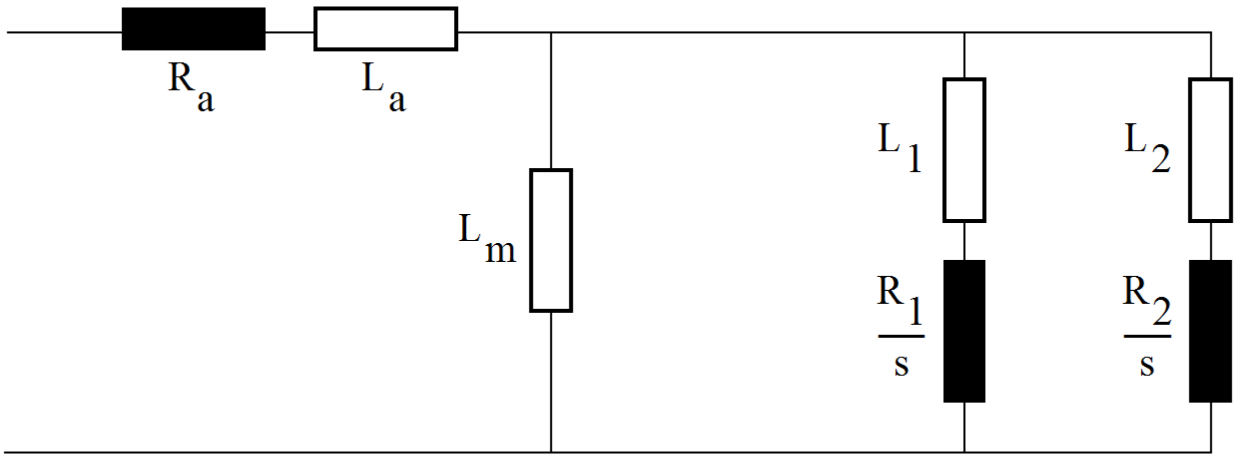


Figure 21.16. Induction Motor Equivalent Circuit for Type 1 Specification in Program IMD

The following equations can be used to convert data from this form to the flux linkage model given in Figure 21.9, "Induction Model With Rotor Flux Linkages Represents Both Type 1 and Type 2 Models in IMD":

Type 1	
Double Cage	Single Cage
$L = L_A + L_M$	$L = L_A + L_M$
$L_1 = L_A$	$L_1 = L_A$
$L' = L_A + \dfrac{1}{\dfrac{1}{L_M} + \dfrac{1}{L_1}}$	$L' = L_A + \dfrac{1}{\dfrac{1}{L_M} + \dfrac{1}{L_1}}$
$L'' = L_A + \dfrac{1}{\dfrac{1}{L_M} + \dfrac{1}{L_1} + \dfrac{1}{L_2}}$	$L'' = 0$
$T'_o = \dfrac{L_1 + L_M}{\omega_o R_1}$	$T'_o = \dfrac{L_M + L_1}{\omega_o R_1}$

Type 1	
Double Cage	Single Cage
$T''_o = \dfrac{L_2 + \dfrac{L_1 L_M}{L_1 + L_M}}{\omega_o R_2}$	$T''_o = 0$

where ω_o is rated supply frequency in rad/sec or 377 rad/sec for a 60-Hz system; X and L are equal in the per-unit system.

If the equivalent circuit describing the induction motor is that noted as type 2 motor in IMD and shown in Figure 21.4, "Circuit for Type 2 Specification in Program IMD", the following equations should be used to convert data into the flux linkage components:

Type 2	
Double Cage	Single Cage
$L = L_A + L_M$	$L = L_A + L_M$
$L_l = L_A$	$L_l = L_A$
$L' = L_A + \dfrac{1}{\dfrac{1}{L_M} + \dfrac{1}{L_1}}$	$L' = L_A + \dfrac{1}{\dfrac{1}{L_M} + \dfrac{1}{L_1}}$
$L'' = L_A + \dfrac{1}{\dfrac{1}{L_M} + \dfrac{1}{L_1 + L_2}}$	$L'' = 0$
$T'_o = \dfrac{L_M + L_1 + L_2}{\omega_o R_2}$	$T'_o = \dfrac{L_M + L_1}{\omega_o R_1}$
$T''_{do} = \dfrac{\dfrac{1}{\dfrac{1}{L_M + L_1} + \dfrac{1}{L_2}}}{\omega_o R_1}$	$T''_o = 0$

Model CMOTOR [4]

Definition and Setup

Model CMOTOR represents a double-cage induction motor driving a load such as a fan or pump where load torque is a function of its rotational speed. The motor is modeled by its steady-state equivalent circuit as shown in Figure 21.4, "Circuit for Type 2 Specification in Program IMD". A single-cage motor may be modeled by setting R_2 and L_2 to 999. The instantaneous electrical slip and torque are given by:

$s = BSFREQ - n$

[4]Obsolete; this discussion is provided for backward compatibility with pre-PSS®E-26 dynamics setups.

$$T_e = \frac{I_1^2 R_1 + I_2^2 R_2}{s}$$

where:

BSFREQ

= The per-unit frequency deviation at the bus to which the motor is connected.

n

= The per-unit deviation of shaft speed from nominal value.

The load on the motor is given by:

$T_L = T_{nom}(1 + n)^D$

where:

T_{nom}

= The load torque when the load is turning at *synchronous* speed.

D

= The exponent relating load torque to speed.

The value of D must be specified in CON(M+2). The specification of T_{nom} is described below in the initialization discussion.

All motor equivalent-circuit parameters and driven load parameters are stated per unit relative to electrical motor base quantities. This implies that the per-unit electrical torque developed when the motor operates at 1 per-unit voltage and 1 per-unit current is:

$$T_e = \frac{\text{power factor} \times \text{efficiency}}{1 - \text{slip}}$$

A typical value for T_e under such conditions is 0.9.

Because the induction motor can present the network with an apparent admittance varying with a very small time constant, CMOTOR uses an implicit numerical integration scheme and requires coordinated calls of the form:

CALL CMOTOR (N,I,M,K,J,L) in CONEC CALL TMOTOR (N,I,M,K,J,L) in CONET

The argument values must be identical in the two calls.

The implicit integration process affects the convergence of the network solution at each time step and usually requires deceleration from iteration to iteration. Accordingly, each call to TMOTOR references a CON,

(CON(L)), containing a deceleration factor value. The value of this factor may be set initially at about 0.5, though trials will be needed to determine an optimum value.

The CMOTOR model handles the electrical connection of the motor to the network by overriding the values of the total load at the bus to which the motor is connected. The values of load are not changed in the working case even though the motor model has the effect of changing their values for the purpose of network solutions during the dynamic simulation run. The actual real and reactive power flow into the motor at its terminals are available for output plotting in VAR(J+5) and VAR(J+6), respectively, and may be selected for plotting by assigning these VARs to channels with activity CHAN. CMOTOR may be initialized either online (running) or off-line (standstill).

Initialization Online

When CMOTOR is initialized online, the real power consumed by the motor is considered to have been included in the real power load specified in the power flow case. Similarly the reactive power consumed by the motor is considered to have been included in the constant Q reactive load at the bus in the power flow case.

For example, consider a bus having a load consisting of the following:

- Controlled rectifiers drawing constant real and reactive power of 2.0 MW and 1.0 Mvar.
- A 3000-hp induction motor consuming 2.25 MW at 0.85 power factor.
- Static capacitors to deliver 1.5 Mvar at unity voltage.
- Electric heating load of 0.5 MW.

The motor reactive load is:

$(2.25 / 0.85) \times \sqrt{}(1 - 0.85 \times 0.85) = 1.39$ Mvar

The bus load should, therefore, be specified for the initial condition power flow solution as:

MWLOAD = (2.0 + 2.25) = 4.25

MVARLOAD = (1.0 + 1.39) = 2.39

GLOAD = 0.5

BLOAD = 1.5

ILOAD = (0 + J0)

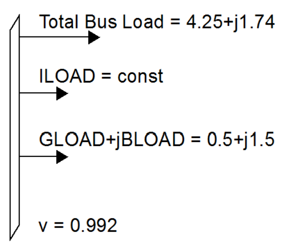
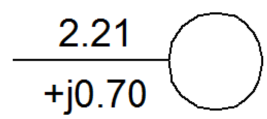
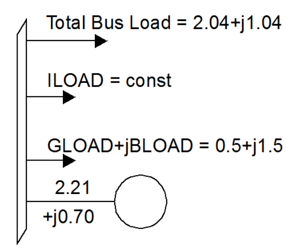
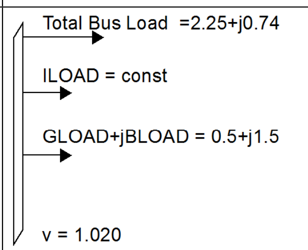
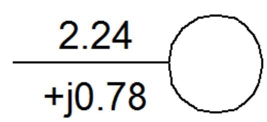
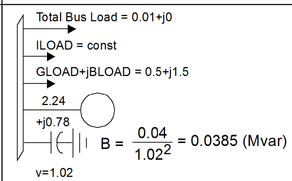
Model CMOTOR initializes itself in accordance with the *initial condition slip* specified by the user. The value of slip for a given bus voltage and load may be determined by activity IMD. Usually a small imprecision in the estimation of initial condition slip exists because it is often desirable to specify one value based on an assumed bus voltage and leave this unchanged on the simulation data from one case to the next. This imprecision will cause the motor to initialize its real and reactive consumption at values slightly different from those used in determining the power flow data.

Adjustment of Bus Loads when Model CMOTOR is Initialized as Onlinesummarizes the action of CMOTOR on initialization. The initial condition slip specified for the motor considered above might, for example, at the voltage existing in the initial condition power flow solution, give a motor consumption of:

P = 2.21 MW Q = 1.30 Mvar

This implies that the ensuing dynamic simulation run will treat the load at the bus as the motor plus:

(4.25 – 2.21) = 2.04 MW of constant power load (2.39 – 1.30) = 1.09 Mvar of constant Mvar load 0.5 MW of constant admittance load 1.5 MW of shunt capacitors

Condition	Data as Specified in Converted Power Flow Case	Initial Condition Motor Consumption	Effective Values of Load Parameters in Initial Condition and Subsequent Simulation
MVARLOAD > MOTOR CONSUMPTION			
MVARLOAD < MOTOR CONSUMPTION			

Adjustment of Bus Loads when Model CMOTOR is Initialized as Online

If the constant Mvar load at the bus is less than the reactive power consumption of the motor at initial voltage and slip, CMOTOR automatically adds static capacitors at the motor terminals to make up the difference. For example, if the power flow case has:

MWLOAD = 2.25 MW MVARLOAD = 1.39 Mvar Bus voltage = 1.02 pu

The motor's initial consumption is:

P = 2.24 MW Q = 1.42 Mvar

The dynamic simulation run will represent the motor plus:

- (2.25 – 2.24) = 0.01 MW of constant power load.
- 0 constant Mvar load.
- (1.42 – 1.39)/1.02 × 1.02 = 0.0288 Mvar of shunt capacitors at the motor terminals (unity voltage value).

plus constant current (ILOAD) and constant admittance load (GLOAD + jBLOAD) as contained in the power flow setup.

The initialization and subsequent simulation of the motor by CMOTOR overrides the specified values of bus load, BLOAD, to replace the appropriate part of each with the motor's instantaneous consumption, but does not modify the value of any of these data items in the power flow working case.

CMOTOR requires the presence of *constant power* load equal to or greater than its consumption in order to be initialized online. This requirement must be recognized when using activity CONL to create the converted initial condition power flow. It is recommended that all buses to be connected to CMOTOR be placed in a separate zone so that they can easily be excluded from a general system-wide conversion of load characteristics by CONL.

CMOTOR cannot initialize itself if the initial condition slip (specified by the user) and its initial condition voltage (from the power flow solution) give an initial consumption greater than the value of the MW load at its bus. The user can provide a small safety margin for initialization by specifying a MW load slightly larger than the motor's expected consumption or by reducing the value of initial condition slip slightly. Both approaches result in a small residual constant power load remaining on the bus throughout the dynamic simulation.

When it is initialized online, the data entered for CMOTOR should follow these rules:

1. CON(M), the motor base MVA, must be nonzero.

2. CON(M+4), the nominal load torque, may be given a nonzero value, but is ignored.

When it is initialized online, CMOTOR calculates the exact value of synchronous-speed load torque corresponding to the initial voltage and slip, and places this in VAR(J+4), allowing for a convenient check of the initialization. The value of VAR(J+4) should be between 0.8 and 0.9 if the initial condition requires the motor to be at full load.

Example — Online Initialization

As an example, consider the small system of Figure 13-1. For this case, assume the load on bus 151 consists of four 2.8 MW induction motors with parameters as determined by the IMD program (Figure 21.5, "Use of IMD to Estimate Induction Motor Equivalent Circuit Parameters to Match Given Nameplate Data (Sheet 1 of 3)" and Figure 21.8, "Plotted Induction Motor Performance from IMD"), and a controlled SCR device accounting for the remainder of the 15 MW. Figure 21.5, "Use of IMD to Estimate Induction Motor Equivalent Circuit Parameters to Match Given Nameplate Data (Sheet 1 of 3)" and Figure 21.8, "Plotted Induction Motor Performance from IMD" show that the four motors will consume approximately 10.92 + j4.97 MVA. The reactive power load of 7.9 Mvar is assumed to consist of the 4.97 Mvar consumed by the motors plus 2.93 Mvar of reactive power consumed by the SCR device.

Assume that the SCR control scheme is such that the voltage variation of the 2.93 Mvar reactive load corresponds to constant inductive susceptance. Accordingly the (15 + j7.9) constant MVA load at bus 151 must be changed to the following:

	15 MW constant P:	10.92 for motors and 4.08 for SCR devices
	4.97 Mvar constant Q:	for motors
	2.93 Mvar constant B:	for SCR device

This does not imply that there will be (15 + j4.97) MVA of constant MVA load during the dynamic simulation; the CMOTOR model will override (10.92 + j4.97) MVA leaving only 4.08 MW of constant power load. The load at all other buses (bus 150 in this case) will be assumed to be 50% constant current and 50% constant admittance for dynamics purposes.

Table 21.1, "Files Used in Simulation of Induction Motors Initialized Online" summarizes the files used in setting up this example simulation.

Table 21.1. Files Used in Simulation of Induction Motors Initialized Online

Original system power flow saved case	SME1
Power flow saved case as converted and prepared for use with CMOTOR model	SMECM
Dynamic Simulation Raw Data File	SMEDM
Dynamics CONEC subroutine	CONEC
Dynamics CONET subroutine	CONET
Initial condition snapshot	SN1M

Figure 21.17, "Setup of Power Flow Case to Accommodate CMOTOR Load of 10.92 + j4.97 MVA at Bus 151" shows the dialog for establishing the converted initial condition power flow case. Figure 21.18, "CMOTOR Model Data Sheet as Completed From Adjustment of Bus Loads when Model CMOTOR is Initialized as Online " shows the CMOTOR data sheet filled in to prepare a record for the data file, SMEDM.

Note the following from the data sheet:

1. The initial motor load is stated only by implication through the initial condition slip, CON(M+3). This value is arrived at by the use of program IMD. In this case, Figure 21.5, "Use of IMD to Estimate Induction Motor Equivalent Circuit Parameters to Match Given Nameplate Data (Sheet 1 of 3)" and Figure 21.8, "Plotted Induction Motor Performance from IMD" show that the slip of 0.0085 pu will give a power consumption of $4 \times 3 \times (0.910 + j0.415) = 10.92 + j4.97$ at unity voltage. This value of slip is accurate enough because the discrepancy between 11.2 and 10.92 can be taken from the 4.08 MW of constant power load at bus 151 with no significant effect on the accuracy of the simulation. The exact initial condition power will be placed in VAR(J+5) and VAR(J+6) during activity STRT.

2. The load torque at synchronous speed is entered as zero; it will be calculated by CMOTOR in activity STRT to balance electrical and load torque in the initial condition.

The procedure for setting up the dynamic simulation is straightforward [5] . Activity DYRE automatically places the required coordinated calls to CMOTOR and TMOTOR in CONEC and CONET, respectively. Activity CHAN is used to place these VARs in output channels with appropriate labels. For convenience VAR(15), which is VAR(J +7), is placed in channel 4 to allow examination of the trimming capacitance (if any) assigned by CMOTOR. Motor terminal voltage is monitored by using CHAN to place the voltage at bus 151 into a channel.

After compiling and linking CONEC and CONET, activity STRT may be used to initialize the CMOTOR model along with all other models as shown in Figure 21.19, "Initialization of Simulation Using Model CMOTOR (Sheet 1 of 2)". The output from DOCU shows that the motor's VARs, J to J+7, have been assigned as VAR(8) through VAR(15) and hence that slip, P, and Q are available in VARs 9, 13, and 14, respectively. The output from activity DLST at the end of Figure 21.19, "Initialization of Simulation Using Model CMOTOR (Sheet 1 of 2)" shows the initialized values of VARs 13, 14, and 15. Because the bus Q load is 4.97 Mvar and the motor reactive power consumption is 4.923 Mvar (see VAR(14)) at a terminal voltage of 0.99484 (see channel 18), the trimming capacitance simulated by CMOTOR would be zero because no deficit of vars exists (i.e., the trimming capacitance cannot be negative). Because the actual initial motor power consumption is 10.81 MW, the constant power consumption of the SCR device will be simulated as 4.19 MW instead of 4.80 MW, an acceptable deviation.

[5]Obsolete; the calls to CMOTOR/TMOTOR must be existing in a pre-PSS®E-26 dynamics setup.

```
ACTIVITY? CASE SME1
SMALL EXAMPLE SYSTEM
BOONDOCKS POWER AND LIGHT

CASE SME1.SAV WAS SAVED ON TUE, MAY 23 1989  13:44

ACTIVITY? CHNG

ENTER CHANGE CODE:
 0 = EXIT ACTIVITY                  1 = BUS DATA
 2 = GENERATOR DATA                 3 = BRANCH DATA
 4 = TRANSFORMER DATA               5 = AREA INTERCHANGE DATA
 6 = TWO-TERMINAL DC LINE DATA      7 = SOLUTION PARAMETERS
 8 = CASE HEADING                   9 = SWITCHED SHUNT DATA
10 = IMPEDANCE CORRECTION TABLES   11 = MULTI-TERMINAL DC
DATA: 1

ENTER BUS NUMBER (0 FOR NEW CHANGE CODE, -1 TO EXIT): 151

BUS DATA FOR BUS   151 [LOAD    3.30] :
  CODE     PLOAD     QLOAD        S H U N T
OLD  1     15.00      7.90     0.00     0.00 CHANGE IT? 1
ENTER CODE, PLOAD, QLOAD, G, B
,,4.97,,-2.93
NEW  1     15.00      4.97     0.00    -2.93

    AREA     VOLT   ANGLE    NAME   BASVLT LOSZON
OLD    2  0.9947   -3.10 LOAD          3.3      1 CHANGE IT? t
.
ENTER BUS NUMBER (0 FOR NEW CHANGE CODE, -1 TO EXIT): -1

ACTIVITY? FNSL
.
ENTER ITERATION NUMBER FOR VAR LIMITS
 0 FOR IMMEDIATELY, -1 TO IGNORE COMPLETELY: 0

ITER   DELTAP   BUS     DELTAQ   BUS     DELTA/V/   BUS
DELTAANG   BUS
  0    0.0000(  200)    0.0003(  151)    0.00015( 201)
0.00003(  201)
  1    0.0000(  150)    0.0002(  201)
REACHED TOLERANCE IN   1 ITERATIONS

LARGEST MISMATCH:     0.00 MW    -0.02 MVAR      0.02 MVA-BUS
200 [STEAM   33.0]
SYSTEM TOTAL ABSOLUTE MISMATCH:                  0.03 MVA

ACTIVITY? CONL
ENTER UP TO 20 BUS NUMBERS
150

ENTER % CONSTANT I, % CONSTANT G FOR REAL POWER: 50 50
ENTER % CONSTANT I, % CONSTANT B FOR REACTIVE POWER: 50 50
|
LOAD TO BE REPRESENTED AS:
   REAL  REACTIVE
  0.00%     0.00% CONSTANT POWER
 50.00%    50.00% CONSTANT CURRENT
 50.00%    50.00% CONSTANT ADMITTANCE

ENTER 1 IF O.K., 0 OTHERWISE: 1
ENTER UP TO 20 BUS NUMBERS
0

LOADS CONVERTED AT      1 OF      2 LOAD BUSES

ENTER 1 TO CONVERT LOADS AT REMAINING      1 BUSES: 0

LOADS CONVERTED AT      2 OF      2 LOAD BUSES

ACTIVITY? CONG
GENERATORS CONVERTED

ACTIVITY? SAVE SMECM
CASE SAVED IN FILE SMECM.SAV ON FRI, MAY 26 1989  15:34
```

Recover original base case

Change load on bus 151 to model motor load

Reassign nonmotor part of reactive load to shunt; new Mvar load is motor Q consumption at initial conditions

Make sure case is solved

Convert loads at other buses

Model assumption for nonmotor loads in this study

Convert generators

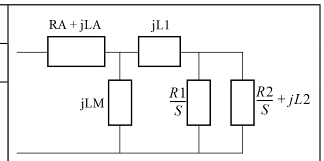
Save new converted case as dynamics initial condition

Figure 21.17. Setup of Power Flow Case to Accommodate CMOTOR Load of 10.92 + j4.97 MVA at Bus 151

CMOTOR

Double Cage Induction Motor

CALL CMOTOR(I,J,M,K,L,M) from CONEC		
CALL TMOTOR(I,J,M,K,L,M) from CONET		
This motor is connected at the bus for which the number is in ICON	#_____	I,
using motor equivalent circuit data stored at CONs	#_____	J,
and motor rating data stored at CONs	#_____	M,
and with motor speed deviation at STATE	#_____	K,
and VARs starting with	#_____	L,
and using local iteration acceleration factor at CON	#_____	N.
The power flow admittance for this motor is ______ + j on motor base and ______ + j on system base.		



Resistance, Impedance on Motor Base MVA

ICON	#	Description
I	151	Bus number

CONs	#	Value	Description
J		0.005	RA
J+1		0.083	LA
J+2		4.0	LM
J+3		0.04	R1
J+4		0.08	L1
J+5		0.011	R2
J+6		0.05	L2
M		12	Motor base MVA
M+1		0.9	Motor base, H
M+2		2.0	Load damping factor, D
M+3		0.000085	Initial condition slip
M+4		0	Load torque at 1 pu speed; on motor base
N		0.9	Local iteration acceleration

STATE	#	Description
K		Motor speed deviation

VARs	#	Description
L		Old speed deviation

VARs	#	Description
L+1		Present speed deviation
L+2		Internal use
L+3		Internal use
L+4		Load torque at 1 pu speed; on motor base
L+5		Motor P
L+6		Motor Q
L+7		Admittance of initial condition Mvar shortage

IBUS, 'CMOTOR', RA, LA, LM, R1, L1, R2, L2, MBASE, H, D, SLIP, TORQUE, ACC/

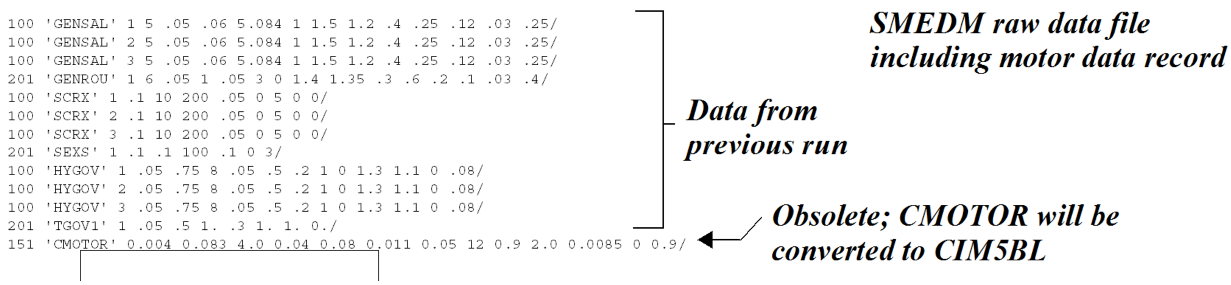


Figure 21.18. CMOTOR Model Data Sheet as Completed From Adjustment of Bus Loads when Model CMOTOR is Initialized as Online

```
                 POWER TECHNOLOGIES INCORPORATED

          12000 BUS POWER SYSTEM SIMULATOR--PSS®E-17.0

  INITIATED AT DYNAMICS ENTRY POINT ON THU, JUN 01 1989  08:41

  ACTIVITY? RSTR SNIM.
  SMALL EXAMPLE SYSTEM
  BOONDOCKS POWER AND LIGHT

  SNAPSHOT SNIM.SNP WAS SAVED ON THU, JUN 01 1989  08:38

  NUMBER OF ELEMENTS RESTORED:
    CONS STATES   VARS  ICONS CHANNELS
     136     44     17      3      6

  ACTIVITY? LOFL

  ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? CASE SMECM
  SMALL EXAMPLE SYSTEM
  BOONDOCKS POWER AND LIGHT

  CASE SMECM.SAV WAS SAVED ON FRI, MAY 26 1989  15:34

  ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? RTRN

  ACTIVITY? STRT.
  CMOTOR AT BUS   151--MVA/CURRENT LOAD ARRAYS MODIFIED

      PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU, JUN 01 1989  08:42
  SMALL EXAMPLE SYSTEM
  BOONDOCKS POWER AND LIGHT

  INITIAL CONDITION LOAD FLOW USED   1 ITERATIONS

  --------------------------MACHINE INITIAL CONDITIONS---------------------------
  X------ BUS -----X ID  ETERM   EFD    POWER     VARS   P.F.   ANGLE    ID      IQ
    100 HYDRO   33.0  1 1.0352 1.7804    4.01     0.48 0.9929  41.39 0.5875 0.5251
    100 HYDRO   33.0  2 1.0352 1.7804    4.01     0.48 0.9929  41.39 0.5875 0.5251
    100 HYDRO   33.0  3 1.0352 1.7804    4.01     0.48 0.9929  41.39 0.5875 0.5251
    201 STEAM   3.30  1 1.0167 1.8531    8.00     2.36 0.9591  40.05 0.6551 0.4938

  INITIAL CONDITIONS CHECK O.K.

  ENTER CHANNEL OUTPUT FILENAME: GPM
  ENTER SNAPSHOT FILENAME: SNIM.

  NUMBER OF ELEMENTS IN USE ARE:
    CONS STATES   VARS  ICONS CHANNELS
     136     44     17      3      6
  ENTER NUMBER TO BE SAVED OR CARRIAGE RETURN FOR ABOVE VALUES

  SNAPSHOT STORED IN FILE SNIM.SNP AT TIME = -0.017

  ACTIVITY? DOCU,ALL

  ENTER OUTPUT DEVICE CODE:
   0 FOR NO OUTPUT   1 FOR CRT TERMINAL
   2 FOR A FILE      3 FOR VERSATEC
   4 FOR PRINTER     5 FOR HARD COPY TERMINAL
   6 FOR ALTERNATE SPOOL DEVICE:

  ENTER 0 FOR REPORTING MODE, 1 FOR DATA CHECKING MODE: 0


                                  CONEC MODELS

            *** CALL CMOTOR(    1,   125,   132,    44,     8,   124) ***

    BUS    NAME BASKV ICON   CIRCUIT CON'S   RATING CON'S   STATE  V A R ' S   ACC CON
    151 LOAD     3.30    1       125-  131      132-  136      44      8-  15       124
```

Recover dynamics setup

Initial condition power flow

Initialize simulation

Output file of channels used later for plotting results

Save the initialized setup

Figure 21.19. Initialization of Simulation Using Model CMOTOR (Sheet 1 of 2)

```
 RA         LA         LM         R1         L1        R2         L2
 0.004      0.083      4.000      0.040      0.080     0.011      0.050

        MOTOR BASE        H         DAMP  INIT SLIP    TORQUE   ACCEL
             12.00      0.900      2.000   0.00850      0.000  0.9000

                                  CONET MODELS

           *** CALL TMOTOR(     1,   125,   132,    44,      8,   124) ***

   BUS    NAME  BASKV  ICON   CIRCUIT  CON'S   RATING CON'S  STATE   V A R ' S   ACC CON
   151  LOAD     3.30     1        125-   131       132-   136     44       8-   15       124

 ACTIVITY? DLST <------------------------------------ List CONs and VAR
                                                      initialization by CMOTOR
 ENTER OUTPUT DEVICE CODE:
  0 FOR NO OUTPUT    1 FOR CRT TERMINAL
  2 FOR A FILE       3 FOR VERSATEC
  4 FOR PRINTER      5 FOR HARD COPY TERMINAL
  6 FOR ALTERNATE SPOOL DEVICE: 1

 ENTER CON RANGE: 1 136
 ENTER VAR RANGE: 1 20
 ENTER STATE RANGE: 1 22
 ENTER ICON RANGE: 1 2
 ENTER OUTPUT CHANNEL RANGE:1 6


 CONS:
     1:   5.000           2: 0.5000E-01         3: 0.6000E-01         4:   5.084
     5:   1.000           6:   1.500            7:   1.200            8: 0.4000
     9: 0.2500           10: 0.1200            11: 0.3000E-01        12: 0.2500


   125: 0.4000E-02      126: 0.8300E-01       127:   4.000          128: 0.4000E-01
   129: 0.8000E-01      130: 0.1100E-01       131: 0.5000E-01       132:  12.00
   133: 0.9000          134:   2.000          135: 0.8500E-02       136: 0.0000E+00

 VARS:
     1: 0.4043E-01        2:   1.000            3: 0.4043E-01         4:   1.000
     5: 0.4043E-01        6:   1.000            7: 0.4000E-01         8:-0.8500E-02
     9:-0.8500E-02       10: 0.0000E+00        11: 0.0000E+00        12: 0.9121
    13:  10.81           14:   4.923           15: 0.0000E+00        16:   1.045
    17: 0.9948           18: 0.0000E+00        19: 0.0000E+00        20: 0.0000E+00

 STATES:
     1:   1.056           2: 0.8919             3: 0.4988             4: 0.0000E+00
     5: 0.7224            6:   1.056            7: 0.8919             8: 0.4988
     9: 0.0000E+00       10: 0.7224            11:   1.056           12: 0.8919
    13: 0.4988           14: 0.0000E+00        15: 0.7224            16:   1.013
    17: 0.3092           18: 0.8823            19: 0.5561            20: 0.0000E+00
    21: 0.6990           22: 0.7739E-02

 ICONS:
     1:    151            2:    150
                                               VAR(J+6) contains
 OUTPUT CHANNELS:          VAR(J+5) contains   motor initial Qelec
                           motor initial Pelec
 #:ADDR      1: 44009       2: 44013        3: 44014        4: 44015       5: 44016
                 VAR            VAR              VAR            VAR     BUS VOLTAGE
                   9             13               14             15            150
 IDENT   MOT-SLIP          MOT-P           MOT-Q          TRIM-CAP        V-150
 VALUE   -0.85000E-02       10.807          4.9229         0.00000E+00      1.0450
 #:ADDR       6: 44017
         BUS VOLTAGE
                 151   <- Initial condition voltage        VAR(J+7) contains value of capacitor
 IDENT   V-151            at motor terminals               needed to make up excess of motor Q
 VALUE     0.99479                                         load over Q assigned to bus

 ACTIVITY? RUN <-------- Run simulation
```

Figure 21.20. Initialization of Simulation Using Model CMOTOR (Sheet 2 of 2)

After CMOTOR has been set up and initialized, simulation runs may be made in the conventional manner. Figure 21.21, “Motor Behavior Following Fault at Bus 150” shows the effect on the motor of a three-cycle single-phase fault with effective positive sequence impedance of j0.02 pu at bus 150. The fault reduces the positive sequence voltage at bus 151 to 0.43 pu, which causes the motor slip to increase from 0.0085 pu to 0.024 pu. On clearance of the fault, the positive sequence voltage at bus 151 returns immediately to 0.70 pu and then returns fairly slowly to nominal voltage as the motor accelerates back to its initial speed.

The small overshoot in the motor slip curve when the fault is cleared is an aberration introduced by the numerical algorithm of the CMOTOR model; it has no significant effect on the true result, which may be seen by smoothing through the overshoot.

Initialization Off-Line

If the motor MVA base is specified as zero in CON(M), the motor is initialized as being off-line and at standstill. In this case, the value of T_{nom}, the load torque at synchronous speed should be specified in CON(M+4) and the initial condition slip need not be specified because it is set to unity by the model in activity STRT. Initialization of motors off-line is useful primarily for simulations of motor starting where the voltage dip produced by the starting of one motor may be sufficient to knock other motors off the line.

The setup of an off-line motor requires no special treatment in the initial condition power flow case, except for recognition that only one CMOTOR model may be placed at any one bus, and hence that an initially off-line motor should not be assigned to the same bus as any other motor whether online or off-line.

Set-up of CMOTOR for off-line initialization is handled by activity DYRE in the same way as for online motors. Switching the motor onto the bus at which it is assigned is handled simply by using activity ALTR to change the value of motor base MVA in CON(M) from zero to the proper value.

Example — Off-Line Initialization

Consider a case in which the four 2.8 MW motor of the previous example are initially off-line, the majority of the other load on the system is supplied by the steam turbine unit, and the four motors are to be started by switching them directly onto the line.

The first step is to expand bus 151 in the power flow case as shown in Figure 21.22, “Expansion of Load Bus 151 into Separate Buses for SCR Load and Each 2.0-MW Motor for Motor Starting Simulation Using CMOTOR” to represent the three load components individually. The data records for the two off-line motors can then be prepared as shown in Figure 21.23, “CMOTOR Data for Off-Line Initialization”. The synchronous load torque, CON(M+4), is specified as 0.9216 pu indicating that each motor must accelerate its full mechanical load when switched on, as would be the case in starting a large ventilation fan without shut-off dampers. The synchronous load torque is determined from the rated torque and the rated speed through the equation for the load torque:

$T_L = T_{nom}(1 + n)^D$

where the load torque, T_L, is equal to the rated electrical torque in the steady-state. The value for rated torque was found from program IMD to be 0.906 at a rated speed of 0.9915, see Figure 21.5, “Use of IMD to Estimate Induction Motor Equivalent Circuit Parameters to Match Given Nameplate Data (Sheet 1 of 3)”. The synchronous torque is then:

$T_{nom} = T_L / \ (1 + n)^D = 0.906/(0.9915)^2 = 0.9216$

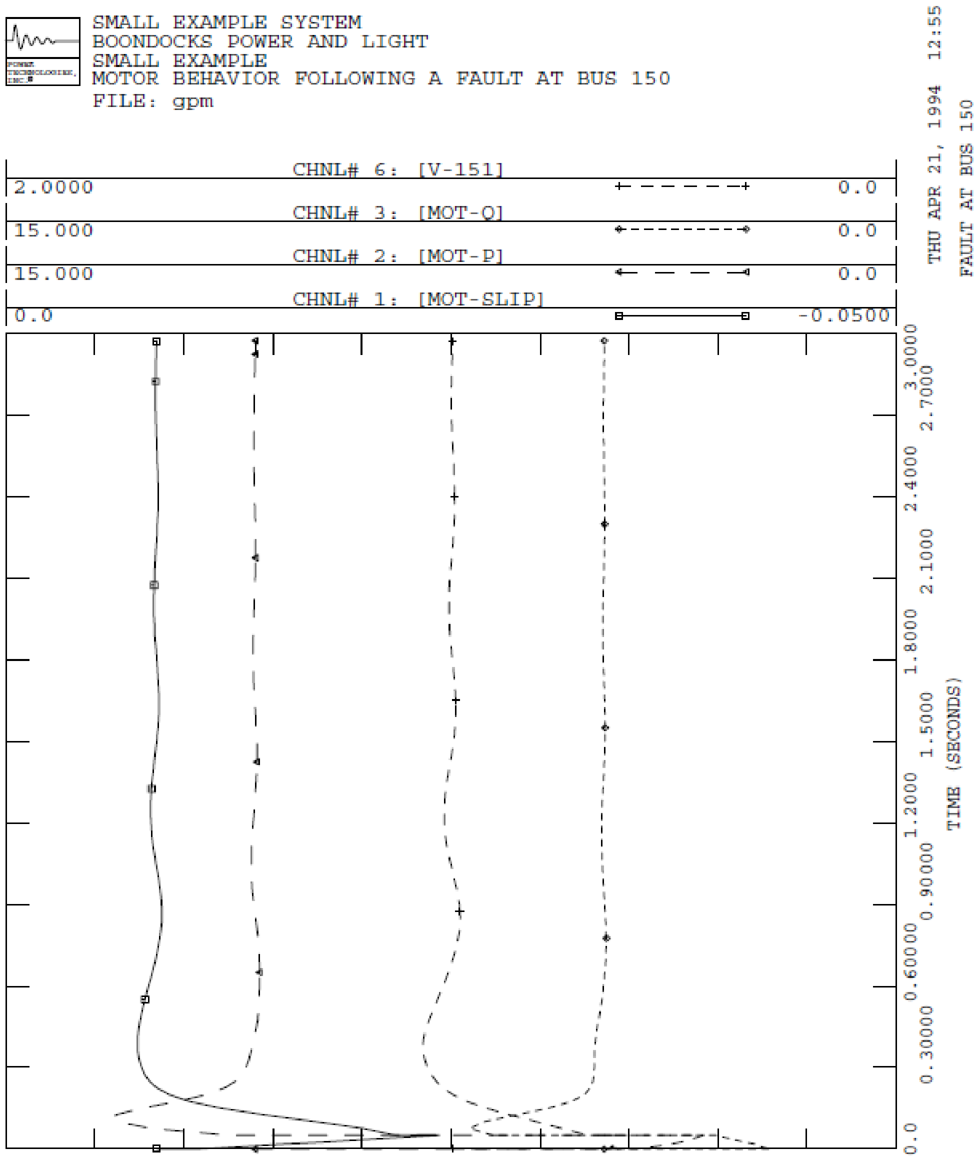
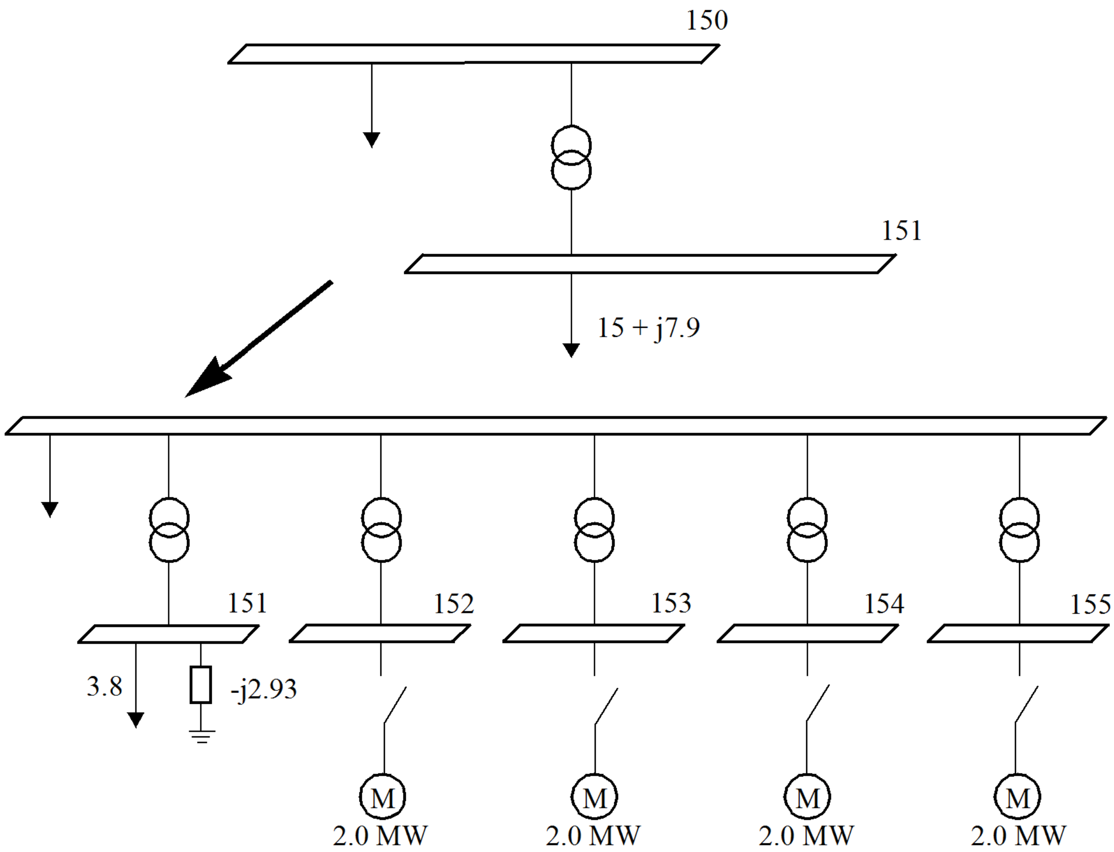


Figure 21.21. Motor Behavior Following Fault at Bus 150



PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E FRI APR 29, 1994 11:26
SMALL EXAMPLE SYSTEM BUS DATA
BOONDOCKS POWER AND LIGHT

BUS#	NAME	BSKV	COD	VOLT	ANGLE	MVA-LOAD		CUR-LOAD		Y-LOAD		S H U N T		AREA	ZONE
100	HYDRO	33.0	2	1.0500	0.0	0	0	0	0	0	0	0	0	1	1
150	LOAD	33.0	1	1.0488	-0.1	0	0	2	1	2	-1	0	0	2	1
151	LOAD	3.30	1	0.9860	-2.8	4	0	0	0	0	0	0	-3	2	1
152	MOTOR-1	3.30	1	1.0232	-0.1	0	0	0	0	0	0	0	0	1	1
153	MOTOR-2	3.30	1	1.0232	-0.1	0	0	0	0	0	0	0	0	1	1
154	MOTOR-1	3.30	1	1.0232	-0.1	0	0	0	0	0	0	0	0	1	1
155	MOTOR-1	3.30	1	1.0232	-0.1	0	0	0	0	0	0	0	0	1	1
200	STEAM	33.0	1	1.0511	0.2	0	0	0	0	0	0	0	0	1	1
201	STEAM	3.30	2	0.9990	3.9	0	0	0	0	0	0	0	0	1	1

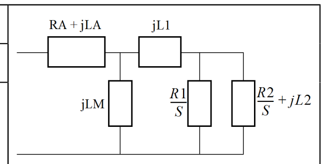
PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E FRI APR 29, 1994 11:26
SMALL EXAMPLE SYSTEM BRANCH DATA
BOONDOCKS POWER AND LIGHT

FROM	TO	CKT	NAME	NAME	LINE R	LINE X	CHRGING	TP	ST	RATA	RATB	RATC
100*	150	1	HYDRO	LOAD	0.0100	0.1000	0.0180		1	15	18	20
100*	200	1	HYDRO	STEAM	0.0200	0.2000	0.0300		1	15	18	20
150*	151	1	LOAD	LOAD	0.0000	1.2500	0.0000	F	1	4	10	15
150*	152	1	LOAD	MOTOR-1	0.0000	1.2500	0.0000	F	1	4	10	15
150*	153	1	LOAD	MOTOR-2	0.0000	1.2500	0.0000	F	1	4	10	15
150*	154	1	LOAD	MOTOR-1	0.0000	1.2500	0.0000	F	1	4	10	15
150*	155	1	LOAD	MOTOR-1	0.0000	1.2500	0.0000	F	1	4	10	15
150*	200	1	LOAD	STEAM	0.0100	0.1000	0.0180		1	15	18	20
200*	201	1	STEAM	STEAM	0.0000	0.8000	0.0000	F	1	10	12	15

Figure 21.22. Expansion of Load Bus 151 into Separate Buses for SCR Load and Each 2.0-MW Motor for Motor Starting Simulation Using CMOTOR

CMOTOR

Double Cage Induction Motor

CALL CMOTOR(I,J,M,K,L,M) from CONEC			 Resistance, Impedance on Motor Base MVA
CALL TMOTOR(I,J,M,K,L,M) from CONET			
This motor is connected at the bus for which the number is in ICON	#_____	I,	
using motor equivalent circuit data stored at CONs	#_____	J,	
and motor rating data stored at CONs	#_____	M,	
and with motor speed deviation at STATE	#_____	K,	
and VARs starting with	#_____	L,	
and using local iteration acceleration factor at CON	#_____	N.	
The power flow admittance for this motor is ______ + j on motor base and _______ + j on system base.			

ICON	#	Description
I		Bus number

CONs	#	Value	Description
J		0.004	RA
J+1		0.083	LA
J+2		4.0	LM
J+3		0.04	R1
J+4		0.08	L1
J+5		0.011	R2
J+6		0.05	L2
M		0	Motor base MVA
M+1		0.9	Motor base, H
M+2		2.0	Load damping factor, D
M+3		1.0	Initial condition slip
M+4		0.9216	Load torque at 1 pu speed; on motor base
N		0.5	Local iteration acceleration

STATE	#	Description
K		Motor speed deviation

VARs	#	Description
L		Old speed deviation

VARs	#	Description
L+1		Present speed deviation
L+2		Internal use
L+3		Internal use
L+4		Load torque at 1 pu speed; on motor base
L+5		Motor P
L+6		Motor Q
L+7		Admittance of initial condition Mvar shortage

IBUS, 'CMOTOR', RA, LA, LM, R1, L1, R2, L2, MBASE, H, D, SLIP, TORQUE, ACC/

```
100 'GENSAL' 1 5 .05 .06 5.084 1 1.5 1.2 .4 .25 .12
.03 .25/
100 'GENSAL' 2 5 .05 .06 5.084 1 1.5 1.2 .4 .25 .12
.03 .25/
100 'GENSAL' 3 5 .05 .06 5.084 1 1.5 1.2 .4 .25 .12
.03 .25/
201 'GENROU' 1 6 .05 1 .05 3 0 1.4 1.35 .3 .6 .2 .1 .03
.4/
```

Motor initially off line

Obsolete; CMOTOR records will be converted to CIM5BL records

Figure 21.23. CMOTOR Data for Off-Line Initialization

Figure 21.24, "Setup of Dynamic Simulation for Motor Starting using Model CMOTOR (Sheet 1 of 3)" shows the CONEC/CONET subroutines, partial DOCU report, and channel assignments established in setting up the simulation with activity DYRE and CHAN. CONEC and CONET have no special logic, and the initial values of motor real and reactive power in VARs 13, 14, 21, and 22 are zero. This case requires the following for acceptable convergence of the network solutions in dynamic simulations:

1. The induction motor acceleration factor, CON(L), is set to a value between 0.3 and 0.5. (DYRE used CON(124) as CON(L) for both calls to CMOTOR, hence forcing the same acceleration for each motor.)

2. The dynamics network solution accelerating factor is set to approximately 0.7 via the dynamic solution parameters option of activity ALTR.

With the setup established, the dynamic simulation of motor starting is handled simply by changing CON(132) to switch the motor onto bus 152 and changing CON(144) to switch on the motor at bus 153. The PSAS input file (PSAS is the Simulation Run Assembler section of PSS®E) to simulate the sequential starting of the motors at a time interval of 10 sec is shown at the end of Figure 21.24, "Setup of Dynamic Simulation for Motor Starting using Model CMOTOR (Sheet 1 of 3)".

```
      SUBROUTINE CONEC
C
$INSERT COMON4
C
      CALL CMOTOR(    1,   125,   132,    44,     8,   124)
      CALL CMOTOR(    2,   137,   144,    45,    16,   124)
      CALL CMOTOR(    3,   149,   156,    46,    24,   124)
      CALL CMOTOR(    4,   161,   168,    47,    32,   124)
C
      RETURN
      END
      SUBROUTINE USRXXX(MC,SLOT,IT)
      INTEGER MC,SLOT,IT
      SELECT (IT)
      FIN
      RETURN
      END


      SUBROUTINE CONET
C
$INSERT COMON4
C
      CALL TMOTOR(    1,   125,   132,    44,     8,   124)
      CALL TMOTOR(    2,   137,   144,    45,    16,   124)
      CALL TMOTOR(    3,   149,   156,    46,    24,   124)
      CALL TMOTOR(    4,   161,   168,    47,    32,   124)
C
      IF (.NOT. IFLAG) GO TO 9000

C
C  NETWORK MONITORING MODELS
C
C
 9000 CONTINUE
C
      RETURN
      END
```

Figure 21.24. Setup of Dynamic Simulation for Motor Starting using Model CMOTOR (Sheet 1 of 3)

```
                         CONEC MODELS

         *** CALL CMOTOR(    1,  125,  132,   44,    8,  124) ***

 BUS   NAME BASKV ICON  CIRCUIT CON'S  RATING CON'S  STATE  V A R ' S  ACC CON
 152 MOTOR-1 3.30    1       125-  131     132-  136     44     8-  15       124

    RA         LA         LM         R1         L1         R2         L2
  0.004      0.083      4.000      0.040      0.080      0.011      0.050

  MOTOR BASE        H          DAMP  INIT SLIP    TORQUE   ACCEL
        0.00      0.900      2.000    1.00000    0.9216  0.5000


         *** CALL CMOTOR(    2,  137,  144,   45,   16,  124) ***

 BUS   NAME BASKV ICON  CIRCUIT CON'S  RATING CON'S  STATE  V A R ' S  ACC CON
 153 MOTOR-2 3.30    2       137-  143     144-  148     45    16-  23       124

    RA         LA         LM         R1         L1         R2         L2
  0.004      0.083      4.000      0.040      0.080      0.011      0.050

  MOTOR BASE        H          DAMP  INIT SLIP    TORQUE   ACCEL
        0.00      0.900      2.000    1.00000    0.9216  0.5000


         *** CALL CMOTOR(    3,  149,  156,   46,   24,  124) ***

 BUS   NAME BASKV ICON  CIRCUIT CON'S  RATING CON'S  STATE  V A R ' S  ACC CON
 154 MOTOR-3 3.30    3       149-  155     156-  160     46    24-  31       124

    RA         LA         LM         R1         L1         R2         L2
  0.004      0.083      4.000      0.040      0.080      0.011      0.050

  MOTOR BASE        H          DAMP  INIT SLIP    TORQUE   ACCEL
        0.00      0.900      2.000    1.00000    0.9216  0.5000


         *** CALL CMOTOR(    4,  161,  168,   47,   32,  124) ***

 BUS   NAME BASKV ICON  CIRCUIT CON'S  RATING CON'S  STATE  V A R ' S  ACC CON
 155 MOTOR-4 3.30    4       161-  167     168-  172     47    32-  39       124

    RA         LA         LM         R1         L1         R2         L2
  0.004      0.083      4.000      0.040      0.080      0.011      0.050

  MOTOR BASE        H          DAMP  INIT SLIP    TORQUE   ACCEL
        0.00      0.900      2.000    1.00000    0.9216  0.5000
```

Motors off line

```
                         CONET MODELS
*** CALL TMOTOR(    1,  125,  132,   44,    8,  124) ***

 BUS   NAME BASKV ICON  CIRCUIT CON'S  RATING CON'S  STATE  V A R ' S  ACC CON
 152 MOTOR-1 3.30    1       125-  131     132-  136     44     8-  15       124


         *** CALL TMOTOR(    2,  137,  144,   45,   16,  124) ***

 BUS   NAME BASKV ICON  CIRCUIT CON'S  RATING CON'S  STATE  V A R ' S  ACC CON
 153 MOTOR-2 3.30    2       137-  143     144-  148     45    16-  23       124
```

Figure 21.25. Setup of Dynamic Simulation for Motor Starting Using Model CMOTOR (Sheet 2 of 3)

```
          *** CALL TMOTOR(    3,  149,  156,   46,   24,  124) ***

   BUS    NAME BASKV ICON  CIRCUIT CON'S  RATING CON'S  STATE  V A R ' S  ACC CON
   154 MOTOR-3 3.30    3       149-  155     156-  160     46     24-  31      124


          *** CALL TMOTOR(    4,  161,  168,   47,   32,  124) ***

   BUS    NAME BASKV ICON  CIRCUIT CON'S  RATING CON'S  STATE  V A R ' S  ACC CON
   155 MOTOR-4 3.30    4       161-  167     168-  172     47     32-  39      124

 ACTIVITY? DLST

 ENTER OUTPUT DEVICE CODE:
  0 FOR NO OUTPUT   1 FOR CRT TERMINAL
  2 FOR A FILE      3 FOR VERSATEC
  4 FOR PRINTER     5 FOR HARD COPY TERMINAL
  6 FOR ALTERNATE SPOOL DEVICE:

 ENTER CON RANGE:
 ENTER VAR RANGE:
 ENTER STATE RANGE:
 ENTER ICON RANGE:
 ENTER OUTPUT CHANNEL RANGE: 1 24

 OUTPUT CHANNELS:

 #:ADDR    1: 44009       2: 44010       3: 44011       4: 44017       5: 44018
             VAR            VAR            VAR            VAR            VAR
              9             10             11             17             18
 IDENT  SLIP-1         MOT-1-P        MOT-1-Q        SLIP-2         MOT-2-P
 VALUE   -1.0000        0.00000E+00    0.00000E+00   -1.0000         0.00000E+00

 #:ADDR    6: 44019       7: 44025       8: 44026       9: 44027      10: 44033
             VAR            VAR            VAR            VAR            VAR
             19             25             26             27             33
 IDENT  MOT-2-Q        SLIP-3         MOT-3-P        MOT-3-Q        SLIP-4
 VALUE   0.00000E+00   -1.0000         0.00000E+00    0.00000E+00   -1.0000

 #:ADDR   11: 44034      12: 44035      13: 44040      14: 44041      15: 44042
             VAR            VAR        BUS VOLTAGE    BUS VOLTAGE    BUS VOLTAGE
             34             35            150            151            152
 IDENT  MOT-4-P        MOT-4-Q        V-150          V-151          V-152
 VALUE   0.00000E+00    0.00000E+00    1.1507         1.0740         1.1227

 #:ADDR   16: 44043      17: 44044      18: 44045      19: 16001      20: 16004
        BUS VOLTAGE    BUS VOLTAGE    BUS VOLTAGE    FIELD VLTAGE   FIELD VLTAGE
            153            154            155       BUS  100 MC 1  BUS  201 MC 1
 IDENT  V-153          V-154          V-155          EFD100-1       EFD201-1
 VALUE    1.1227         1.1227         1.1227         1.1522         1.1904

 #:ADDR   21: 20001      22: 20004      23: 24001      24: 24004
        P MECHANICAL   P MECHANICAL   SPD DEVIAT'N   SPD DEVIAT'N
       BUS  100 MC 1  BUS  201 MC 1  BUS  100 MC 1  BUS  201 MC 1
 IDENT  PMECH100-1     PMECH201-1     SPEED100-1     SPEED201-1
 VALUE   0.42843        0.34421        0.00000E+00    0.00000E+00

 RECOVER initial conditions from SNIM2 AND SMECM1
 INITIALIZE, OUTPUT=GPM2, SNAPSHOT=SNIM2
 RUN to 0.1 SECONDS PRINT=25 PLOT=3
 SET CON 132 TO 3.0
 SET CON 144 TO 3.0                        Switch motors 3 and 4 online
 RUN to 10.0 SECONDS PRINT=25 PLOT=3
 SET CON 156 TO 3.0
 SET CON 168 TO 3.0                        Switch motors 1 and 2 online
 RUN to 20.0 SECONDS PRINT=25 PLOT=3
```

Figure 21.26. Setup of Dynamic Simulation for Motor-Starting Using Model CMOTOR (Sheet 3 of 3)

Figure 21.27, "Behavior of Motor 1 – Direct Online Starting Against Full Load" and Figure 21.28, "Generator Behavior Direct Online Starting Against Full Load" show the simulation result. Switching on motors 1 and 2 drops the voltage at its terminals instantaneously to 0.65 pu; it then droops to 0.58 pu before the generator voltage regulator action starts to return it to schedule. The motor electrical power rises first as a function of recovering terminal voltage and then less rapidly as the voltage hovers around 0.825 pu. As the motor approaches rated speed, the reactive power demand drops very rapidly, voltage rises rapidly to a peak of 1.4 pu, and the motor snaps up to rated speed. Motors 1 and 2 reach rated speed at 5.7 sec. At 10.0 sec, motors 3 and 4 are switched online. Figure 21.28, “Generator Behavior Direct Online Starting Against Full Load” shows the response of the generators to the motor starting. The bus fed excitation systems on the hydro generators do not reach their 5.0 per-unit ceiling until t = 2.0 because of depressed bus voltage. The steam-turbine governor responds to raise turbine power to the maximum of 1.0 pu while the response of the hydro governors is very sluggish. Both excitation systems drop to zero field voltage briefly as motor 1 snaps-over the hump of its characteristic and its heavy reactive power demand disappears.

Figure 21.29, “Motor Starting Behavior as Figure 21.27, “Behavior of Motor 1 – Direct Online Starting Against Full Load” Except Motor Starting Against 0.1-pu Load” and Figure 21.30, “ Generator Behavior Direct Online as Figure 21.28, “Generator Behavior Direct Online Starting Against Full Load” Except Motor Starting Against 0.1-pu Load” show the behavior of the system when the same two motors are started in the same way as before, but against 0.1 per-unit load, as would occur in starting pumps with closed discharge valves. The PSAS input file to produce this changed simulation is:

```
RECOVER initial conditions FROM SNIM2 AND SMECM1
SET CON 136 TO 0.0906
SET CON 148 TO 0.0906
SET CON 160 TO 0.0906
SET CON 172 TO 0.0906
INITIALIZE, OUTPUT=GPM3, SNAPSHOT=SNIM3
RUN to 0.1 SECONDS PRINT=25 PLOT=1
SET CON 132 TO 3.0
SET CON 144 TO 3.0
RUN TO 10.0 SECONDS PRINT=25 PLOT=1
SET CON 156 TO 3.0
SET CON 168 TO 3.0
RUN TO 20.0 SECONDS PRINT=25 PLOT=1
END
```

The file differs from Figure 21.24, “Setup of Dynamic Simulation for Motor Starting using Model CMOTOR (Sheet 1 of 3)” only in setting the CON(M+4) for each motor (CONs 136 and 148) to 0.09216 pu instead of 0.9216 pu. As expected, Figure 21.29, “Motor Starting Behavior as Figure 21.27, “Behavior of Motor 1 – Direct Online Starting Against Full Load” Except Motor Starting Against 0.1-pu Load” and Figure 21.30, “ Generator Behavior Direct Online as Figure 21.28, “Generator Behavior Direct Online Starting Against Full Load” Except Motor Starting Against 0.1-pu Load” show more rapid acceleration of the motor and a reduced dip in system frequency.

Simulation of Switching

The CMOTOR model simulates the run-down of the motor if it is tripped off the line. Tripping is handled by changing the value of CON(M), the motor MVA base, to zero. The motor may be reconnected at any time after tripping by returning CON(M) to the proper value. Changes of mechanical load may be handled at any time by appropriately changing the value of VAR(J+4).

Summary of PSS®E Induction Motor Models

Table 21.2, “Summary of PSS®E Induction Motor Models” contains a new summary of the important features for the different induction motor models available within PSS®E.

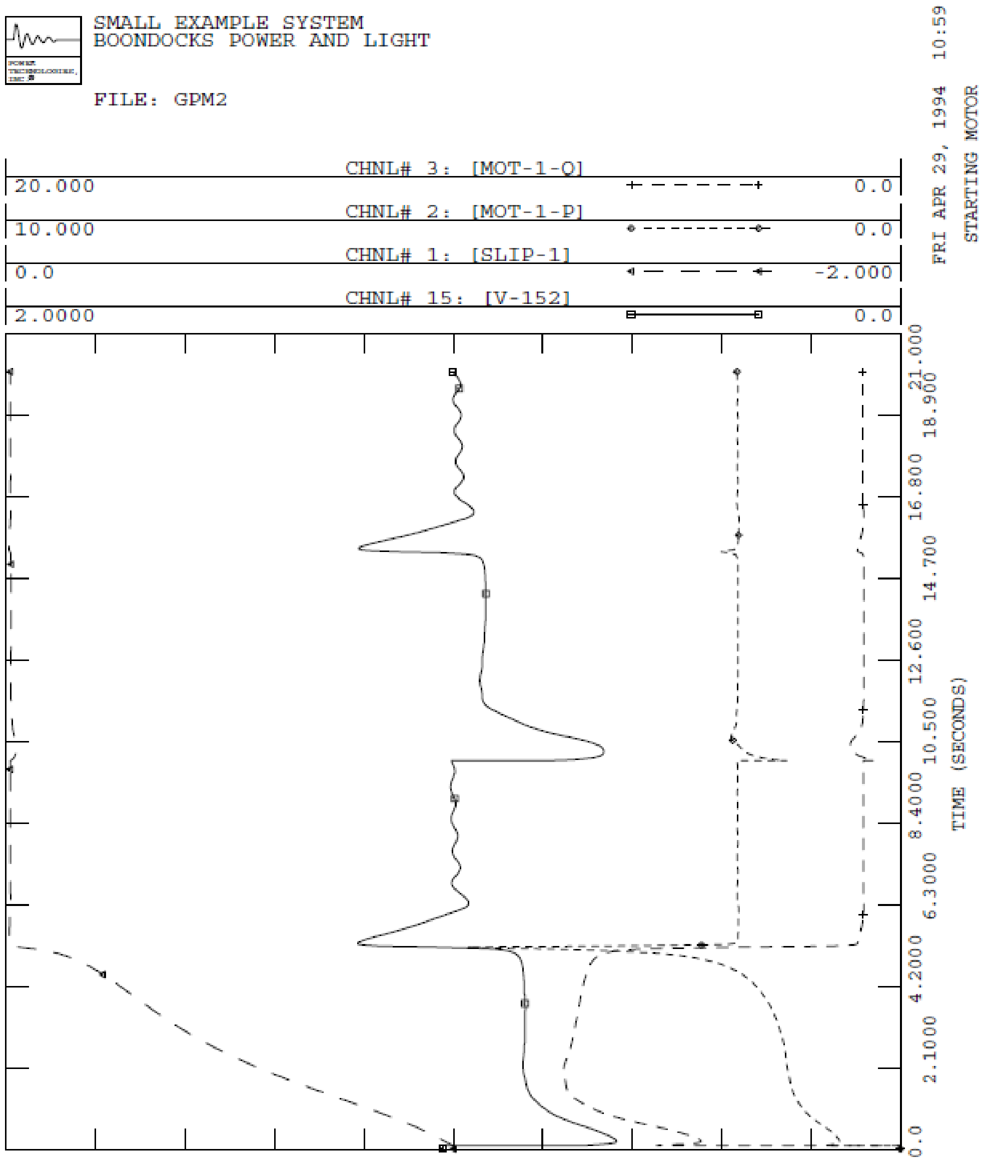


Figure 21.27. Behavior of Motor 1 – Direct Online Starting Against Full Load

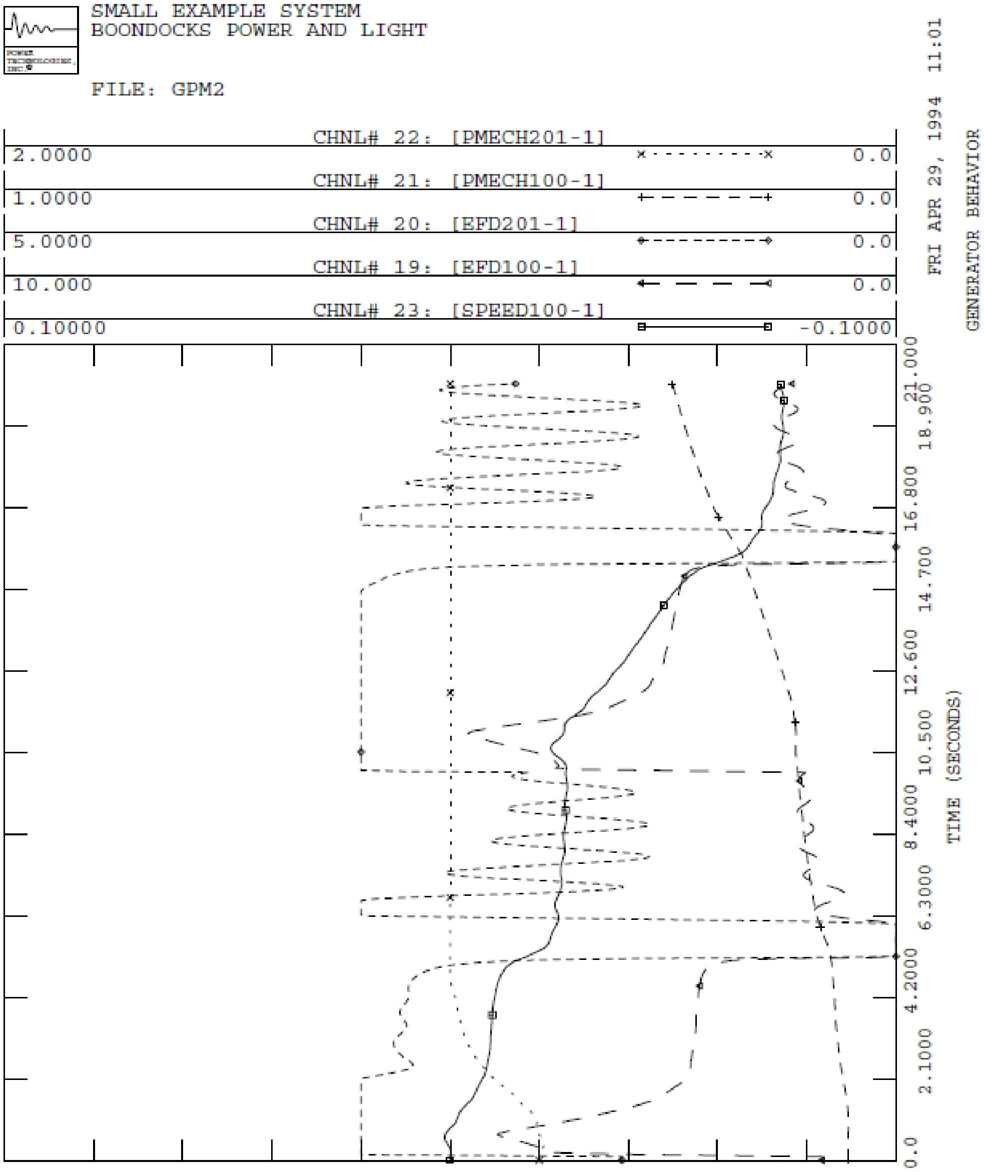


Figure 21.28. Generator Behavior Direct Online Starting Against Full Load

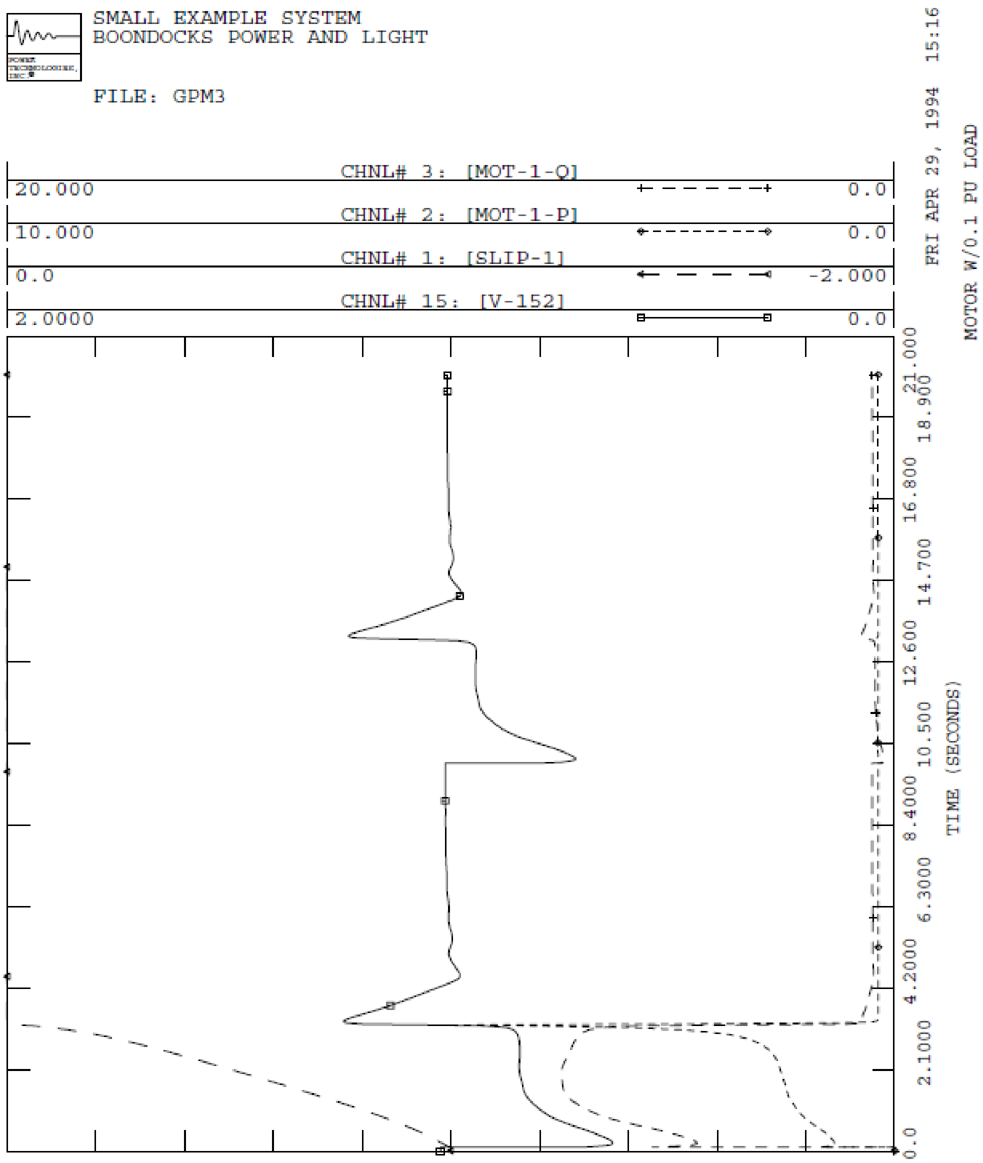


Figure 21.29. Motor Starting Behavior as Figure 21.27, “Behavior of Motor 1 – Direct Online Starting Against Full Load” Except Motor Starting Against 0.1-pu Load

Figure 21.30. Generator Behavior Direct Online as Figure 21.28, “Generator Behavior Direct Online Starting Against Full Load” Except Motor Starting Against 0.1-pu Load

Table 21.2. Summary of PSS®E Induction Motor Models

Model Type	Level of Representation	Power Flow Representation	Input Data	Motor Starting	Special Features
CIM5	Rotating load plus motor electromagnetic dynamics. Single or double cage motor: $T_{LOAD} = T_{NOM}(1 + n)^D$	Bus load consisting of constant MVA, constant current or constant admittance. All load for an individual load ID is treated as the motor load.	Equivalent circuit data. Type 1 or type 2. For single cage: $R_2 = X_2 = 0$.	User sets load ID in-service and specifies positive value for Tnom.	Model calculates initial slip. Motor MVA base can be assigned as a multiplier of MW load at bus. Undervoltage relay.
CIMW	Rotating load plus motor electromagnetic dynamics. Single or double cage motor: $T_{LOAD} = T_o(A\,\omega^2 + B\,\omega + C_o + D\,\omega^e)$	Load consisting of constant MVA, constant current or constant admittance. All load for an individual load ID is treated as the motor load.	Equivalent circuit data. Type 1 or type 2. For single cage: $R_2 = X_2 = 0$.	Not valid for motor starting analysis.	Model calculates initial slip. Motor MVA base can be assigned as a multiplier of MW load at bus. Undervoltage relay.
CIMTR2	See CIMTR4. CIMTR4 is recommended for use over CIMTR2.				
CIMTR4	Rotating load plus motor electromagnetic dynamics. Single or double cage motor: $T_{LOAD} = T_{NOM}(1 + n)^D$	Machine with negative power output. ZSOURCE must match X″ or X′ (single cage). All load for the machine is treated as the motor load.	Operational impedance and time constants as derived from type 1 or 2 equivalent circuit. For single cage: $X'' = T'' = 0$.	User sets machine in- service and specifies negative value for Tnom.	Model calculates initial slip.
CMOTOR (Obsolete)	Rotating load dynamics with steady-state electrical characteristics. Single- or double-cage motor: $T_{LOAD} = T_{NOM}(1 + n)^D$	Load consisting of constant MVA or constant current. All load IDs attached to this bus are considered available to be represented as motor load.	Equivalent circuit data. Type 2. For single cage: $R_2 = L_2 = 999$	User sets MBASE to motor MVA base and specifies a positive value for Tnom.	User must specify initial slip from which the model determines the required MW. Not valid for use in extended term simulations.

21.3. Load Relay Models

21.3.1. Basic Considerations

The PSS®E model library includes two general groups of load relay models: underfrequency and undervoltage load shedding relays. The models provide for the setting of multiple load shedding stages. For each stage, the user may specify a frequency or voltage threshold, pickup time, and the fraction of load to shed.

All models have the capability of shedding load for either a CONL-type representation of load (constant MVA, current and admittance components), or if the load is modeled using one of the load characteristic models. In the case where the traditional CONL load components are present, all models operate identically on the real and reactive parts of the constant MVA, current and admittance components.

The effective value of load as it varies during the simulation may be tracked by assigning the load to an output channel in activities CHSB or CHAN. Likewise, a total subsystem load may be monitored by assigning subsystem totals output channels in activity CHSB.

The load shedding relays also set flags (ICONs) that can be then utilized by user-supplied logic in subroutine CONET. The user-supplied logic can be developed in order to run a more complex coordination of relays or for additional supervisory action not provided within a specific model.

21.3.2. Underfrequency Load Shedding Models

LDSH Type Models (LDSHBL, LDSHOW, LDSHZN, LDSHAR, LDSHAL)

The LDSH type models (LDSHBL, LDSHOW, LDSHZN, LDSHAR, LDSHAL) represent solid-state type load-shedding relays. The models disconnect either a fraction of the load at which the model is applied or sets flags to switch lines, capacitors, etc. with user-supplied logic when frequency falls below each of its pickup points. The load to be shed at each of three steps is specified in CON(J+2), CON(J+5), and CON(J+8) as a fraction of the original load.

Each of the above loads is reduced to a fraction of its original value, with the fraction being equal to the value specified for the stage, as corrected to account for load already shed in the prior stage. For example, if the three load-shedding stages are set to shed 0.3, 0.3, and 0.2 per-unit of the original load, the above load elements are all multiplied by:

1 - 0.3 on the first stage

$$\frac{0.7 - 0.3}{0.7}$$

on the second stage

$$\frac{0.4 - 0.2}{0.4}$$

on the third stage

When used to set flags, CON(J+2), CON(J+5), and CON(J+8) must be set to zero. ICON(N+2), ICON(N+5), and ICON(N+8) are set to –1 when the breaker timer times out for that state. Each stage is triggered only once in a simulation; when set to –1 it stays there. The time characteristic of the load-shedding relay is illustrated by Figure 21.31, "Underfrequency Detection and Load Shedding in LDSH Type Models".

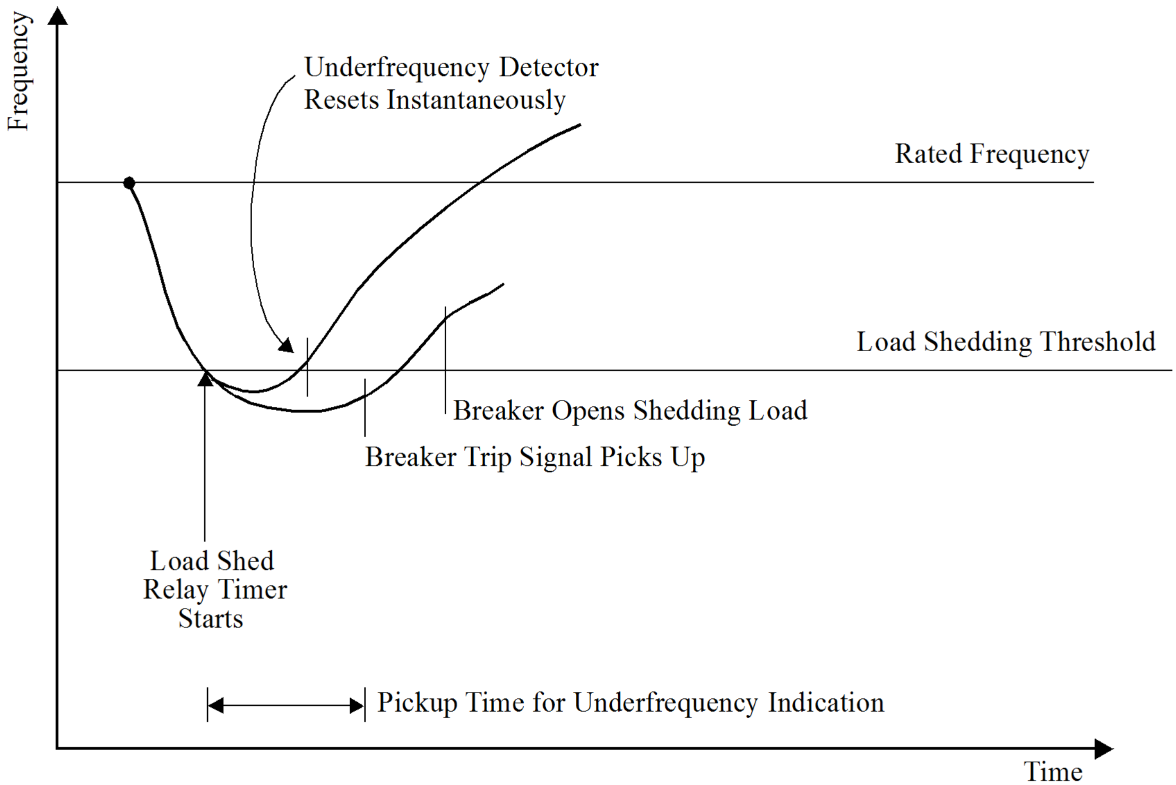


Figure 21.31. Underfrequency Detection and Load Shedding in LDSH Type Models

The timer for each stage is started when frequency falls below its threshold value and is reset instantaneously if frequency rises above its threshold. A trip signal is sent to the circuit breaker if the timer reaches its setting; frequency must have remained below the threshold for the entire time delay for shedding to occur. Actual shedding of load or setting of the flag is delayed by the circuit breaker time.

The three shedding stages are independent of one another, and the second stage could operate before the first if the threshold and time delay settings called for it. The models do not affect bus connected shunt devices as characterized by the bus shunt data entries GSHUNT and BSHUNT.

LDST Type Models (LDSTBL, LDSTOW, LDSTZN, LDSTAR, LDSTAL)

The LDST type models (LDSTBL, LDSTOW, LDSTZN, LDSTAR, LDSTAL) represent load-shedding as controlled by a relay with an inverse time characteristic. The models implement single-stage load-shedding which, when the circuit breaker(s) opens, disconnects a fraction of the load components. The models utilize an underfrequency detector with an inverse-time characteristic, defined by Figure 21.32, "Time Inverse Operating Characteristic of LDST Type Models", as distinct from the simple delay characteristic modeled by the LDSH type models.

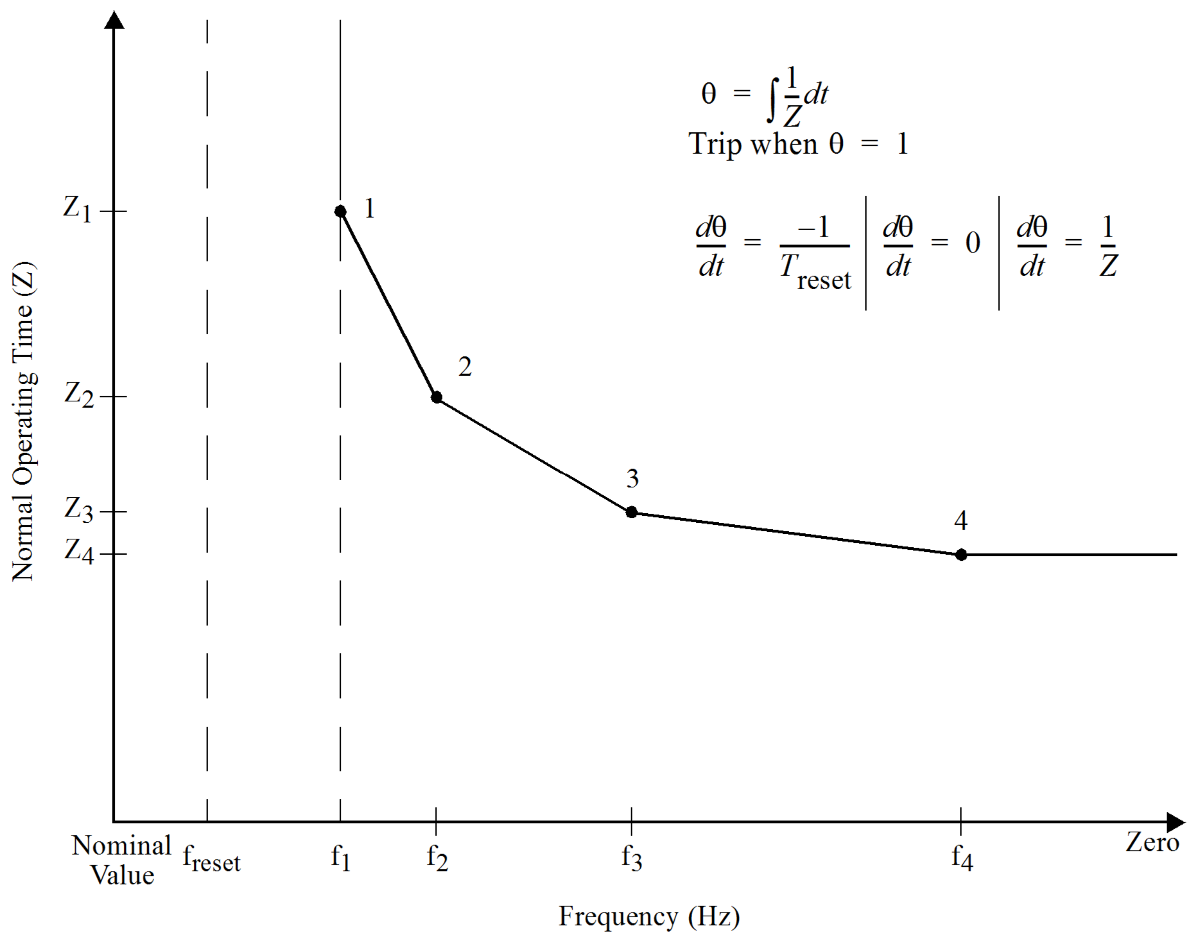


Figure 21.32. Time Inverse Operating Characteristic of LDST Type Models

Points 1, 2, 3, and 4 are specified by CONs J through J+7. The values of the nominal operating time, Z, are the times that the relay would take to close its trip contact if presented with a constant input frequency. The actual time taken to close the trip contact in response to a varying input frequency is given by the integral of the rate of motion of the sensitive element. The frequency detector does not reset immediately if frequency rises above its threshold value; it resets in a linear fashion at such a rate that it takes Treset seconds to reset after just reaching its trip point. If frequency falls below the pickup threshold (CON(J)) during the resetting process, the relay commences integrating from its partially reset condition.

The models can also be used just to set a flag that can be used by user supplied logic for functions such as tripping a line with subroutine LINTRP. CON(J+9) should be set to zero to disable load tripping. ICON(M) is set to −1 when the timer times out. ICON(M+2) is set to 1 when the breaker timer times out and stays there.

DLSH Type Models (DLSHBL, DLSHOW, DLSHZN, DLSHAR, DLSHAL)

The DLSH type models (DLSHBL, DLSHOW, DLSHZN, DLSHAR, DLSHAL) are an extension to the LDSH type models to include frequency of decay. Timers will only be active when frequency is below the shedding point values *and* the magnitude of the rate of change of frequency is above its threshold. Violation of either of the above causes timers to reset. These models can either shed load or set flags for user-supplied logic. The flags are set identically to the LDSH type models.

LDS3 Type Models (LDS3BL, LDS3OW, LDS3ZN, LDS3AR, LDS3AL)

The LDS3 type models (LDS3BL, LDS3OW, LDS3ZN, LDS3AR, LDS3AL) represent solid-state load shedding relays with generator transfer trip capability. These models are similar in function and performance to the LDSH type models. These models add the following enhancements to the LDSH type models:

1. It allows up to five stages of load to be tripped.
2. This model allows separate circuit breaker times for each stage.
3. This model allows the user to trip the bus connected shunt devices as characterized by GSHUNT and BSHUNT in same fractions as load.
4. This model allows the user to trip a plant or specific machine if any breakers become activated. The transfer trip breaker has its own timer.

21.3.3. Undervoltage Load Shedding Models

LVSH Type Models (LVSHBL, LVSHOW, LVSHZN, LVSHAR, LVSHAL)

The LVSH type undervoltage load shedding relay models (LVSHBL, LVSHOW, LVSHZN, LVSHAR, LVSHAL) represent a solid-state type load-shedding relays that disconnect load based on low voltage. The model has three stages. The fractions of load to be shed are specified in CON(J+2), CON(J+5) and CON(J+8). The models can also be used to set flags. For this case, the ICONs are set identically to the LDSH type models.

LVS3 Type Models (LVS3BL, LVS3OW, LVS3ZN, LVS3AR, LVS3AL)

The LVS3 type models (LVS3BL, LVS3OW, LVS3ZN, LVS3AR, LVS3AL) are an extension of the LVSH models:

1. It allows five stages of load, each with its own individual circuit breaker timer.
2. It optionally allows tripping of GSHUNT and BSHUNT in the same fractions as load.
3. It allows the user to specify two branches that may also be tripped. Each branch has its own circuit breaker timer.

21.3.4. Under voltage and underfrequency load shedding models

UVUF Type Models (UVUFBL, UVUFOW, UVUFZN, UVUFAR, UVUFAL)

The UVUF type models (UVUFBLU1, UVUFOWU1, UVUFZNU1, UVUFARU1, UVUFALU1) represent solid-state type load-shedding relays. The models disconnect a fraction of each of the component of the composite load namely static load, electronic load, 3-phase induction motor load, single-phase air conditioner load based on the applicable undervoltage or underfrequency setting. The model increases the feeder impedance in reverse proportion to the load shedding fraction and reduces the feeder compensation as a direct proportion of the load shedding fraction to simulate the tripping of an equivalent fraction of the feeder from the substation. The substation transformer and substation shunt values do not change due to load shedding. The model has 3 voltage-based trip settings and 3 frequency-based trip settings.

Chapter 22
Generic Wind Models

All varieties of available wind turbines can be conventionally split into several types. Currently, four types have been suggested as follows:

- Type 1. Direct connected Conventional Induction Generator
- Type 2. Wound rotor Induction Generator with Variable Rotor Resistance
- Type 3. Doubly-Fed Induction Generator
- Type 4. Full Size Converter Unit

The description of generic models in this chapter correspond to the above classification.

Generic Wind Models are designed to be used in studies related to the integration of Wind Turbine Generators (WTG) in an Electrical Power System.

The generic WTG models (WT1, WT2, WT3, and WT4) were not developed with the intent of being accurate for the study of frequency excursions. Furthermore, generic models were not designed to reproduce the behavior of advanced power management features such as programmed intertia and "spinning reserve" by spilling wind.

Standard PSS®E CONET models VTGDCA and FRQDCA can be used to simulate characteristics of the voltage and frequency protection systems.

Note: The representation of implicit transformers is not allowed for any of these four types of wind generators.

22.1. Generic WT1 (Type 1) Model

22.1.1. Introduction

The WT1 PSS®E wind turbine stability model was developed to simulate the performance of a wind turbine employing a conventional induction generator directly connected to the grid.

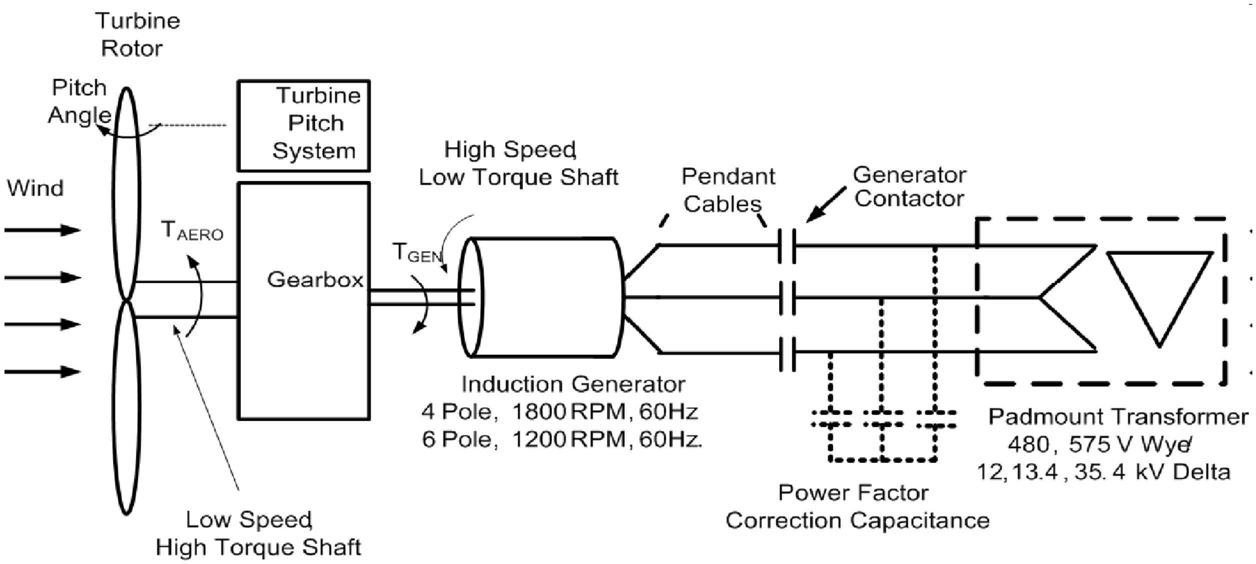


Figure 22.1. Conventional Directly-Connected Induction Generator

22.1.2. Power Flow Setup

A wind turbine generator in power flow is treated as related to a wind machine category of the existing generator record of the Power Flow Raw Data File. The wind control mode should be set as 3, i.e., a wind machine that operates at a fixed power, with the machine's reactive power output and reactive power upper and lower limits all equal and set based on the specified power factor and on the machine's active power setting (PG on the data record). Negative value of the power factor must be specified and is interpreted as a leading power factor (i.e., the wind machine produces active power and absorbs reactive power).

All issues of making an equivalent of a wind farm to be modeled is the users' responsibility. They should make a decision on how many original units will be lumped into an equivalent machine presented in the power flow case. For N lumped machine they need to multiply MBASE of the original machine by N.

They also have to take care of the adequate equivalent of the wind farm feeders, collectors, and step-up transformers.

A vast majority of wind turbines with this type of a machine includes a set of compensating capacitors to keep the power factor in steady state within the given range. These capacitors should be added in a fixed shunt data record.

22.1.3. Dynamic Setup

PSS®E WT1 Generic Wind Model comprises models as follows

- WT1G: generator/converter model
- WT12T: wind turbine model
- WT12A: pseudo governor model

Figure 22.2, “WT1 Connectivity Diagram” shows the interaction between these models.

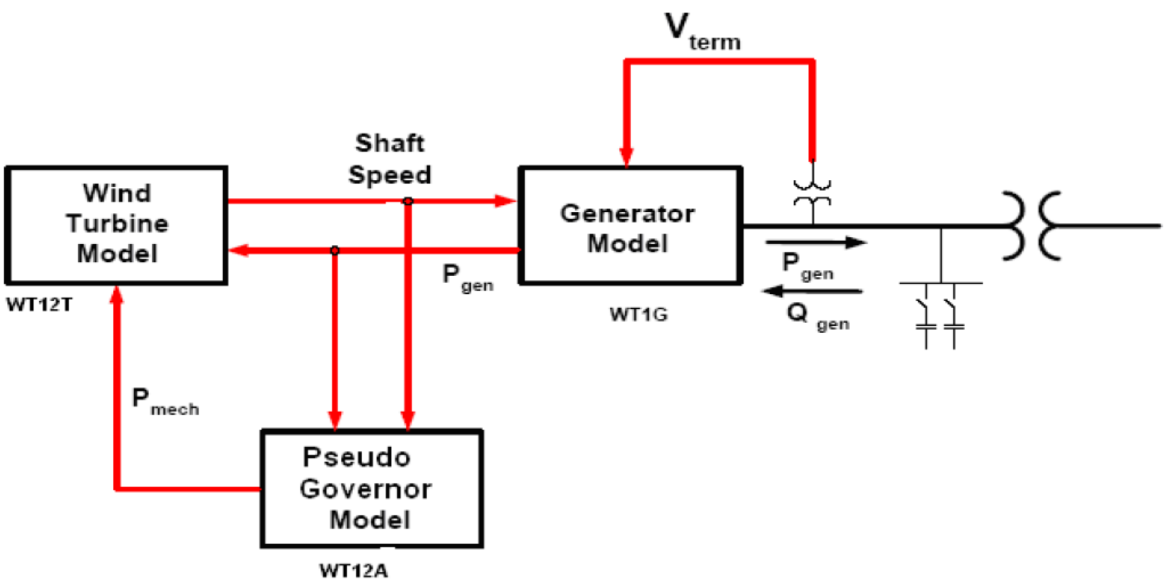


Figure 22.2. WT1 Connectivity Diagram

The generator model WT1G is based on the standard PSS®E model of the induction generator CIMTR3. This model takes into account the rotor flux dynamics and can be used for single cage or double cage machines. At initialization this model calculates the reactive power consumption of the machine Qact at given terminal voltage and MW-dispatch. It places a “hidden” shunt on the machine terminal bus, with the size equal to a difference between Q_{gen} from the power flow and Q_{act}.

The turbine model WT12T uses the two-mass representation of the wind turbine shaft drive train. It calculates the speed deviations of the rotor on the machine and on the blade sides. By setting the turbine inertia fraction H_{tfrac} = 0 the model can be switched to a conventional single mass representation.

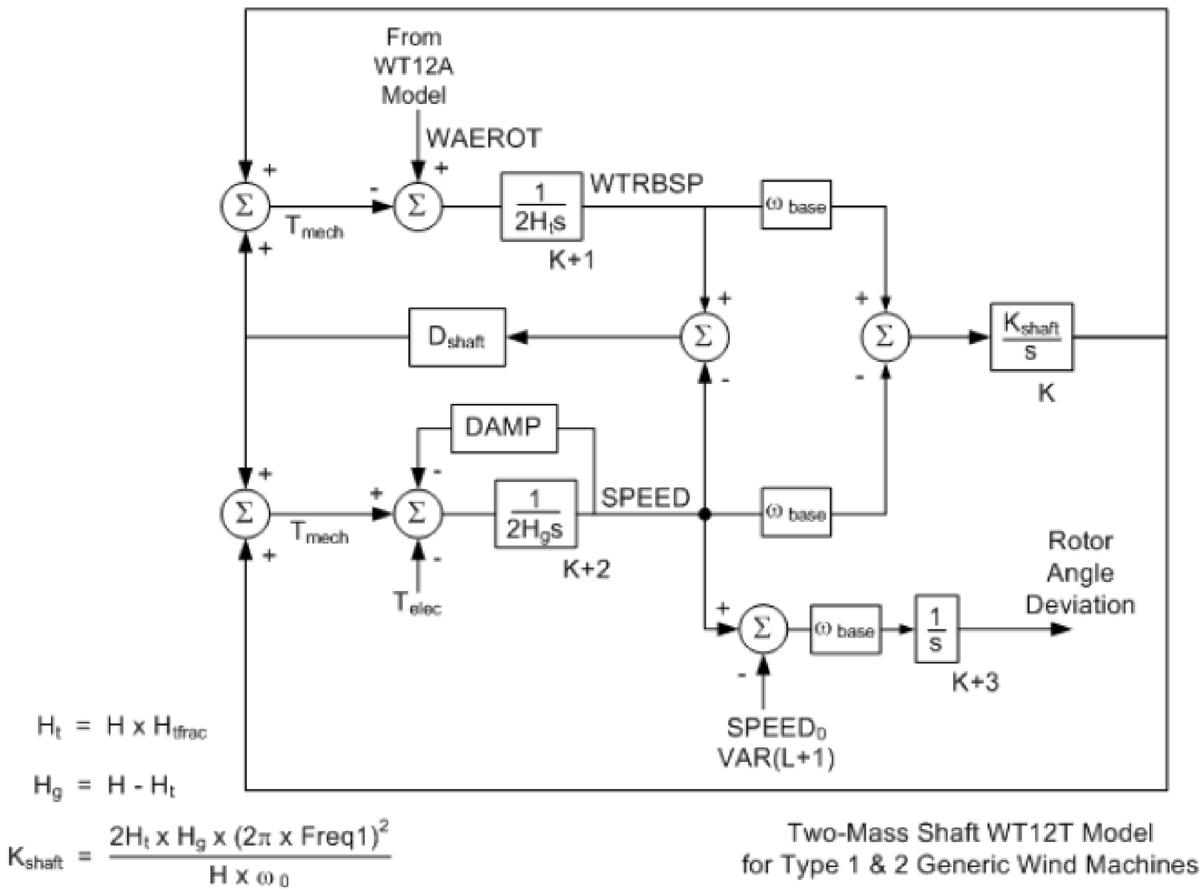


Figure 22.3. WT12T Two-Mass Shaft model

The pseudo governor model WT12A is an attempt to simplify and generalize calculation of the aerodynamic torque. This model was designed and developed after thorough investigation of aerodynamic characteristics and pitch control of several vendor specific wind turbines. Finally the arrangement shown below was suggested.

Figure 22.4. Pseudo-Governor Model

The model uses two inputs, one in terms of the blade rotor speed deviation and another in terms of the real power at the machine terminals. These two inputs combined together are processed by a PI controller with non-wind-up limits. The filtered output is the mechanical torque on the rotor blade side that is used by the WT12T model.

The example dynamic data input file is provided below, along with the example documentation of the dynamic parameters.

```
 5   'WT1G1'  1
0.84600        0.0000        3.9270        0.17730       0.0000
0.10000        1.0000        0.30000E-01   1.2000        0.17900   /

5 'WT12T1'   1
5.3000         0.0000        0.91800        5.0000         1.0000 /

5 'WT12A1'   1
0.1500E-01     0.1000        0.1500E-01     0.1000         0.1000
0.1000         0.9000        0.2500     /
```

Figure 22.5. Example Dynamic Data Input File, WT1

To mitigate sustained increase in power output for a sustained drop in frequency, Limax should be set to the rated power on the machine MVA base. Typically, Limax = 0.9 on the machine MVA base at rated power output. For instance, if the generator is rated at 111MVA and it is dispatched at 100 MW, Limax should be 0.9 (100/111). This baseline behavior is consistent with the assumption that the wind turbine is operating at rated power output, and wind speed remains constant.

```
PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS(R)E     THU, AUG 14 2008   11:14
WECC WGMG TEST SYSTEM
SCR=20 FULL POWER

WIND MODELS

REPORT FOR ALL MODELS                             BUS 5 [CLR_1       0.6000] MODELS


** WT1G1 **   BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S       V A R S
                 5 CLR_1         0.6000 1       3-12          3-7            1-3

             MBASE      Z S O R C E
             111.1  0.00000+J 0.17729

                T'     T''       X       X'       X''      XL
              0.846  0.000    3.93  0.1773  0.0000  0.1000

              E1       S(E1)      E2      S(E2)
            1.0000   0.0300   1.2000   0.1790


** WT12T1 **   BUS X-- NAME --X BASEKV MC  C O N S     S T A T E S       V A R S
                 5     CLR_1     0.6000 1     13-17          8-11           4-6

       H            DAMP          Htfrac        Freq1        DSHAFT
     5.3000        0.0000        0.9180       5.0000       1.0000



** WT12A1 **   BUS X-- NAME --X BASEKV MC  C O N S     S T A T E S        V A R S
                 5 CLR_1         0.6000 1     18-25        12-15           7-8

       DROOP      KP        TI        T1        T2       TPE      LIMMAX    LIMMIN
       0.015     0.100     0.050     0.100     0.100     0.100    0.900     0.250
```

Figure 22.6. Example of Documentation, WT1

22.2. Generic WT2 (Type 2) Model

22.2.1. Introduction

The WT2 PSS®E wind turbine stability model was developed to simulate performance of a wind turbine employing a wound rotor induction generator with the variable rotor resistance control.

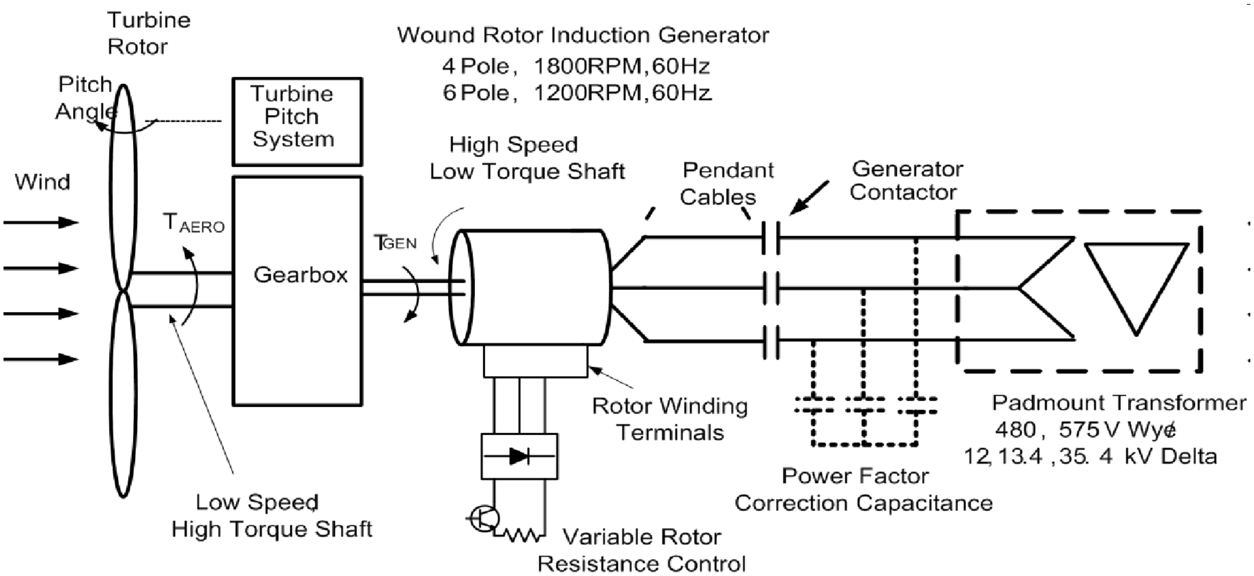


Figure 22.7. Wound Rotor Induction Generator with Variable Rotor Resistance Control

22.2.2. Power Flow Setup

A wind turbine generator in power flow is treated as related to a wind machine category of the existing generator record of the Power Flow Raw Data File. The wind control mode should be set as 3, i.e. a wind machine that operates at a fixed power, with the machine's reactive power output and reactive power upper and lower limits all equal and set based on the specified power factor and on the machine's active power setting (PG on the data record). Negative value of the power factor must be specified and is interpreted as a leading power factor (i.e., the wind machine produces active power and absorbs reactive power).

All issues of making an equivalent of a wind farm to be modeled is the users' responsibility. They should make a decision on how many original units will be lumped into an equivalent machine presented in the power flow case. For N lumped machine they need to multiply MBASE of the original machine by N.

They also have to take care of the adequate equivalent of the wind farm feeders, collectors, and step-up transformers.

A vast majority of wind turbines with this type of a machine includes a set of compensating capacitors to keep the power factor in steady state within the given range. These capacitors should be added in a fixed shunt data record.

22.2.3. Dynamic Setup

PSS®E WT2 Generic Wind Model comprises models as follows

- WT2G: generator/converter model
- WT2E: electrical control model
- WT12T: wind turbine model
- WT12A: pseudo governor model

Figure 22.8, "WT2 Connectivity Diagram" shows the interaction between these models.

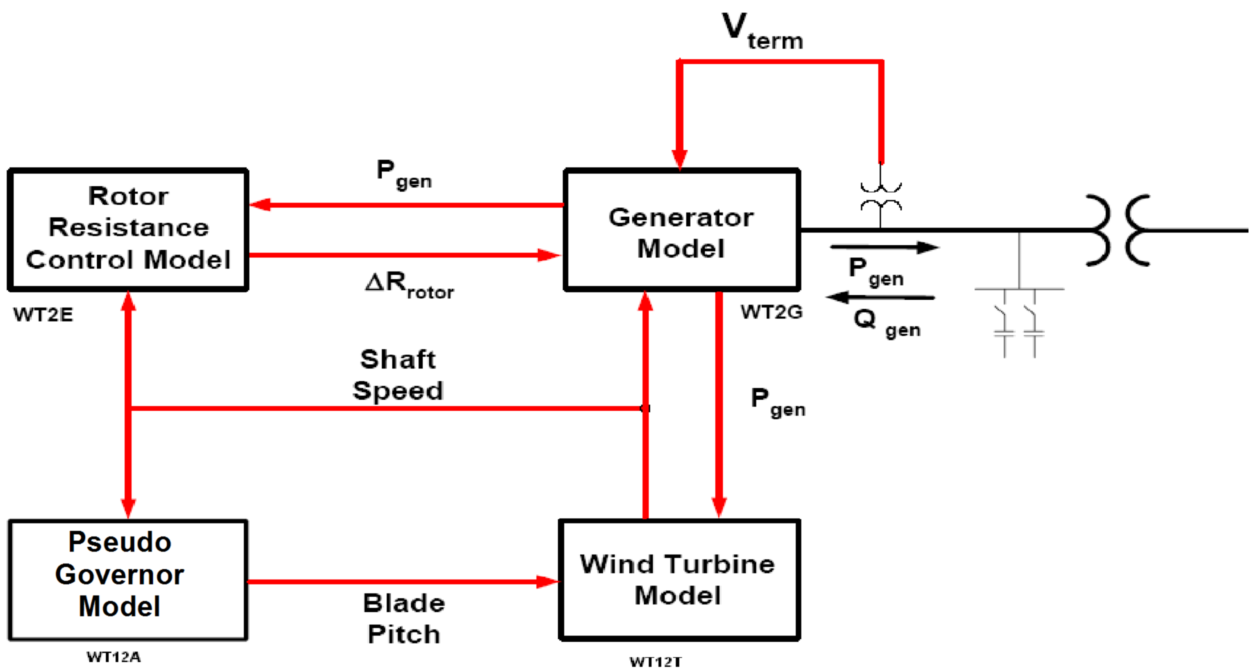


Figure 22.8. WT2 Connectivity Diagram

The generator model WT2G is based on the standard PSS®E model of the induction generator CIMTR3. This model takes into account the rotor flux dynamics and can be used for single cage or double cage machines. At initialization, this model calculates the reactive power consumption of the machine Qact at given terminal voltage and MW-dispatch. It places a "hidden" shunt on the machine terminal bus, with the size equal to a difference between Qgen from the power flow and Qact. It also determines what portion of available external rotor resistance should be added to fit the steady-state operating point.

During the simulation, the value of the external rotor resistance is calculated by the electrical control model WT2E (Figure 22.9, "WT2E Electrical Control model"). This model uses the machine rotor speed and electrical power as inputs and calculates the portion of the available rotor external resistance to be added to the internal rotor resistance.

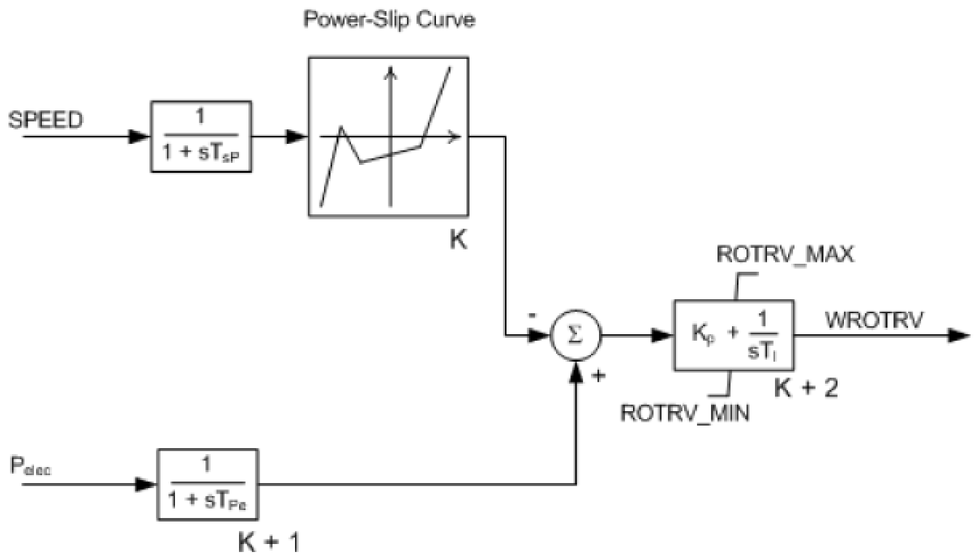


Figure 22.9. WT2E Electrical Control model

The turbine model WT12T uses the two-mass representation of the wind turbine shaft drive train. It calculates the speed deviations of the rotor on the machine and on the blade sides. By setting the turbine inertia fraction Htfrac = 0 the model can be switched to a conventional single mass representation. A diagram of this model is shown in Figure 22.3, "WT12T Two-Mass Shaft model".

The pseudo-governor model WT12A is an attempt to simplify and generalize calculation of the aerodynamic torque. A diagram of this model is shown in Figure 22.4, "Pseudo-Governor Model".

The model uses two inputs, one in terms of the blade rotor speed deviation and another in terms of the real power at the machine terminals. These two inputs combined together are processed by a PI controller with non-wind-up limits. The filtered output is the mechanical torque on the rotor blade side that is used by the WT12T model.

The example dynamic data input file is provided below, along with the example documentation of the dynamic parameters.

```
5 ' WT2G1' 1
0.12602     6.8399      0.18084     0.44190E-02  0.10994   1.0000   0.0000
1.2000      0.0000      0.0000      0.21700E-01  0.89880   0.90000  0.90500
0.0000      0.54000E-02 0.20000E-01 0.40000E-01  0.10000  /

5 ' WT2E1' 1
0.5000E-01  0.5000E-01  1.000   1.000   0.9900   0.5000E-01  /

5 ' WT12T1' 1
3.4600  0.0000  0.81000  1.5000  0.30000  /

5 ' WT12A1' 1
0.1500E-01  20.00  1.000  .1000  .1000  .1000  1.000  .2500  /
```

Figure 22.10. Example Dynamic Data Input File, WT2

```
PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS(R)E FRI, AUG 22 2008 13:38

TEST WT2


WIND MODELS

REPORT FOR WIND MECH. MODELS AT ALL BUSES


** WT2G1 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S V A R S ICON

5 CLR_1 0.6000 1 3-21 3-5 1-3 1

MBASE Z S O R C E

112.0 0.00000+J 0.30220

XA XM X1 R_ROT_MACH R_ROT_MAX

0.126 6.840 0.18 0.0044 0.1099

E1 S(E1) E2 S(E2)

1.0000 0.0000 1.2000 0.0000

POWER_REF_1 POWER_REF_2 POWER_REF_3 POWER_REF_4 POWER_REF_5

0.0000 0.0217 0.8988 0.9000 0.9050
```

```
SLIP_1 SLIP_2 SLIP_3 SLIP_4 SLIP_5
0.0000 0.0054 0.0200 0.0400 0.1000


** WT2E1 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S ICON
5 CLR_1 0.6000 1 22-27 6-8 2

Tsp Tpe Ti Kp ROTRV_MAX ROTRV_MIN
0.050 0.050 1.000 1.000 0.990 0.050


** WT12T1 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S V A R S
5 CLR_1 0.6000 1 28-32 9-12 4-6

H DAMP Htfrac Freq1 DSHAFT
3.4600 0.0000 0.8100 1.5000 0.3000


** WT12A1 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S V A R S
5 CLR_1 0.6000 1 33-40 13-16 7-8

DROOP KP TI T1 T2 TPE LIMMAX LIMMIN
0.015 20.000 1.000 0.100 0.100 0.100 1.000 0.250
```

Example of Documentation, WT2

22.3. Generic WT3 (Type 3) Model

22.3.1. Introduction

The WT3 PSS®E wind turbine stability model was developed to simulate performance of a wind turbine employing a doubly fed induction generator (DFIG) with the active control by a power converter connected to the rotor terminals.

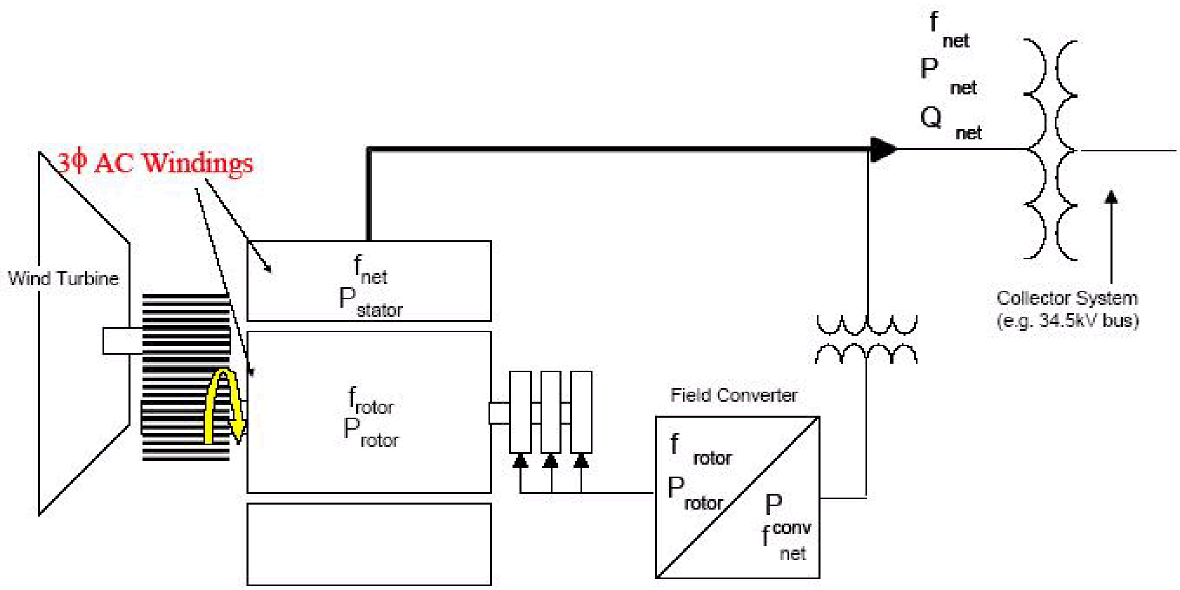


Figure 22.11. Doubly Fed Induction Generator with the Active Control by a Power Converter Connected to the Rotor Terminals

The model is to be used in studies related to the integration of Wind Turbine Generators (WTG) in an Electrical Power System.

22.3.2. Power Flow Setup

A wind turbine generator in power flow is treated as related to a wind machine category of the existing generator record of the Power Flow Raw Data File. The wind control mode should be set as 2, i.e., a wind machine that controls a remote bus voltage within the given range of reactive power [Q_{min}, Q_{max}].

All issues of making an equivalent of a wind farm to be modeled is the users' responsibility. They should make a decision on how many original units will be lumped into an equivalent machine presented in the power flow case. For N lumped machine they need to multiply MBASE of the original machine by N.

They also have to take care of the adequate equivalent of the wind farm feeders, collectors, and step-up transformers.

22.3.3. Dynamic Setup

PSS®E WT3 Generic Wind Model comprises models as follows:

- WT3G: generator/converter model
- WT3E: electrical control model
- WT3T: mechanical control (wind turbine) model
- WT3P: pitch control model.

There are two different generator/converter models available, namely WT3G1 and WT3G2.

The WT3G2 model, which is recommended for new dynamic setups, includes improvements in the original WT3G1. The original WT3G1 model is being retained for reasons of backward compatibility.

The electrical control model WT3E1 can be used with WT3G1 as well as with the improved WT3G2 models. When WT3E1 is used with the WT3G1 model, it is recommended that ICON(M+2) be set to 1, and when used with WT3G2 model, the ICON be set to 2.

Figure 22.12, "Interaction among Generic Wind Models" shows the interaction between these models.

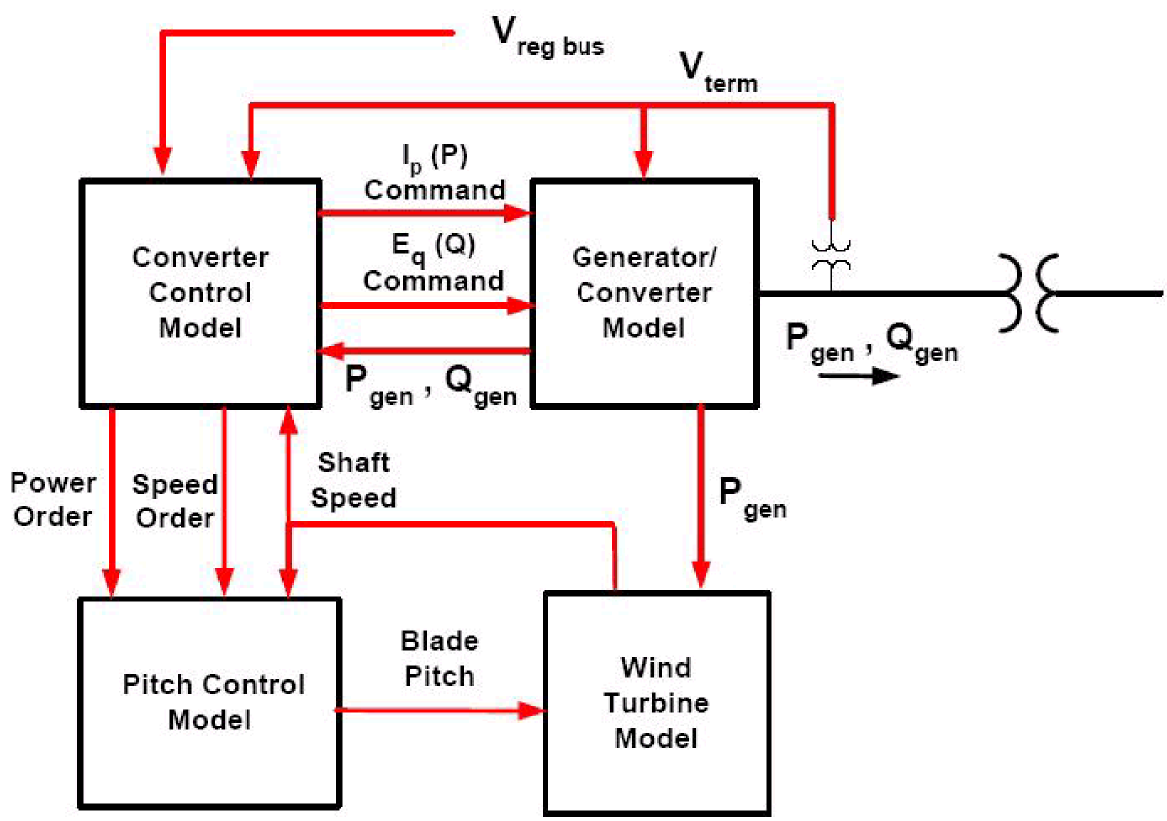
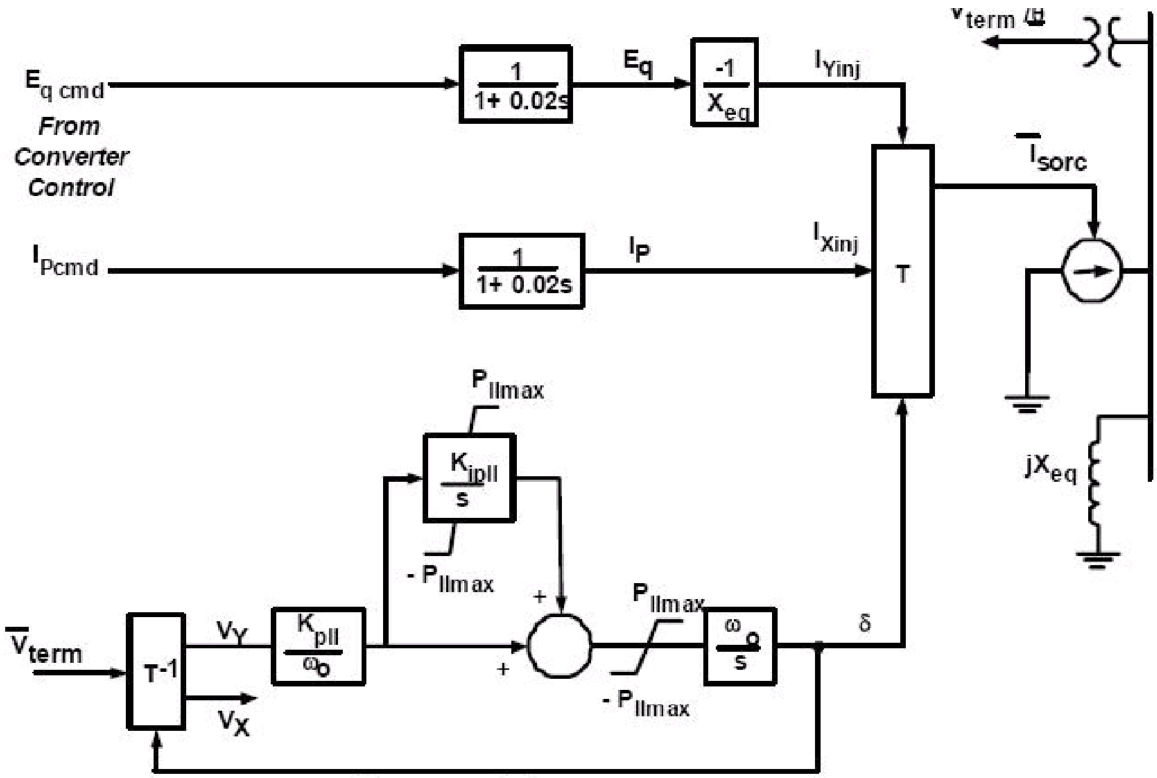


Figure 22.12. Interaction among Generic Wind Models

The example dynamic data input files are provided below, along with the example documentation of the dynamic parameters.



Notes: 1. $\overline{V}_{term}$ and $\overline{I}_{sorc}$ are complex values on network reference frame.

2. In steady-state, $V_Y = 0$, $V_X = V_{term}$, and $\delta = \theta$.

3. X_{eq} = Imaginary (ZSORCE)

Figure 22.13. WT3G1 Model

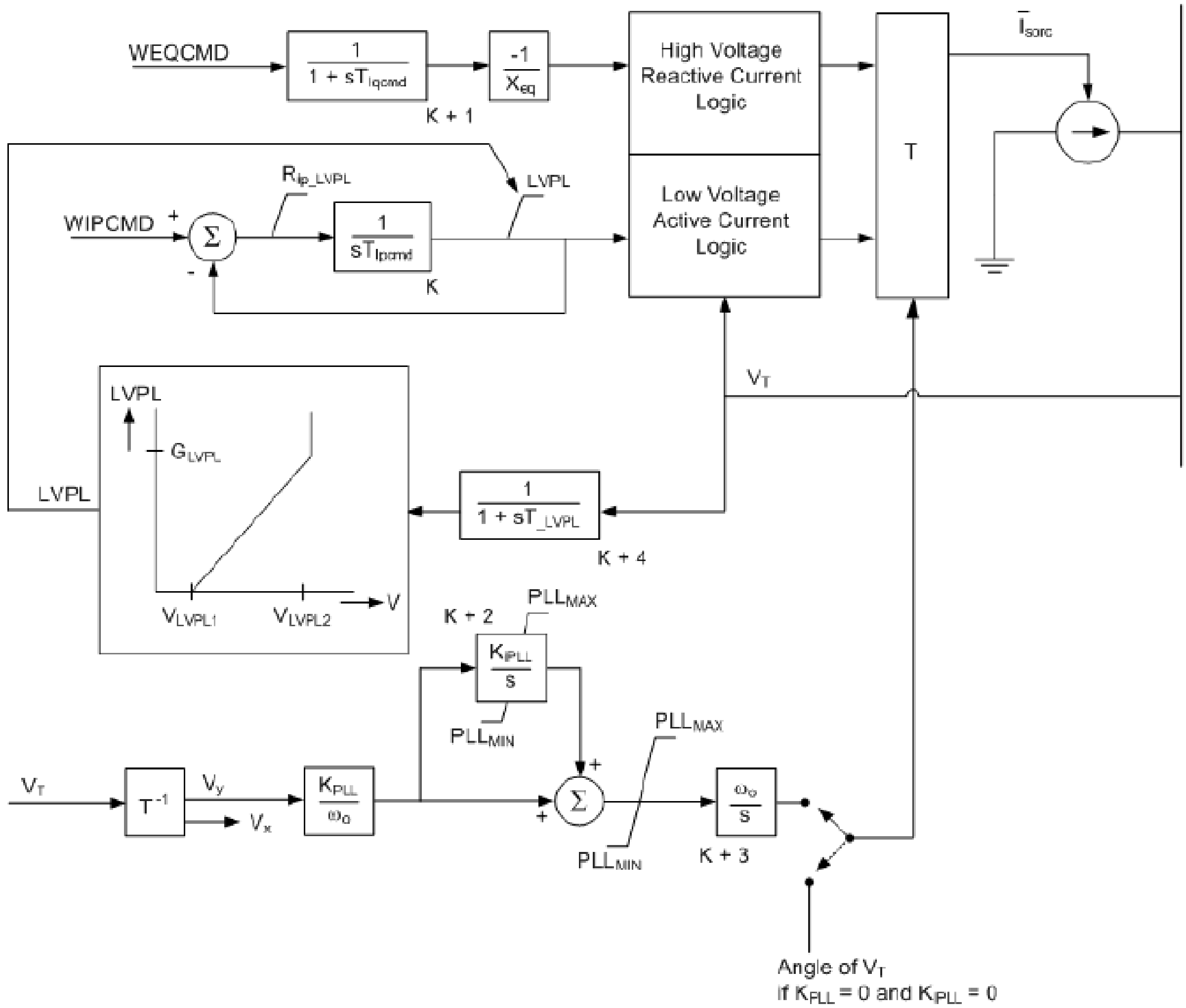


Figure 22.14. WT3G2 Model

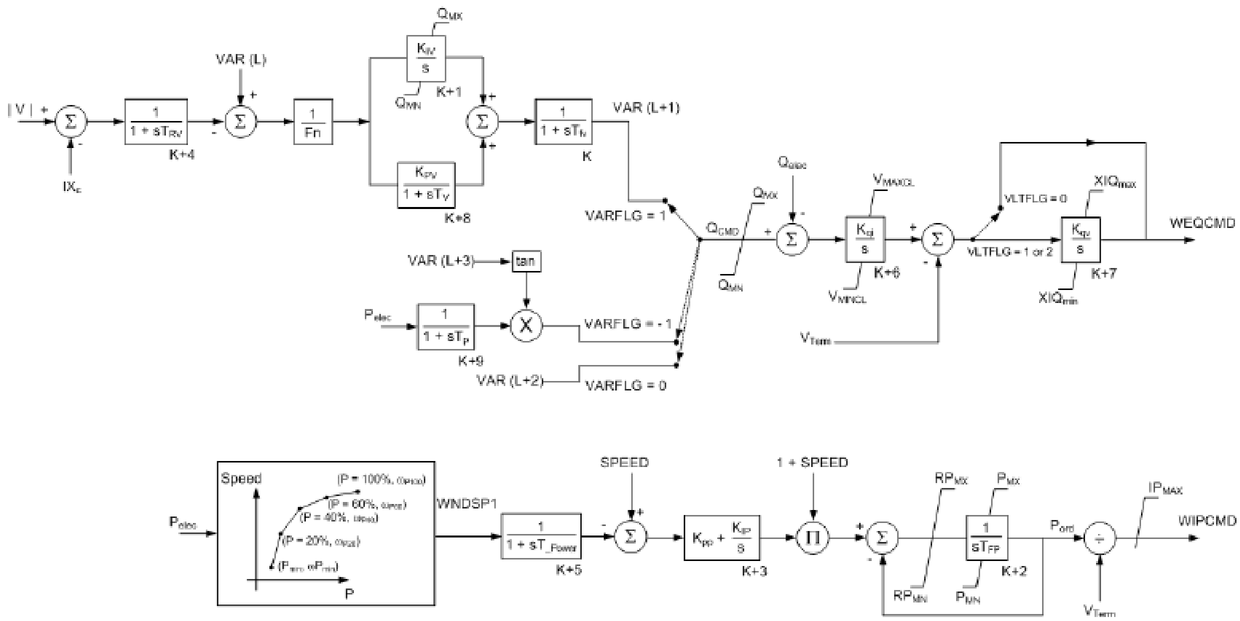


Figure 22.15. WT3E1 Model

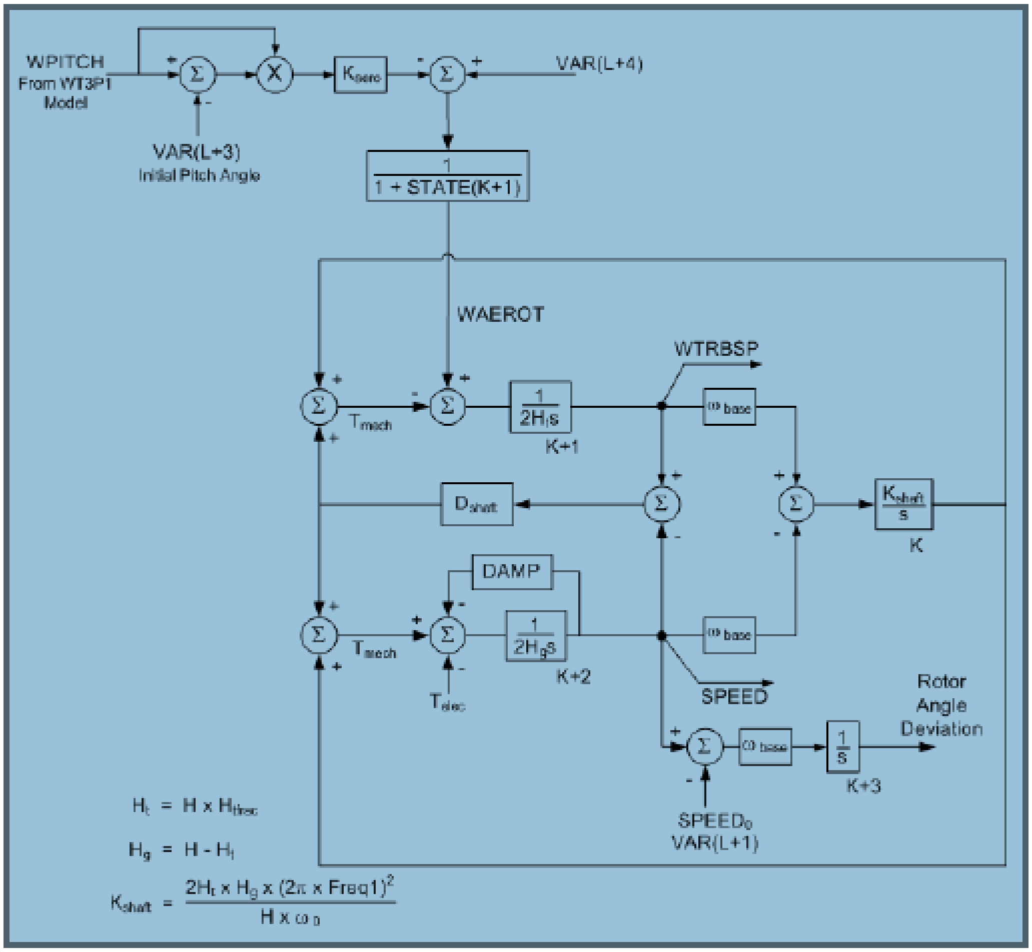


Figure 22.16. WT3T1 Model

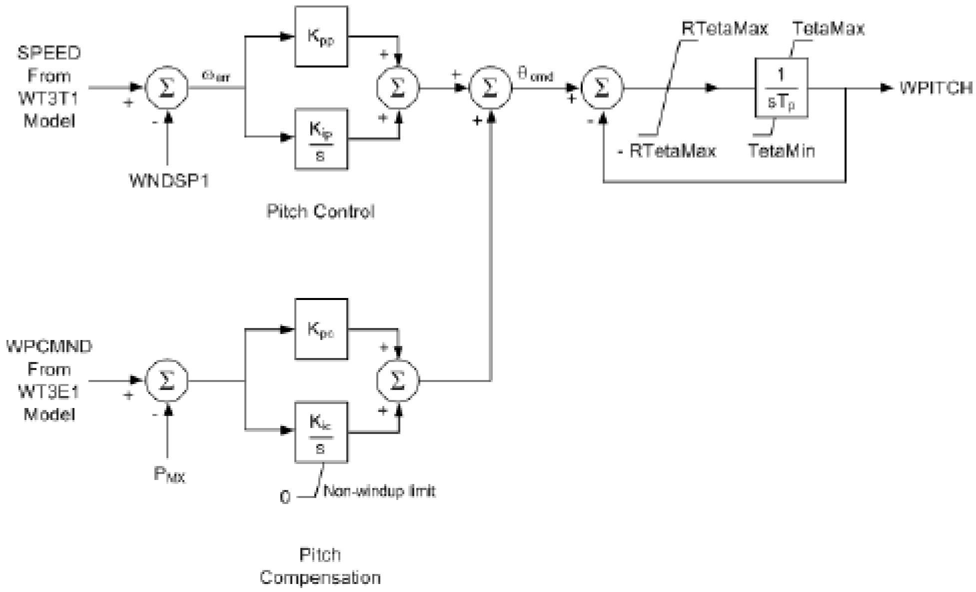


Figure 22.17. WT3P1 Model

```
5 'WT3G1' 1

67 0.80000 30.000 0.0000 0.10000 1.5000 /

5 'WT3E1' 1 5 1 1 3 2 '1 '

0.15000 18.000 5.0000 0.0000 0.50000E-01

3.0000 0.60000 1.1200 0.10000 0.29600

-0.43600 1.1000 0.50000E-01 0.45000 -0.45000

5.0000 0.50000E-01 0.90000 1.2000 40.000

-0.50000 0.40000 0.50000E-01 0.50000E-01 1.0000

0.69000 0.78000 0.98000 1.1200 0.74000

1.2000 /

5 'WT3T1' 1

1.2500 4.9500 0.0000 0.70000E-02 21.980

0.0000 1.8000 1.5000 /

5 'WT3P1' 1

0.30000 150.00 25.000 3.0000 30.000 0.0000 27.000 10.000 1.0000 /
```

Example Dynamic Data Input File (Set 1) with Reference to GE 1.5 MW Wind Turbine

```
5 'WT3G2' 1 30
0.02000 0.02000 0.0000 0.0000 0.10000
1.5000 0.50000 0.9000 1.1100 1.2000
2.0000 5.0000 0.20000E-01 /

5 'WT3E1' 1 5 1 2 3 2 '1'
0.15000 18.000 5.0000 0.0000 0.50000E-01
3.0000 0.60000 1.1200 0.40000E-01 0.43600
-0.43600 1.1000 0.20000E-01 0.45000 -0.45000
5.0000 0.10000 0.90000 1.1000 40.000
0.50000 1.45000 0.50000E-01 0.50000E-01 1.0000
0.30000 0.69000 0.78000 0.98000 0.74000
1.2000 /

5 'WT3T1' 1
1.2500 4.9500 0.0000 0.70000E-02 21.980
0.0000 1.8000 1.5000 /

5 'WT3P1' 1
0.30000 150.00 25.000 3.0000 30.000
0.0000 27.000 10.000 1.0000 /
```

Example Dynamic Data Input File (Set 2) with Reference to GE 1.5 MW Wind Turbine

```
PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS(R)E MON, DEC 29 2008 8:14
GE BENCHMARK SYSTEM
TEST OF GE-1.5/3.6 MODEL

WIND MODELS

REPORT FOR WIND MODELS AT ALL BUSES
```

```
** WT3G1 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S V A R S ICON

5 WT 0.5750 1 1-5 1-4 1-4 1

XEQ Kpll Kipll PLLMX Prated

0.8000 30.0000 0.0000 0.1000 1.5000


** WT3E1 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S V A R S I C O N S

5 WT 0.5750 1 6-36 5-14 5-11 2-7

TFV KPV KIV XC TFP KPP KIP

0.1500 18.0000 5.0000 0.0000 0.0500 3.0000 0.6000

PMX PMN QMX QMN IPMAX TRV RPMX

1.1200 0.1000 0.2960 -0.4360 1.1000 0.0500 0.4500

RPMN T_POWER KQi

-0.4500 5.0000 0.0500
```

Example of Documentation (Set 1) with Reference to GE 1.5 MW Wind Turbine

```
VMINCL VMAXCL Kqv XIQmin XIQmax Tv

0.9000 1.2000 40.0000 -0.5000 0.4000 0.0500

Tp Fn Wpmin Wp20

0.0500 1.0000 0.6900 0.7800

Wp40 Wp60 Pwp Wp100

0.9800 1.1200 0.7400 1.2000


REMOTE CONTROLLED BUS # 5

VARFLG = 1 VLTFLG = 1

FROM BUS = 3, TO BUS = 2, ID = '1 '
```

```
** WT3T1 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S V A R S ICON

5 WT 0.5750 1 37-44 15-18 12-16 8

Vw H DAMP Kaero Theta2

1.2500 4.9500 0.0000 0.0070 21.9800


Htfrac Freq1 DSHAFT

0.0000 1.8000 1.5000



** WT3P1 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S ICON

5 WT 0.5750 1 45-53 19-21 9

Tp Kpp Kip Kpc Kic

0.3000 150.0000 25.0000 3.0000 30.0000

TetaMin TetaMax RTetaMax PMX

0.0000 27.0000 10.0000 1.0000
```

Example of Documentation (Set 1) with Reference to GE 1.5 MW Wind Turbine

```
PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS(R)E MON, DEC 29 2008 8:14

GE BENCHMARK SYSTEM

TEST OF GE-1.5/3.6 MODEL

WIND MODELS

REPORT FOR ALL MODELS AT ALL BUSES BUS 5 [WT 0.5750] MODELS


** WT3G2 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S VAR ICON

5 WT 0.5750 1 3-15 3-7 1 1
```

```
Tiqcmd Tipcmd Kpll Kipll PLLMX

0.2000 0.0000 0.0000 0.0000 0.1000


Prated VLVPL1 VLVPL2 GLVPL

1.5000 0.5000 0.9000 1.0000


VHVRCR CURHVRCR Rip_LVPL T_LVPL

1.2000 2.0000 5.0000 0.0200


Number of Lumped Wind Machines: 67


** WT3E1 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S V A R S I C O N S

5 WT 0.5750 1 16-46 8-17 2-8 2-7


TFV KPV KIV XC TFP KPP KIP

0.1500 18.0000 5.0000 0.0000 0.0500 3.0000 0.6000


PMX PMN QMX QMN IPMAX TRV RPMX

1.1200 0.0400 0.4360 -0.4360 1.1000 0.0200 0.4500


RPMN T_POWER KQi

-0.4500 5.0000 0.1000


VMINCL VMAXCL Kqv XIQmin XIQmax Tv

0.9000 1.1000 40.0000 0.5000 1.5000 0.0500


Tp Fn Wpmin Wp20

0.0500 1.0000 0.3000 0.6900


Wp40 Wp60 Pwp Wp100

0.7800 0.9800 0.7400 1.2000


REMOTE CONTROLLED BUS # 5
```

```
VARFLG = 1 VLTFLG = 2

FROM BUS = 3, TO BUS = 2, ID = '1 '
```

Example of Documentation (Set 2) with Reference to GE 1.5 MW Wind Turbine

```
** WT3T1 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S V A R S ICON

5 WT 0.5750 1 47-54 18-21 9-13 8

Vw H DAMP Kaero Theta2

1.2500 4.9500 0.0000 0.0070 21.9800


Htfrac Freq1 DSHAFT

0.0000 1.8000 1.5000



** WT3P1 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S ICON

5 WT 0.5750 1 55-63 22-24 9

Tp Kpp Kip Kpc Kic

0.3000 150.0000 25.0000 3.0000 30.0000

TetaMin TetaMax RTetaMax PMX

0.0000 27.0000 10.0000 1.0000
```

Example of Documentation (Set 2) with Reference to GE 1.5 MW Wind Turbine

22.4. Generic WT4 (Type 4) Model

22.4.1. Introduction

The WT4 PSS®E wind turbine dynamic stability model was developed to simulate performance of a wind turbine employing a generator connected to the grid via the power converter.

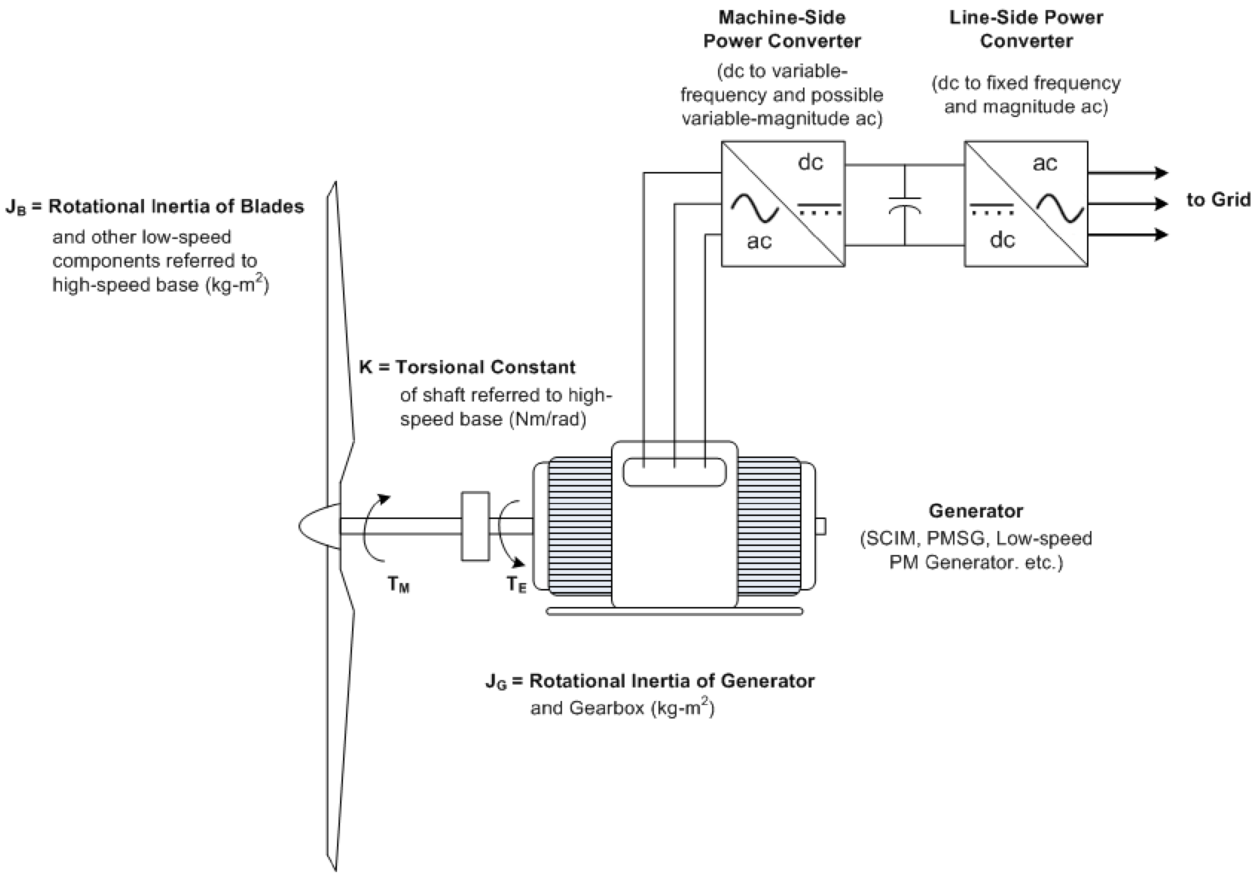


Figure 22.18. A Generator Connected to the Grid via the Power Converter

22.4.2. Power Flow Setup

A wind turbine generator is decoupled from the grid by a power converter that is actually connected to the grid. In power flow a power converter is treated as a generator related to a wind machine category of the existing generator record of the Power Flow Raw Data File. The wind control mode should be set as 2, i.e., a wind machine that controls a remote bus voltage within the given range [Qmin; Qmax] of reactive power.

All issues of making an equivalent of a wind farm to be modeled are the user's responsibility. A decision must be made for the number of original units to be lumped into an equivalent machine presented in the power flow case. For N lumped machines, multiply MBASE of the original machine by N.

The user must also define an adequate equivalent of the wind farm feeders, collectors, and step-up transformers.

22.4.3. Dynamic Setup

PSS®E WT4 Generic Wind Model comprises two modules as follows

- WT4G: power converter/generator module
- WT4E: electrical control module

Figure 22.19, "WT4 Connectivity Diagram" shows the interaction between these modules.

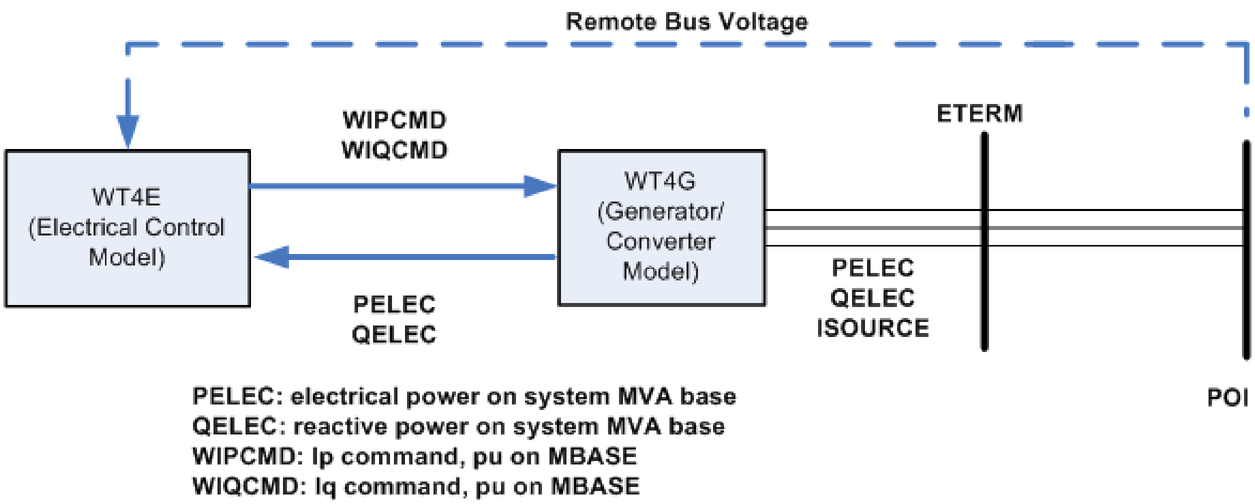


Figure 22.19. WT4 Connectivity Diagram

The power converter/generator module (Figure 22.20, "WT4 Generator/Converter Module") calculates the current injection to the grid based on filtered active and reactive power commands from the electrical control module. Both components of the injected current are processed under the high/low voltage conditions by means of a special logic.

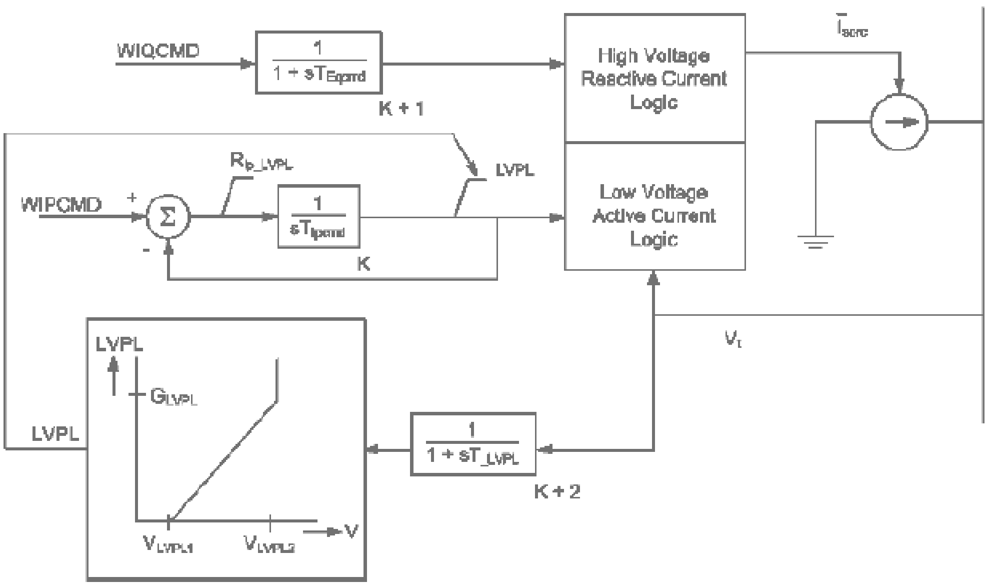


Figure 22.20. WT4 Generator/Converter Module

The converter control module includes reactive and active power controls.

The reactive control calculates the reactive current command for the various control options, which could be any of the following:

- Remote bus voltage control
- Power factor control
- Reactive power control

The active power control is based on the concept that a machine does not need to be simulated. No matter how the active power control is implemented and what criteria it uses, this control is responsible for keeping the power balance between the machine and the grid injection.

In the suggested model (Figure 22.21, “WT4E Electrical Control Module”, lower part), the active power control compares the active power injected to the grid against the power reference and changes the active component of the injected current accordingly. The Converter Current Limiter is an essential part of the model. Depending on whether active or reactive priority was selected, it uses different algorithms to update limits of active and reactive components of the converter current. The example dynamic data input file for WT4G1 and WT4E1 models, with reference to the GE 2.5 MW wind turbine, are provided in Figure 22.22, “Example of Dynamic Data Input File for WT4 with reference to the GE 2.5 MW wind turbine” and Figure 22.23, “Example of Documentation for WT4 with reference to the GE 2.5 MW wind turbine”.

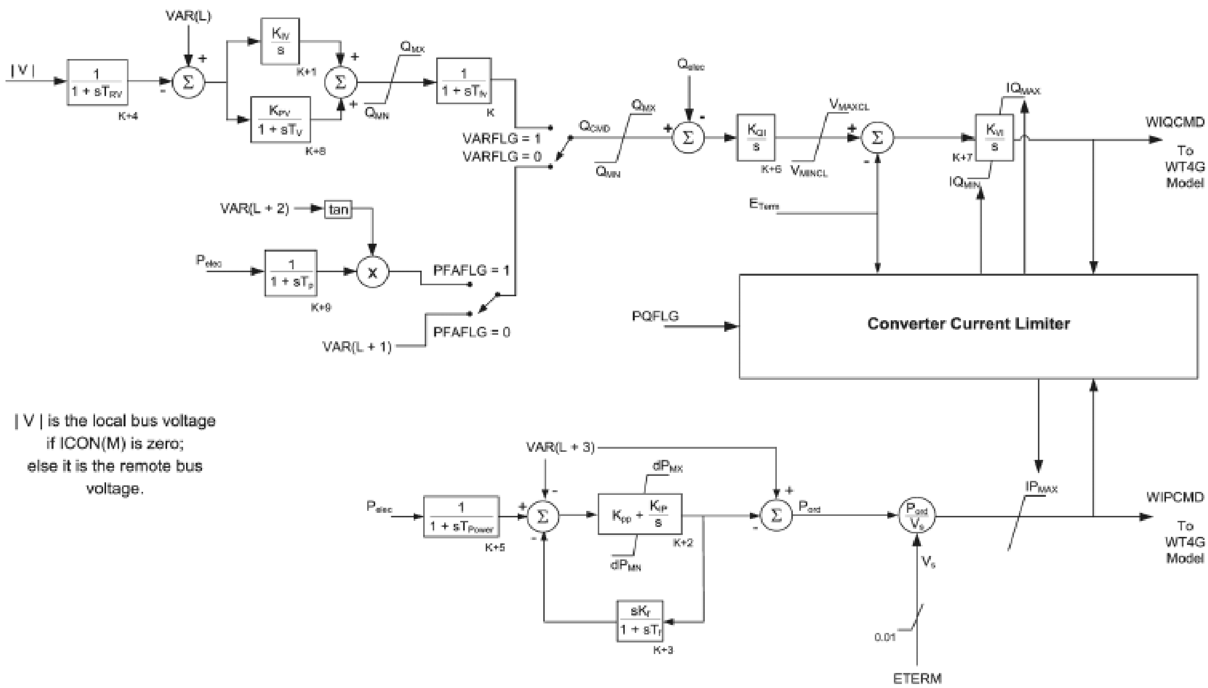


Figure 22.21. WT4E Electrical Control Module

```
5 'WT4G1' 1 0.20000E-01 0.20000E-01 0.40000 0.90000

1.1100 1.2000 2.0000 2.0000 0.20000E-01 /


5 'WT4E1' 1 5 0 1 0

0.15000 18.000 5.0000 0.50000E-01 0.10000

0.0000 0.80000E-01 0.47000 -0.47000 1.1000

0.0000 0.50000 -0.50000 0.50000E-01 0.10000

0.90000 1.1000 120.00 0.50000E-01 0.50000E-01

1.7000 1.1100 1.1100 /
```

Figure 22.22. Example of Dynamic Data Input File for WT4 with reference to the GE 2.5 MW wind turbine

Figure 22.23. Example of Documentation for WT4 with reference to the GE 2.5 MW wind turbine

```
PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS(R)E TUE, DEC 02 2008 13:23

TEST SYSTEM
```

```
TEST OF WT4 MODEL

WIND MODELS

REPORT FOR ALL MODELS AT ALL BUSES BUS 5 [WT 0.5750] MODELS


** WT4G1 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S V A R S

5 WT 0.5750 1 3-11 3-5 1-3


TIqCmd TIpCmd VLVPL1 VLVPL2 GLVPL

0.0200 0.0200 0.4000 0.9000 1.1100

VHVRCR CURHVRCR RIp_LVPL T_LVPL

1.2000 2.0000 2.0000 0.0200



** WT4E1 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S V A R S I C O N S

5 WT 0.5750 1 12-34 6-15 6-9 1-4


TFV KPV KIV KPP

0.1500 18.0000 5.0000 0.0500


KIP Kf Tf QMX QMN IPMAX TRV

0.1000 0.0000 0.0800 0.4700 -0.4700 1.1000 0.0000


dPMX dPMN T_POWER KQi VMINCL VMAXCL Kvi

0.5000 -0.5000 0.0500 0.1000 0.9000 1.1000 120.0000


Tv Tp ImaxTD Iph1 Iqh1

0.0500 0.0500 1.7000 1.1100 1.1100
```

```
ICON(M) - Remote controlled Bus : 5

ICON(M+1) - PFAFLG = 0 (1 if PF fast control is enabled; else 0)

ICON(M+2) - VARFLG = 1 (1 if Qcmd is provided by WindVar; else 0)

ICON(M+3) - PQFLAG = 0 (1 for P priority, =0 for Q priority)
```

In the course of validation studies for Siemens 2.3 and 3.6 MW Wind Turbines, another set of the WT4 generator/converter and electrical control models was developed:WT4G2 and WT4E2. These two models should be used together; neither of them can be used with either WT4G1 or WT4E1.

The main difference between the existing Type 4 and the new set of models is that the converter current limiter takes into consideration such factors as:

- P, Q converter capability curves.

  Note: In load flow, the reactive power output should be set inside the capability curve; otherwise it will experience an immediate change at the model initialization.

- The effect of the DC link connection between the machine side converter and the grid side converter.
- Restriction on the magnitude of the internal voltage generated by the grid side converter.
- Constraints of the internal smoothing reactor.

Several model parameters are used to achieve the above.The recommended values of these parameters are suggested in example files.

To improve the network solution at abrupt voltage changes (applying or removing a fault), the reactive component of the converter current limit is filtered by a lag with one cycle time constant.

To avoid instability, potential ringing (or hunting), caused by the voltage crossing fault ride-through (FRT) threshold on the way down and back up, the FRT hysteresis is implemented.

Example parameters for WT4G2 and WT4E2 with the reference to the SMK-213 2.3 MW wind turbine are provided below.

```
20 'WT4G2' 1

0.0100 0.0020 0.4000 -0.10000 1.1100 1.2500

2.0000 2.0000 0.02000 /


20 'WT4E2' 1

20 0 1 0

0.00000 15.000 2.0000 0.08000 0.0100 0.0000

0.08000 1.0000 -1.20000 1.10000 0.0000 0.50000
```

```
-0.50000 0.05000 0.0100 0.87500 1.1250 55.0000

0.05000 0.0500 1.1150 1.25000 1.0850 0.0200

0.87500 0.0500 0.0000 2.00000 1.0000 1.0000

1.00000 1.0000 1.1000 0.14154 /
```

Example of Dynamic Data Input File for WT4 with reference to the Siemens 2.3 MW wind turbine

```
WIND MODELS

REPORT FOR ALL MODELS AT ALL BUSES BUS 20 [WT4 0.6900] MODELS


** WT4G2 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S V A R S

20 WT4 0.6900 1 3-11 3-5 1-5

TIqCmd TIpCmd VLVPL1 VLVPL2 GLVPL

0.0100 0.0200 0.4000 -0.1000 1.1100

VHVRCR CURHVRCR RIp_LVPL T_LVPL

1.2500 2.0000 2.0000 0.0200


** WT4E2 ** BUS X-- NAME --X BASEKV MC C O N S S T A T E S V A R S I C O N S

20 WT4 0.6900 1 12-45 6-16 6-9 1-4

TFV KPV KIV KPP

0.0000 15.0000 2.0000 0.0800

KIP Kf Tf QMX QMN IPMAX TRV

0.0100 0.0000 0.0800 1.0000 -1.2000 1.1000 0.0000

dPMX dPMN T_POWER KQi VMINCL VMAXCL Kvi

0.5000 -0.5000 0.0500 0.0100 0.8750 1.1250 55.0000

Tv Tp ImaxTD Iph1 Iqh1
```

```
0.0500 0.0500 1.1150 1.2500 1.0850

Tiqf FRT_Thres FRT_Hys FRT_Droop FRT_Iq_Gain

0.0200 0.8750 0.0500 0.0000 2.0000

Max_FRT_Iq IQMax_Fact1 IQMax_Fact2

1.0000 1.0000 1.0000

DC_Link_Droop VinvMax0 NBR_X

1.0000 1.1000 0.1415


ICON(M) - Remote controlled Bus : 20

ICON(M+1) - PFAFLG = 0 (1 if PF fast control is enabled; else 0)

ICON(M+2) - VARFLG = 1 (1 if Qcmd is provided by WindVar; else 0)

ICON(M+3) - PQFLAG = 0 (1 for P priority, =0 for Q priority)
```

Example of Documentation for WT4 with reference to the Siemens 2.3 MW wind turbine

Chapter 23
Photovoltaic (PV) System Model

23.1. Introduction

The PSS®E Solar PV Unit dynamic stability model was developed to simulate performance of a photovoltaic (PV) plant connected to the grid via a power converter. The model is largely based on the generic type 4 wind model, WT4, with the added ability to simulate output changes due to solar irradiation.

23.1.1. Load flow Representation

PV panels are decoupled from the grid by a power converter which is actually connected to the grid.

The wind control mode should be set as 2, i.e. a wind machine which controls a remote bus voltage within the given range [Qmin; Qmax] of reactive power. As for load flow models of most power electronic devices, the source reactance of this machine should be set as infinite: XSORCE = 99999.

All issues of making an equivalent of a PV plant to be modeled is the users' responsibility. They should make a decision on how many original panels and converters will be lumped into an equivalent machine presented in the load flow case. For N lumped converters they need to multiply MBASE of the original converter by N.

They also have to take care of the adequate equivalent of the plant feeders, collectors, and step-up transformers.

23.1.2. Dynamic Setup

The PV Generic Wind Model comprises the following modules:

- PVGU: power converter/generator module
- PVEU: electrical control module
- PANEL: linearized model of a panel's output curve
- IRRAD: linearized solar irradiance profile

Figure 23.1, "PV Model Connectivity Diagram" shows the interaction between these modules.

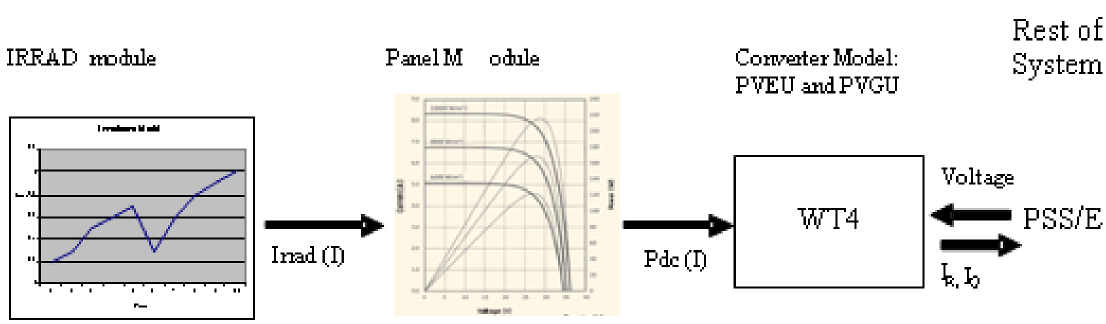


Figure 23.1. PV Model Connectivity Diagram

The modules are conventionally designated as wind modules with PVGU as the generator/converter module, PVEU as the electrical control module, PANEL as the mechanical module, and IRRAD as the pitch module.

The power converter/generator module calculates the current injection to the grid based on filtered active and reactive power commands from the electrical control module.

The converter control module includes reactive and active power controls.

The reactive control calculates the reactive current command for the various control options, which could be any of the following:

- Remote bus voltage control
- Power factor control
- Reactive Power control

The active power control compares the active power injected to the grid against the power reference, VAR (L+3), and changes the active component of the injected current respectively. The power reference is controlled by the amount of DC power coming from the PANEL module.

As converter/generator and electrical control modules are very close to respective modules of the generic WT4 wind model, please refer to the corresponding documentation given in PSS®E 32 Program Application Guide Volume II.

The panel module calculates the DC power from the PV plant at a given irradiance level. The user enters the maximum DC power a panel can produce at standard irradiance levels, which is readily available from a PV manufacturer's I-P curves.

The irrad module allows the user to enter an irradiance profile in the form of up to ten data points (time, irradiance level) as CONs. At each simulation time step, the module will calculate a linearized irradiance level. The irradiance level is initialized based on the steady-state power output.

The user has an option of disabling the "IRRAD" module by changing the especially designated flag.

23.2. Example Dynamic Input Data

```
5 'USRMDL' 1 'PVGU1' 101 1 0 9 3 3

0.20000E-01 0.20000E-01 0.40000 0.90000

1.1100 1.2000 2.0000 2.0000 0.20000E-01 /

5 'USRMDL' 1 'PVEU1' 102 0 4 24 10 4

5 0 1 0

0.15000 18.000 5.0000 0.50000E-01 0.10000

0.0000 0.80000E-01 0.47000 -0.47000 1.1000

0.0000 0.50000 -0.50000 0.50000E-01 0.10000

0.90000 1.1000 120.00 0.50000E-01

0.50000E-01

1.7000 1.1100 1.1100 10.0/

5 'USRMDL' 1 'PANELU1' 103 0 0 5 0 1

0.16 0.38 0.59 0.85 1 /b

5 'USRMDL' 1 'IRRADU1' 104 0 1 20 0 1

1

5 1000 10 900 15 850 20 800 25 700

30 600 35 700 0 0 0 0 0 0 /
```

Chapter 24
Elementary Blocks for Handling Transfer Functions in Dynamic Models

24.1. General

Transfer functions are commonly used in dynamic models. The various transfer function types that are commonly encountered can be classified as follows:

- Integrator
- Integrator with non-windup limit
- First order (lag)
- First order (lag) with non-windup limit
- Washout
- Lead-lag
- Lead-lag with non-windup limit
- Proportional-integrator (PI)
- PI with non-windup limit
- Proportional-integral-derivative (PID) block
- PID with non-windup limit
- Second Order block

One common approach in handling the transfer function blocks is to write the state equations. In PSS®E implementation, the dynamic models calculate the derivative of the states (called DSTATE), which are then used to calculate the state variables (called STATE in PSS®E) using the Modified Euler integration method.

The computation of DSTATEs involves writing out the appropriate equations. Because there could be several ways of formulating the STATE equations, the expressions for initializing the STATE variables, and the equations involved in obtaining the DSTATE could also vary. In addition, implementation of non-windup limits could also prove to be tricky.

In order to provide for an easy and a consistent method of handling of transfer function STATE and DSTATE equations along with the associated non-windup limits, the concept of 'Elementary Blocks) was introduced in PSS®E. The elementary blocks are simply a library of functions (provided with PSS ®E) that can be invoked in dynamic models to initialize the model STATE, for the calculation of DSTATE, to impose non-windup limits (if any), and to calculate the transfer block output.

The description given below illustrates the use of the elementary block FORTRAN functions for all three MODEs for each transfer function configuration.

Some general points about the use of elementary block functions are as follows:

- For each transfer function type given above, there are a set of three FORTRAN functions – one for PSS ®E MODE 1 for initialization of STATE, one for MODE 2 for the calculation of DSTATE; applying non-windup limits (if any); and setting the transfer function block output, and one for MODE 3 for setting the transfer function block output using the updated STATE variable following numerical integration, which in turn is used to calculate the model outputs. Thus, for modeling (say) an integrator without non-windup limits, the functions that would be invoked in the PSS®E dynamic models are: INT_MODE1 (for MODE 1), INT_MODE2 (for MODE 2), and INT_MODE3 (for MODE 3). The corresponding functions for an integrator with non-windup limits are NWINT_MODE1, NWINT_MODE2, and NWINT_MODE3.

- The elementary blocks are implemented as FUNCTION calls (rather than SUBROUTINE), meaning that the block input or output is the name of the FUNCTION itself.
- The name of the function to be invoked will depend on the transfer function type, and the PSS®E MODE (1,2 or 3) for which the calculations are being applied.
- The functions of the MODE1 type returns error codes (IERR). The IERR codes returned back by the MODE1 calls for each transfer function are given in description below. Although not mandatory, the model code in turn could have logic to sense the IERR value and write out appropriate error messages on the progress window. IERR value of zero indicates absence of any error condition.
- One of the input arguments for all the MODE1 functions (except for the washout transfer function) is the block output. For the washout block, because the block output in steady state is zero, the block input is instead specified as one of the input arguments. This is used by the MODE1 function for the calculation of initial value of the corresponding STATE variable.
- One of the input arguments to the MODE2 and the MODE3 type functions is the block input. This is used by the MODE2 and MODE3 functions to calculate the DSTATE (in MODE 2), and calculate the block output.
- The inputs 'U' and 'Y' shown in the figures are generic designation for block inputs and outputs respectively. These have to be calculated and set in the model code. Thus, in the MODE1 function, the block output 'Y' is calculated in the model code, and passed as an argument (VOUT) in the MODE1 function call. The MODE1 function call returns back the block input. Similarly, for the MODE2 and MODE3 functions, the block input 'U' is calculated in the model code and passed as an argument (VINP) in the MODE2 and MODE3 function calls. The MODE2 and MODE3 function calls return the block output.
- The MODE1, MODE2, and the MODE3 functions all require as inputs the STATE index of the block for which the function is invoked. Although in the description given below, this index is shown as 'K' (if the block has only one STATE, and as K, K1 etc., if the block has more than one STATE), the appropriate STATE index (in general K+n, where n could be any number greater than or equal zero) has to be specified.
- The MODE1, MODE2, and the MODE3 functions all require as inputs the model constants (e.g., gains, time constants, maximum and minimum limits etc.), which are usually in the PSS®E 'CON' arrays. The appropriate 'CON' values have to be passed as arguments in the function call.
- The elementary block functions are accessible to user-written models via the INCLUDE of 'COMON4.INS'.

In summary, the use of the elementary blocks would greatly simplify the process of writing PSS®E dynamic models, and in addition, the application of non-windup limits would be consistent with the IEEE recommendation.

24.2. Integrator

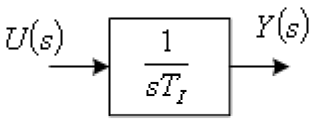


Figure 24.1. Integrator Block

```
INTEGER IERR
REAL VINP
REAL VOUT
```

Figure 24.2. Variable Declaration for Integrator Block

```
C_
C____ UNLIMITED INTEGRATOR (INITIALIZED WITH OUTPUT = Y)
C_
        VOUT = Y                              ! block output
        VINP = INT_MODE1(      TI,            !    time constant (real)
      #                        VOUT,          !    block output variable (real)
      #                        K    ,         !    index for state variable (integer)
      #                        IERR   )       !    error code (integer)

C IERR = 0 => no error
C IERR = 4 => TI is zero
```

Figure 24.3. FORTRAN Code for Initialization of Integrator Block (MODE=1)

```
C_
C____ UNLIMITED INTEGRATOR
C_
        VINP = U
        VOUT = INT_MODE2(      TI,            !    time constant (real)
      #                        VINP,          !    block input variable (real)
      #                        K  )           !    index for state variable (integer)
```

Figure 24.4. FORTRAN Code for Calculation of Derivatives of Integrator Block (MODE=2)

```
C_
C____ UNLIMITED INTEGRATOR
C_
        VINP = U
        VOUT = INT_MODE3(      TI,              ! time constant (real)
     #                         VINP,            ! block input variable (real)
     #                         K  )             ! index for state variable (integer)
```

Figure 24.5. FORTRAN Code for Calculation of Output Integrator Block (MODE=3)

24.3. Non-windup Integrator

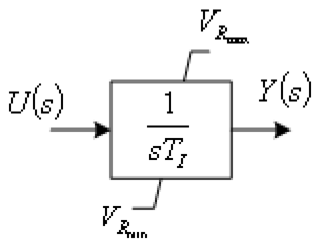


Figure 24.6. Integrator Block with Non-Windup Limits

```
INTEGER IERR
REAL VINP
REAL VOUT
```

Figure 24.7. Variable Declaration for Integrator Block with Non-Windup Limits

```
C_
C____ NON-WINDUP INTEGRATOR (INITIALIZED WITH OUTPUT = Y)
C_
        VOUT = Y
        VINP = NWINT_MODE1( TI,              !    time constant (real)
     #                      VRMAX,           !    max. limit (real)
     #                      VRMIN,           !    min. limit (real)
     #                      VOUT,            !    block output variable (real)
     #                      K,               !    index for state variable (integer)
     #                      IERR   )         !    error code (integer)
C
C IERR = 0 => no error
C IERR = 4 => TI is zero
```

Figure 24.8. FORTRAN Code for Initialization of Integrator Block with Non-Windup Limits (MODE=1)

```
C_
C____ NON-WINDUP INTEGRATOR
C_
        VINP = U
        VOUT = NWINT_MODE2( TI,                  !  time constant (real)
     #                      VRMAX,               !  max. limit (real)
     #                      VRMIN,               !  min. limit (real)
     #                       VINP,               ! block input variable (real)
     #                        K  )               ! index for state variable (integer)
```

Figure 24.9. FORTRAN Code for Calculation of Derivatives of Integrator Block with Non-Windup Limits (MODE=2)

```
C_
C____ NON-WINDUP INTEGRATOR
C_
        VINP = U
        VOUT = NWINT_MODE3( TI,                 ! time constant (real)
     #                      VRMAX,              ! max. limit (real)
     #                      VRMIN,              ! min. limit (real)
     #                      VINP,               ! block input variable (real)
     #                      K  )                ! index for state variable (integer)
```

Figure 24.10. FORTRAN Code for Calculation of Output Integrator Block with Non-Windup Limits (MODE=3)

24.4. First Order (Lag) Block

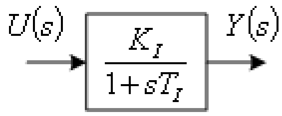


Figure 24.11. First Order Block

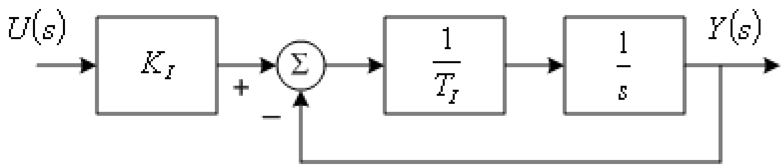


Figure 24.12. PSS®E Implementation of the First Order Block

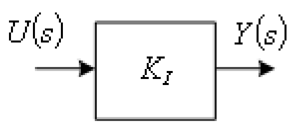


Figure 24.13. PSS®E Implementation of the First Order Block when T = 0

```
INTEGER IERR
REAL VINP
REAL VOUT
```

Figure 24.14. Variable Declaration for First Order Block

```
C_
C____ UNLIMITED FIRST ORDER BLOCK (INITIALIZED WITH OUTPUT = Y)
C_
        VOUT = Y
        VINP = LAG_MODE1( KI,                   ! gain (real)
     #                    TI,                   ! time constant (real)
     #                    VOUT,                 ! block output variable (real)
     #                    K,                    ! index of state variable (integer)
     #                    IERR  )               ! error code (integer)
C
C IERR = 0 => no error
C IERR = 3 => Gain KI = 0 (fatal error at initialization)
C IERR = 4 => TI = 0
```

Figure 24.15. FORTRAN Code for Initialization of First Order Block (MODE=1)

```
C_
C____ UNLIMITED FIRST ORDER LAG
C_
        VINP = U
        VOUT = LAG_MODE2( KI,                   ! gain (real)
     #                    TI,                   ! time constant (real)
     #                    VINP,                 ! block input variable (real)
     #                    K  )                  ! index of state variable (integer)
```

Figure 24.16. FORTRAN Code for Calculation of Derivatives of First Order Block (MODE=2)

```
C_
C____ UNLIMITED FIRST ORDER LAG
C_
        VINP = U
        VOUT = LAG_MODE3( KI,                   ! gain (real)
     #                    TI,                   ! time constant (real)
     #                    VINP,                 ! block input variable (real)
     #                    K  )                  ! index of state variable (integer)
```

Figure 24.17. FORTRAN Code for Calculation of Output of First Order Block (MODE=3)

24.5. First Order (Lag) Block with Non-Windup Limits

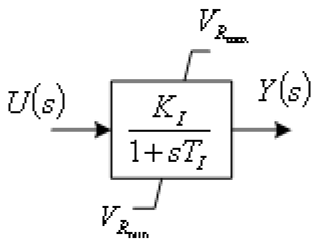


Figure 24.18. First Order Block with Non-Windup Limits

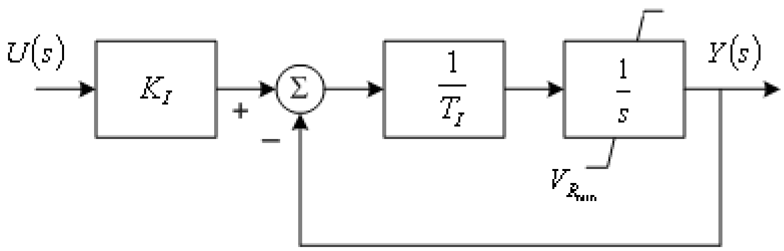


Figure 24.19. PSS®E Implementation of the First Order Block with Non-Windup Limits

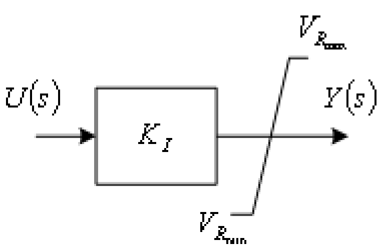


Figure 24.20. PSS®E Implementation of the First Order Block with Non-Windup Limits when T = 0

```
INTEGER IERR
REAL VINP
REAL VOUT
```

Figure 24.21. Variable Declaration for First Order Block with Non-Windup Limits

```
C_
C____ NON-WINDUP FIRST ORDER LAG BLOCK
C_
      VOUT = Y
      VINP = NWLAG_MODE1( KI,              ! gain (real)
     #                    TI,              ! time constant (real)
     #                    VRMAX,           ! max. limit (real)
     #                    VRMIN,           ! min. limit (real)
     #                    VOUT,            ! block output variable (real)
     #                    K,               ! index of state variable (integer)
     #                    IERR   )         ! error code (integer)
C
C IERR = 0 => no error
C IERR = 1 => initialization above VRMAX
C IERR = 2 => initialization below VRMIN
C IERR = 3 => Gain KI = 0 (fatal error at initialization)
C IERR = 4 => TI = 0
```

Figure 24.22. FORTRAN Code for Initialization of First Order Block with Non-Windup Limits (MODE=1)

```
C_
C____ NON-WINDUP FIRST ORDER LAG
C_
      VINP = U
      VOUT = NWLAG_MODE2(KI,              ! gain (real)
     #                   TI,              ! time constant (real)
     #                   VRMAX,           ! max. limit (real)
     #                   VRMIN,           ! min. limit (real)
     #                   VINP,            ! block input variable (real)
     #                   K   )            ! index of state variable (integer)
```

Figure 24.23. FORTRAN Code for Calculation of Derivatives of First Order Block with Non-Windup Limits (MODE=2)

```
C_
C____ NON-WINDUP FIRST ORDER LAG
C_
      VINP = U
      VOUT = NWLAG_MODE3(KI,              ! gain (real)
     #                   TI,              ! time constant (real)
     #                   VRMAX,           ! max. limit (real)
     #                   VRMIN,           ! min. limit (real)
     #                   VINP,            ! block input variable (real)
     #                   K   )            ! index of state variable (integer)
```

Figure 24.24. FORTRAN Code for Calculation of Output of First Order Block with Non-Windup Limits (MODE=3)

24.6. Wash-Out Block

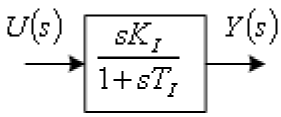


Figure 24.25. Wash-Out Block

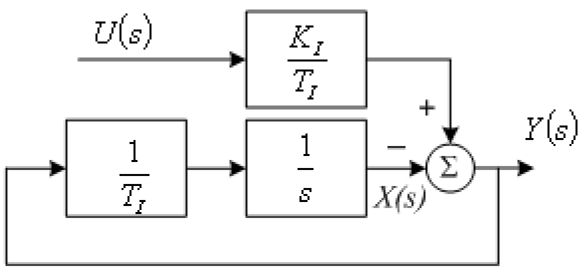


Figure 24.26. PSS®E Implementation of the Wash-Out Block

```
INTEGER IERR
REAL VINP
REAL VOUT
```

Figure 24.27. Variable Declaration for Wash-Out Block

```
C_
C____ WASHOUT BLOCK
C_
        VINP = U
        VOUT = WSHOUT_MODE1( KI,           ! gain (real),
     #                       TI,           ! time constant (real)
     #                       VINP,         ! block input variable (real)
     #                       K,            ! index of state variable (integer)
     #                       IERR   )      ! error code (integer)
C
C IERR = 0 => no error
C IERR = 4 => TI = 0
```

Figure 24.28. FORTRAN Code for Initialization of Wash-Out Block (MODE=1)

```
C_
C____ WASH-OUT
C_
        VINP = U
        VOUT = WSHOUT_MODE2( KI,              ! gain (real)
     #                       TI,              ! time constant (real)
     #                       VINP,            ! block input variable (real)
     #                       K  )             ! index of state variable (integer)
```

Figure 24.29. FORTRAN Code for Calculation of Derivatives of Wash-Out Block (MODE=2)

```
C_
C____ WASH-OUT
C_
        VINP = U
        VOUT = WSHOUT_MODE3( KI,              ! gain (real)
     #                       TI,              ! time constant (real)
     #                       VINP,            ! block input variable (real)
     #                       K  )             ! index of state variable (integer)
```

Figure 24.30. FORTRAN Code for Calculation of Output of Wash-Out Block (MODE=3)

24.7. Lead-Lag Block

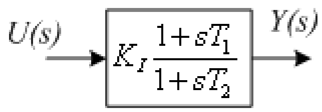


Figure 24.31. Lead-Lag Block

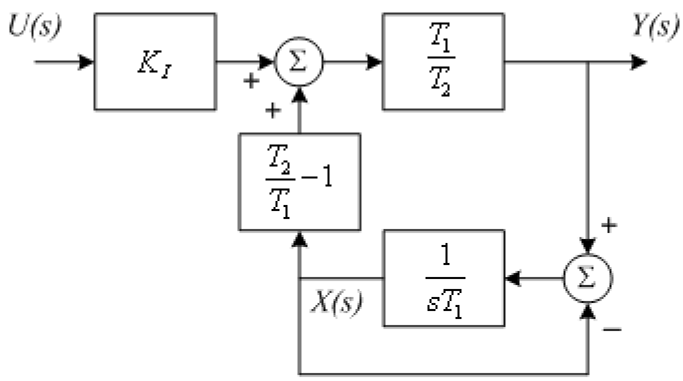


Figure 24.32. PSS®E Implementation of the Lead-Lag Block

```
INTEGER IERR
REAL VINP
REAL VOUT
```

Figure 24.33. Variable Declaration for Lead-Lag Block

```
C_
C____ UNLIMITED LEAD-LAG BLOCK
C_
        VOUT = Y
        VINP = LDLG_MODE1( KI,            ! gain (real)
     #                   T1,            ! numerator (lead) time constant (real)
     #                   T2,            ! denominator (lag) time constant (real)
     #                   VOUT,          ! block output variable (real)
     #                   K,             ! index of state variable (integer)
     #                   IERR   )       ! error code (integer)
C
C IERR = 0 => no error
C IERR = 3 => Gain KI = 0
C IERR = 4 => T2 = 0 (Dynamics of the block is ignored)
C IERR = 5 => T1 = 0 (Block treated as first order lag)
```

Figure 24.34. FORTRAN Code for Initialization of Lead-Lag Block (MODE=1)

```
C_
C____ UNLIMITED LEAD-LAG BLOCK
C_
        VINP = U
        VOUT = LDLG_MODE2( KI,             ! gain (real)
     #                     T1,             ! numerator (lead) time constant (real)
     #                     T2,             ! denominator (lag) time constant (real)
     #                     VINP,           ! block input variable (real)
     #                     K   )           ! index of state variable (integer)
```

Figure 24.35. FORTRAN Code for Calculation of Derivatives of Lead-Lag Block (MODE=2)

```
C_
C____ UNLIMITED LEAD-LAG
C_
        VINP = U
        VOUT = LDLG_MODE3( KI,             ! gain (real)
     #                     T1,             ! numerator (lead) time constant (real)
     #                     T2,             ! denominator (lag) time constant (real)
     #                     VINP,           ! block input variable (real)
     #                     K   )           ! index of state variable (integer)
```

Figure 24.36. FORTRAN Code for Calculation of Output of Lead-Lag Block (MODE=3)

24.8. Lead-Lag Block with Non-Windup Limits

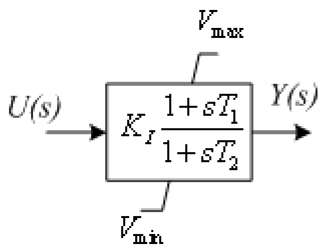


Figure 24.37. Lead-Lag Block with Non-Windup Limits

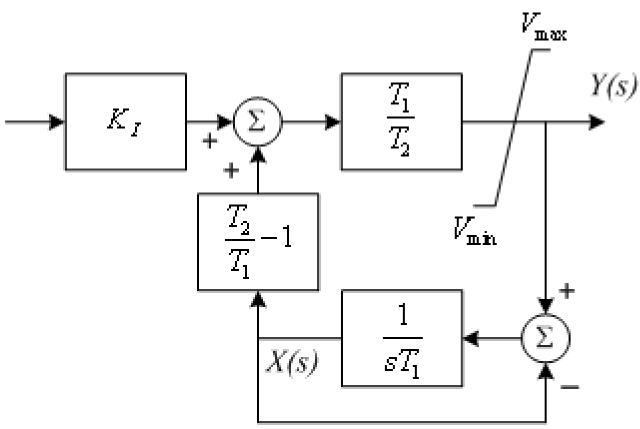


Figure 24.38. PSS®E Implementation of the Lead-Lag Block with Non-Windup Limits

```
INTEGER IERR
REAL VINP
REAL VOUT
```

Figure 24.39. Variable Declaration for Lead-Lag Block with Non-Windup Limits

```
C_
C____ NON-WINDUP LEAD-LAG BLOCK (INITIALIZED WITH OUTPUT = VERR = VINP)
C_
      VOUT = Y
      VINP = NWLDLG_MODE1( KI,            ! gain (real)
     #                     T1,            ! numerator (lead) time constant (real)
     #                     T2,            ! denominator (lag) time constant (real)
     #                     VRMAX,         ! max. limit (real)
     #                     VRMIN,         ! min. limit (real)
     #                     VOUT,          ! block output variable (real)
     #                     K,             ! index of state variable (integer)
     #                     IERR  )        ! error code (integer)
C
C IERR = 0 => no error
C IERR = 1 => initialization above VRMAX
C IERR = 2 => initialization below VRMIN
C IERR = 3 => Gain KI = 0
C IERR = 4 => T2 = 0 (Dynamics of the block is ignored)
C IERR = 5 => T1 = 0 (Block treated as first order lag)
```

Figure 24.40. FORTRAN Code for Initialization of Lead-Lag Block with Non-Windup Limits (MODE=1)

```
C_
C____ NON-WINDUP LEAD-LAG BLOCK
C_
      VINP = U
      VOUT = NWLDLG_MODE2( KI,            ! gain (real)
     #                     T1,            ! numerator (lead) time constant (real)
     #                     T2,            ! denominator (lag) time constant (real)
     #                     VRMAX,         ! max. limit (real)
     #                     VRMIN,         ! min. limit (real)
     #                     VINP,          ! block input variable (real)
     #                     K)             ! index of state variable (integer)
```

Figure 24.41. FORTRAN Code for Calculation of Derivatives of Lead-Lag Block with Non-Windup Limits (MODE=2)

```
C_
C____ NON-WINDUP LEAD-LAG BLOCK
C_
        VINP = U
        VOUT = NWLDLG_MODE3( KI,           ! gain (real)
     #                       T1,           ! numerator (lead) time constant (real)
     #                       T2,           ! denominator (lag) time constant (real)
     #                       VRMAX,        ! max. limit (real)
     #                       VRMIN,        ! min. limit (real)
     #                       VINP,         ! block input variable (real)
     #                       K)            ! index of state variable (integer)
```

Figure 24.42. FORTRAN Code for Calculation of Output of Lead-Lag Block with Non-Windup Limits (MODE=3)

24.9. Proportional-Integral (PI) Block

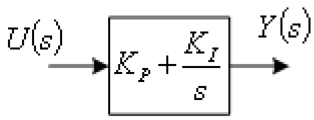


Figure 24.43. Proportional-Integral (PI) Block

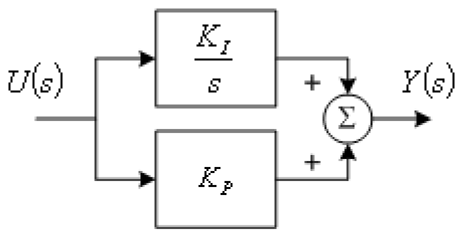


Figure 24.44. PSS®E Implementation of the Proportional-Integral (PI) Block

```
INTEGER IERR
REAL VINP
REAL VOUT
```

Figure 24.45. Variable Declaration for Proportional-Integral (PI) Block

```
C_
C____ UNLIMITED PI BLOCK (INITIALIZED WITH OUTPUT = Y)
C_
        VOUT = Y
        VINP = PI_MODE1( KP,                ! proportional gain (real)
     #                   KI,                ! integral gain (real)
     #                   VOUT,              ! block output variable (real)
     #                   K,                 ! index of state variable (real)
     #                   IERR   )           ! error code (integer)
C
C IERR = 0 => no error
C IERR = 3 => Gain KP = 0 (fatal error at initialization)
```

Figure 24.46. FORTRAN Code for Initialization of Proportional-Integral (PI) Block (MODE=1)

```
C_
C____ UNLIMITED PI
C_
        VINP = U
        VOUT = PI_MODE2( KP,              ! proportional gain (real)
     #                   KI,              ! integral gain (real)
     #                   VINP,            ! block input variable (real)
     #                   K,               ! index of state variable (real)
```

Figure 24.47. FORTRAN Code for Calculation of Derivatives of Proportional-Integral (PI) Block (MODE=2)

```
C_
C____ UNLIMITED PI
C_
        VINP = U
        VOUT = PI_MODE3( KP,              ! proportional gain (real)
     #                   KI,              ! integral gain (real)
     #                   VINP,            ! block input variable (real)
     #                   K,               ! index of state variable (real)
```

Figure 24.48. FORTRAN Code for Calculation of Output of Proportional-Integral (PI) Block (MODE=3)

24.10. Proportional-Integral (PI) Block with Non-Windup Limits

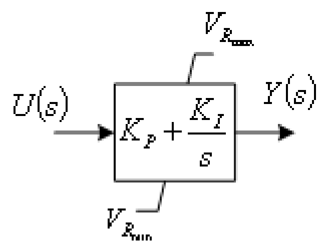


Figure 24.49. Proportional-Integral (PI) Block with Non-Windup Limits

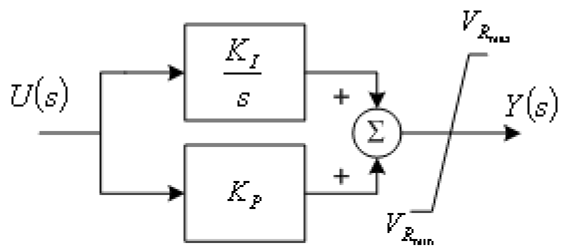


Figure 24.50. PSS®E Implementation of the Proportional-Integral (PI) Block with Non-Windup Limits

```
INTEGER IERR
REAL VINP
REAL VOUT
```

Figure 24.51. Variable Declaration for Proportional-Integral (PI) Block with Non-Windup Limits

```
C_
C____ NON-WINDUP PI BLOCK (INITIALIZED WITH OUTPUT = Y)
C_
      VOUT = Y
      VINP = NWPI_MODE1( KP,              ! proportional gain (real)
    #                    KI,              ! integral gain (real)
    #                    VRMAX,           ! max. limit (real)
    #                    VRMIN,           ! min. limit (real)
    #                    VOUT,            ! block output variable (real)
    #                    K,               ! index of state variable (integer)
    #                    IERR  )          ! error code (integer)
C
C IERR = 0 => no error
C IERR = 1 => initialization above VRMAX
C IERR = 2 => initialization below VRMIN
C IERR = 3 => Gain KP = 0 (fatal error at initialization)
```

Figure 24.52. FORTRAN Code for Initialization of Proportional-Integral (PI) Block with Non-Windup Limits (MODE=1)

```
C_
C____ NON-WINDUP PI
C_
      VINP = U
      VOUT = NWPI_MODE2( KP,              ! proportional gain (real)
    #                    KI,              ! integral gain (real)
    #                    VRMAX,           ! max. limit (real)
    #                    VRMIN,           ! min. limit (real)
    #                    VINP,            ! block input variable (real)
    #                    K)               ! index of state variable (integer)
```

Figure 24.53. FORTRAN Code for Calculation of Derivatives of Proportional-Integral (PI) Block with Non-Windup Limits (MODE=2)

```
C_
C____ NON-WINDUP PI
C_
      VINP = U
      VOUT = NWPI_MODE3( KP,              ! proportional gain (real)
    #                    KI,              ! integral gain (real)
    #                    VRMAX,           ! max. limit (real)
    #                    VRMIN,           ! min. limit (real)
    #                    VINP,            ! block input variable (real)
    #                    K)               ! index of state variable (integer)
```

Figure 24.54. FORTRAN Code for Calculation of Output of Proportional-Integral (PI) Block with Non-Windup Limits (MODE=3)

24.11. Proportional-Integral-Derivative (PID) Block

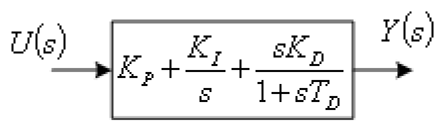


Figure 24.55. Proportional-Integral-Derivative (PID) Block

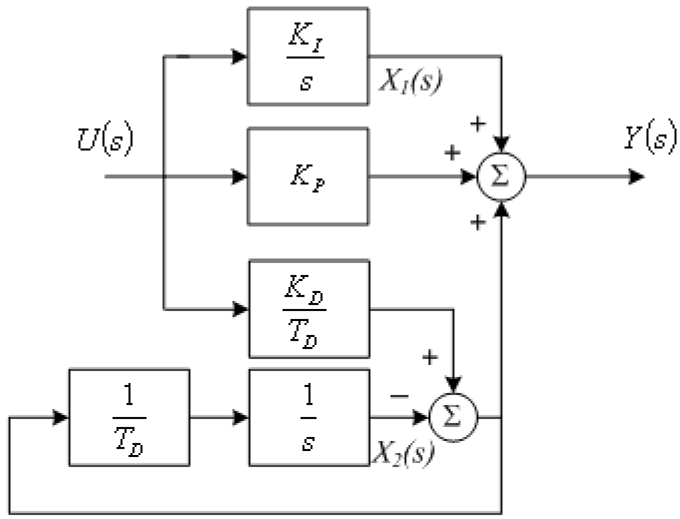


Figure 24.56. PSS®E Implementation of the Proportional-Integral-Derivative (PID) Block

```
INTEGER IERR
REAL VINP
REAL VOUT
```

Figure 24.57. Variable Declaration for Proportional-Integral-Derivative (PID) Block

```
C_
C____ UNLIMITED PID BLOCK (INITIALIZED WITH OUTPUT = Y)
C_
       VOUT = Y
       VINP = PID_MODE1( KP,       ! proportional gain (real)
     #                   KI,       ! integral gain (real)
     #                   KD,       ! derivative gain (real)
     #                   TD,       ! time constant of the derivative channel (real)
     #                   VOUT,     ! block output variable (real)
     #                   K,        ! index of integral state variable (integer)
     #                   K1,       ! index of derivative state variable (integer)
     #                   IERR  )   ! error code (integer)

C IERR = 0 => no error
C IERR = 3 => Gain KP = 0 (fatal error at initialization)
```

Figure 24.58. FORTRAN Code for Initialization of Proportional-Integral-Derivative (PID) Block (MODE=1)

```
C_
C____ UNLIMITED PID
C_
       VINP = U
       VOUT = PID_MODE2( KP,       ! proportional gain (real)
     #                   KI,       ! integral gain (real)
     #                   KD,       ! derivative gain (real)
     #                   TD,       ! time constant of the derivative channel (real)
     #                   VINP,     ! block input variable (real)
     #                   K,        ! index of integral state variable (integer)
     #                   K1    )   ! index of derivative state variable (integer)
```

Figure 24.59. FORTRAN Code for Calculation of Derivatives of Proportional-Integral-Derivative (PID) Block (MODE=2)

```
C_
C____ UNLIMITED PID
C_
       VINP = U
       VOUT = PID_MODE3( KP,       ! proportional gain (real)
     #                   KI,       ! integral gain (real)
     #                   KD,       ! derivative gain (real)
     #                   TD,       ! time constant of the derivative channel (real)
     #                   VINP,     ! block input variable (real)
     #                   K,        ! index of integral state variable (integer)
     #                   K1    )   ! index of derivative state variable (integer)
```

Figure 24.60. FORTRAN Code for Calculation of Output of Proportional-Integral-Derivative (PID) Block (MODE=3)

24.12. Proportional-Integral-Derivative (PID) Block with Non-Windup Limits

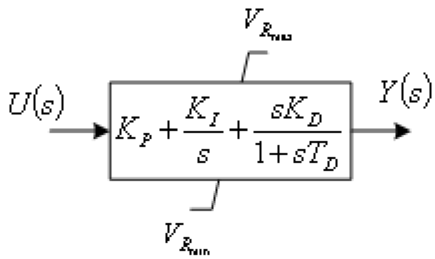


Figure 24.61. Proportional-Integral-Derivative (PID) Block with Non-Windup Limits

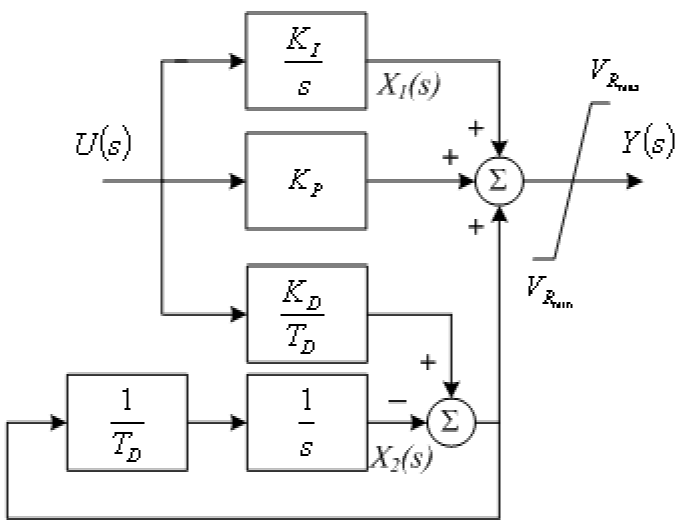


Figure 24.62. PSS®E Implementation of the Proportional-Integral-Derivative (PID) Block with Non-Windup Limits

```
INTEGER IERR
REAL VINP
REAL VOUT
```

Figure 24.63. Variable Declaration for Proportional-Integral-Derivative (PID) Block with Non-Windup Limits

```
C_
C____ NONWINDUP PID BLOCK (INITIALIZED WITH OUTPUT = Y)
C_
        VOUT = Y
        VINP = NWPID_MODE1( KP,      ! proportional gain (real)
     #                      KI,      ! integral gain (real)
     #                      KD,      ! derivative gain (real)
     #                      TD,      ! time constant of derivative channel (real)
     #                      VRMAX,   ! max. limit (real)
     #                      VRMIN,   ! min. limit (real)
     #                      VOUT,    ! block output variable (real)
     #                      K,       ! index of integral state variable (integer)
     #                      K1,      ! index of derivative state variable (integer)
     #                      IERR  )  ! error code (integer)
C
C IERR = 0 => no error
C IERR = 1 => initialization above VRMAX
C IERR = 2 => initialization below VRMIN
C IERR = 3 => Gain KP = 0 (fatal error at initialization)
```

Figure 24.64. FORTRAN Code for Initialization of Proportional-Integral-Derivative (PID) Block with Non-Windup Limits (MODE=1)

```
C_
C____ NON-WINDUP PID
C_
        VINP = U
        VOUT = NWPID_MODE2( KP,      ! proportional gain (real)
     #                      KI,      ! integral gain (real)
     #                      KD,      ! derivative gain (real)
     #                      TD,      ! time constant of derivative channel (real)
     #                      VRMAX,   ! max. limit (real)
     #                      VRMIN,   ! min. limit (real)
     #                      VINP,    ! block input variable (real)
     #                      K,       ! index of integral state variable (integer)
     #                      K1)      ! index of derivative state variable (integer)
```

Figure 24.65. FORTRAN Code for Calculation of Derivatives of Proportional-Integral-Derivative (PID) Block with Non-Windup Limits (MODE=2)

```
C_
C_____ NON-WINDUP PID
C_
      VINP = U
      VOUT = NWPID_MODE3( KP,       ! proportional gain (real)
     #                    KI,       ! integral gain (real)
     #                    KD,       ! derivative gain (real)
     #                    TD,       ! time constant of derivative channel (real)
     #                    VRMAX,    ! max. limit (real)
     #                    VRMIN,    ! min. limit (real)
     #                    VINP,     ! block input variable (real)
     #                    K,        ! index of integral state variable (integer)
     #                    K1)       ! index of derivative state variable (integer)
```

Figure 24.66. FORTRAN Code for Calculation of Output of Proportional-Integral-Derivative (PID) Block with Non-Windup Limits (MODE=3)

24.13. Second Order Block

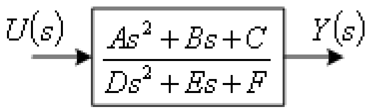


Figure 24.67. Second Order Block

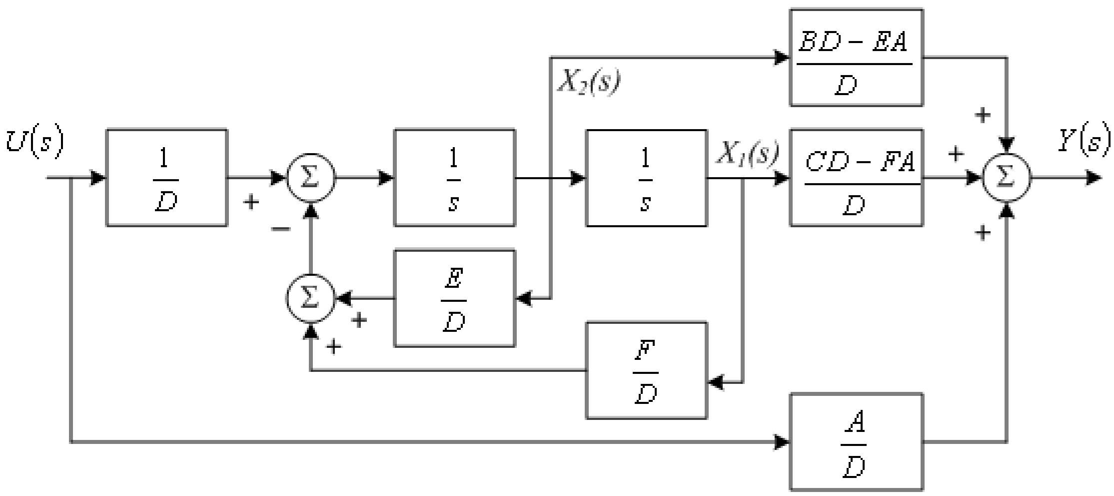


Figure 24.68. PSS®E Implementation of the Second Order Block

```
INTEGER IERR
REAL VINP
REAL VOUT
```

Figure 24.69. Variable Declaration for Second Order Block

```
C_
C____ 2ND ORDER BLOCK (INITIALIZED WITH OUTPUT = Y)
C_
         VOUT = Y
         VINP = ORD2_MODE1( A,          ! parameter A (real)
     #                      B,          ! parameter B (real)
     #                      C,          ! parameter C (real)
     #                      D,          ! parameter D (real)
     #                      E,          ! parameter E (real)
     #                      F,          ! parameter F (real)
     #                      VOUT,       ! block output variable (real)
     #                      K,          ! index of first state variable (integer)
     #                      K1,         ! index of second state variable (integer)
     #                      IERR  )     ! error code (integer)
C
C IERR = 0 => no error
C IERR = 3 => D = 0 (dynamics of block is ignored)
C IERR = 4 => C = 0
```

Figure 24.70. FORTRAN Code for Initialization of Second Order Block (MODE=1)

```
C_
C____ SECOND ORDER BLOCK
C_
         VINP = U
         VOUT = ORD2_MODE2( A,          ! parameter A (real)
     #                      B,          ! parameter B (real)
     #                      C,          ! parameter C (real)
     #                      D,          ! parameter D (real)
     #                      E,          ! parameter E (real)
     #                      F,          ! parameter F (real)
     #                      VINP,       ! block input variable (real)
     #                      K,          ! index of first state variable (integer)
     #                      K1)         ! index of second state variable (integer)
```

Figure 24.71. FORTRAN Code for Calculation of Derivatives of Second Order Block (MODE=2)

```
C____ SECOND ORDER BLOCK
C_
VINP = U
        VOUT = ORD2_MODE3( A,           ! parameter A (real)
     #                     B,           ! parameter B (real)
     #                     C,           ! parameter C (real)
     #                     D,           ! parameter D (real)
     #                     E,           ! parameter E (real)
     #                     F,           ! parameter F (real)
     #                     VINP,        ! block input variable (real)
     #                     K,           ! index of first state variable (integer)
     #                     K1)          ! index of second state variable (integer)
```

Figure 24.72. FORTRAN Code for Calculation of Output of Second Order Block (MODE=3)

Chapter 25
Other Models

25.1. Saturating Reactive Load

25.1.1. Model SAT1

SAT1 is a very simplified model of a saturating reactive device such as a saturated-reactor form of static-var-generator. SAT1 models no device control dynamics or inherent device dynamics; it simply models fundamental frequency inductive current consumption as a piecewise linear function of bus voltage. The initialization procedure is shown in Figure 25.1, “Initialization of SAT1 Model Knee Voltage”. The shape of the current voltage curve is specified by the value of current, CRO, drawn at the knee, and by the slope, R, of the saturated portion. The voltage at the knee, VON, is assumed to be an adjustable parameter. (In a real device being modeled by SAT1, adjustment might occur by tap changing.) The value of VON (VAR(K)) is determined in activity STRT so that the SAT1 model exactly replaces an equivalent linear reactor.

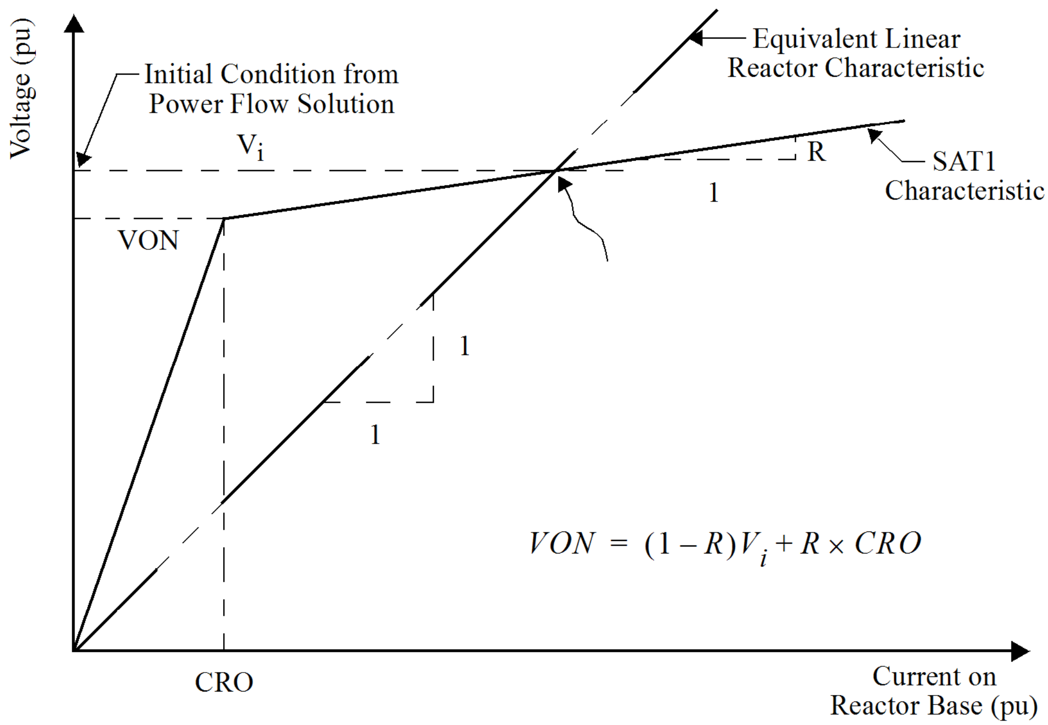


Figure 25.1. Initialization of SAT1 Model Knee Voltage

The initial condition power flow case must be solved with a linear reactor, where the rating must be equal to the rating (CON(J+2)) of the saturating device. This solution establishes the initial operating point of the saturating device, and hence the value of VON. Because the SAT1 model replaces the linear reactor, the linear reactor must be removed from the bus by setting BSHUNT to zero before execution of activity FACT in setting up the initial condition network model. The power flow case must be solved *before* the linear reactor is removed and must not be resolved by any power flow activity after its removal. An initial condition saved case should be made after removal of the linear reactor from the bus. The bus at which SAT1 is connected should have no other shunt device connected to it, but may have a constant admittance component of load. Activity TYSL *must not* be used after the linear reactor has been removed from the power flow case. The initialization sequence for the SAT1 model should be:

```
CHNG, etc. to place linear reactor on bus
```

```
SOLV, etc. to solve power flow case
CONG
CONL as required
ORDR
CHNG to remove linear reactor
SAVE, name
```

followed, in dynamic simulation, by:

```
RSTR to recover dynamics data
LOFL
CASE, name
FACT
RTRN
STRT
```

Because it usually has a very rapid variation of reactive current with voltage, SAT1 usually requires a local deceleration of the iterative network solution. Accordingly, the value of CON(L) will usually need to be substantially less than unity. A reasonable first trial value is 0.5 but it is not unusual to need an acceleration factor as small as 0.05 to obtain good convergence. Typical values of the reactor regulation and knee current might be 0.05 and 0.025, respectively. The saturating device may be disconnected by setting ICON(I) to zero.

25.1.2. Model SAT2

SAT2, a transformer saturating model, adds an inductive shunt current onto the sum of load and other currents drawn from a bus. SAT2 should be applied at the bus on the supply side of the transformer where the magnetizing current is to be modeled. It is permissible to make multiple applications of SAT2 at a bus if several transformers are connected to it. The CON values specified for SAT2 must specify the magnetizing current, per unit, of transformer rated current and the transformer rating must be specified as CON(N).

SAT2 does not initialize itself and so the current drawn by it shows up as a mismatch at the bus if no manual precautions are taken to recognize it. Such manual action is usually unnecessary because transformer magnetizing current is usually very small in relation to load currents at the normal operating voltages existing in the majority of initial conditions. It is usually sufficient to apply SAT2 to a completely conventional initial condition power flow setup and to tolerate a small shift in the voltages and reactive power flows due to the addition of magnetizing current in activity STRT. The network solution in activity STRT should converge in three or four iterations when SAT2 is used, compared to one iteration in a normal situation.

SAT2 is de-activated by setting ICON(I) to zero; this should be done when the transformer with which it is associated is de-energized. SAT2 frequently requires local deceleration of the network solution. It is not unusual to require a value as small as 0.1 for the accelerating factor, CON(L), particularly in cases of radial load rejection where the transformer is at the opened end of a transmission line.

25.2. Models Requiring User-Supplied Logic

The PSS®E model library includes some models that are intended to be called only in response to some user-supplied logic. This logic may be as simple as the following:

```
IF (LOGICAL) CALL XXX
```

in which the user wanted the model to be called at a time equal to 0 sec. This logic may also be quite complicated if the user wanted to use specific bus or machine quantities (see Advanced Uses of CONEC and CONET of the *PSS®E Program Operation Manual* on Advance Uses of CONEC and CONET). The user usually will not want these models called by activity STRT or when TIME is less than zero. These models should be called when MODE is equal to three. Because the models will take no action during the t^+ calls to subroutines CONEC and CONET. Therefore, the user should include the following as part of the logic to all the models:

```
KPAUSE.NE.2
```

25.2.1. Model LINTRP

This line tripping model (LINTRP), when called, will immediately trip the line described by its ICONs. When the line is tripped, a message is printed. If the line is not found, an appropriate message is printed.

25.2.2. Model BSDSCN

BSDSCN, when called, disconnects a bus (makes it Type 4) by tripping all the circuits connected to it, and identifies the bus and circuits in the printout. If the bus cannot be found, an appropriate message is printed.

25.2.3. Model GENTRP

GENTRP, when called, immediately trips the generator (sets its states to zero). When it trips the generator, an appropriate message is printed. If the machine cannot be found, an appropriate message is printed.

25.3. Model NETFRQ

NETFRQ, using selection from dialog opened at *Dynamics>Simulation>Simulation Options...*, causes the network parameters to become frequency-dependent. This model should be called whenever frequency substantially deviates from nominal. It is not automatically called by PSS®E because it may add 10 to 20% to the running time of a stability case. Users should verify this themselves and, if running time is not a problem, always include this model. When the model is called, the following items become frequency-dependent:

1. Line reactances and capacitances.

2. Generator source reactances.

3. Shunts including switched shunts and static var devices.

4. Reactive loads modeled on constant impedance.

The user will typically not see any difference in results during the first swing of a simulation when using this model. Comparing subsequent swings will show better damping when the model is used (i.e., not using frequency dependence gives conservative results).

PSS®E calculates frequency at each bus independently by taking the instantaneous rate of change of angle and placing it through a filter time constant. The default value for the time constant is 0.04 sec. It is this filtered frequency that is used in CMOTOR, CLOAD, etc. when frequency dependence is invoked. On a few rare instances where the system is very weak, no generator sources electrically close. This filter constant may be too short and cause numerical instability. The user should first confirm that the NETFRQ model is causing the numerical instability by deactivating the model and rerunning the simulation before increasing this filter constant via the solution parameters choice in ALTR.

25.4. System-Wide Monitoring Models

There are several PSS®E models that do not affect the solution at all. These models are provided mostly for output purposes to aid the user in interpreting results. All the models are recognized either by activity DYRE, by selection from dialog opened at *Dynamics>Simulation>Simulation Options...*, or by selection in activity CHSB.

25.4.1. Simulation Option Monitoring Models

Model RELANG

PSS®E automatically places the absolute machine angles in the array ANGLE for output purposes. Model RELANG allows the user to choose a reference angle and then modifies the ANGLE array to contain all machine angles relative to the reference. The following choices for the reference are set by dialog:

- Machine average angle.
- Weighted average angle (machine MBASE is used for weighing).
- Bus number and machine identifier.

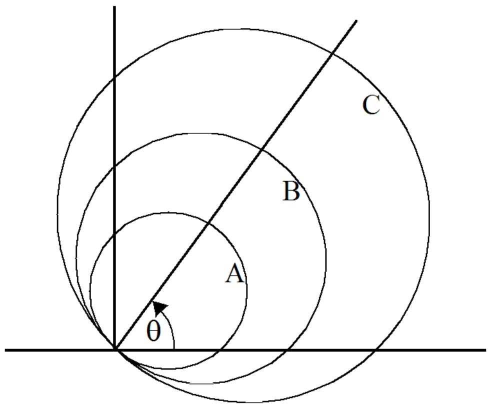
The model is ignored and does print an appropriate message if the bus or machine is not found. This model is extremely useful in smaller systems where a fault would cause the absolute angles of all machines to accelerate so that no good comparison of angles can be made. Care should be taken when using average angles in trying to find intermachine oscillations during dynamics stability cases (several seconds) because the average may filter or introduce new modes.

Model RELAY1

RELAY1 is a relay scanning model that checks every circuit from both ends in the system against the relay characteristics shown in Figure 25.2, “Standard RELAY1 and RELAY2 Relay Circles”. This model only notes circuits within zones; it does not trip any circuits. The model is very good for getting a sense of what happens on the circuits without having to place a relay on every circuit.

Model VSCAN

This model scans to see if any bus voltages are outside the user-specified range and prints appropriate messages. The model helps to locate potential trouble locations.



$$\theta = \tan^{-1}\frac{X_{line}}{R_{line}}$$

$$Z_{line} = \sqrt{R^2 + X^2}$$

Center of A $0.46 \times Z_{line}$

Center of B $0.75 \times Z_{line}$

Center of C $1.10 \times Z_{line}$

Figure 25.2. Standard RELAY1 and RELAY2 Relay Circles

Model OSSCAN

The out-of-step scanning model (OSSCAN) can be used to scan an entire network for out-of-step conditions. With this model, whenever the apparent impedance as seen from either end of a line is less than the line impedance, the line is flagged as out of step. OSSCAN is useful in exploratory simulations, e.g., it is not evident where or if a system will lose synchronism, or the user wishes to avoid placing detailed relay models throughout the system.

The model can be used either to just monitor or to monitor and immediately trip. The model is activated from the *Dynamics > Simulation > Simulation Options...* dialog.

Model GNSCN1

The generator scanning and tripping model (GNSCN1), which is called by selecting *Dynamics > Simulation > Simulation Options...* and specifying the option *Scan for generators exceeding angle threshold* from the dialog, scans those generator angles whose MVA base is more than a set threshold to see if any exceed the system average angle by more than CON(J) degrees. When it finds a machine with a large deviation, it either just monitors or monitors and trips it immediately and prints an appropriate message. This model is valuable in doing preliminary studies in which generators lose synchronism and the user wants to see what effect tripping the generator will have on the system. However, this model should not be used if the user has multiple ac systems or ac systems connected only by dc transmission.

Model GNSCN2

The generator scanning and tripping model (GNSCN2) is called by selecting *Dynamics > Simulation > Simulation Options...* and specifying the option *Scan for generators exceeding power unbalance threshold* from the dialog. This model scans all generator angles and trips immediately any machine where instantaneous per-unit mechanical power exceeds its per-unit electrical power by more than the threshold, CON(J). The model prints a message indicating which generators have been tripped. The value of this model is questionable and it should be used sparingly.

Model GNSCN3

The generator scanning and tripping model (GNSCN3), which is called by selecting *Dynamics > Simulation > Simulation Options....* and specifying the option *Scan for Generators Exceeding Speed Deviation* threshold from the dialog, scans all generator speed deviation to see if any exceed the threshold (which is specified in the dialog as percentage). When it finds a machine whose speed deviation exceeds the threshold, it either just monitors or monitors and trips it immediately and prints an appropriate message.

Model VIOLSCN

This model checks the bus voltages during dynamic simulation fault recovery and reports voltage violations if any.

There are two possible voltage violation checks - voltage recovery and voltage dip. These are collectively called the Voltage Violation check. The two checks can be selected independently.

The voltage recovery may have primary voltage criteria (i.e., voltage to recover above threshold V1 faster than t1 seconds after fault clearing) and secondary voltage criteria (i.e., voltage to recover above threshold V2 faster than t2 seconds after fault clearing).

The voltage dip check will be based on voltage threshold V3 and time t3 (seconds). Once voltage has recovered above threshold V3, it should not dip below that value for longer than t3.

For definitions of V1, V2, V3, and t1, t2 and t3, refer to Figure 25.3, "Voltage Violation Check".

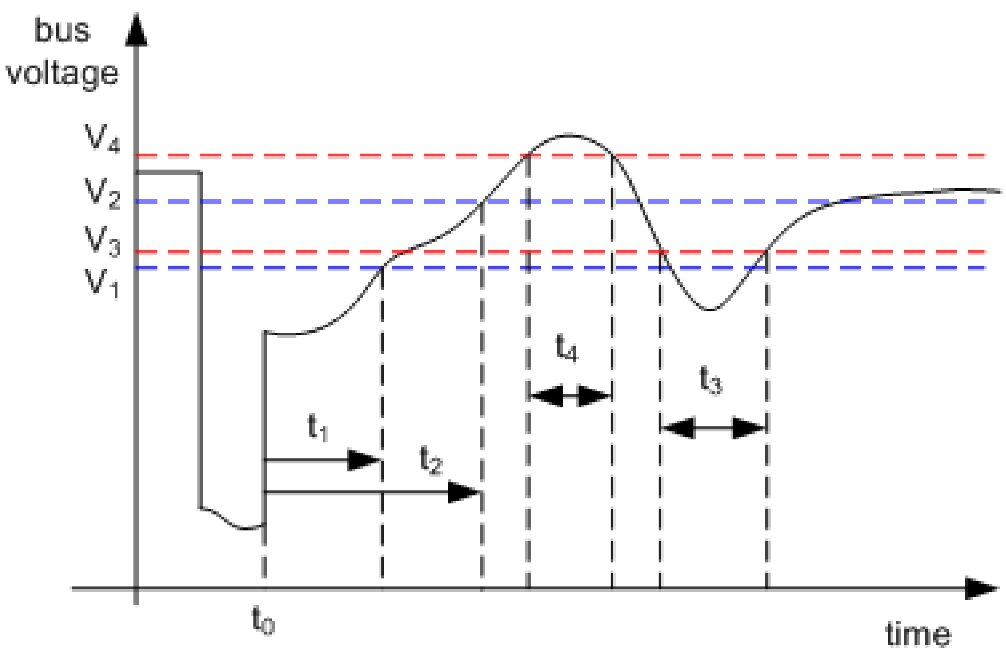


Figure 25.3. Voltage Violation Check

The dialog for selection of voltage recovery and voltage dip checks will be under Dynamics Simulation Options. Users can select the voltage recovery check and the voltage dip check independent of each other. Under the voltage recovery check, users can select just the primary recovery check or the primary as well as the secondary recovery checks.

Selection of the voltage recovery and voltage dip in the Dynamic Simulation Options window will not automatically trigger the voltage monitoring functions during the dynamic simulation.

In practice, the voltage violation checks (voltage recovery and/or voltage dip) should start after fault clearing. The fault clearing time is not pre-determined in a PSS®E simulation, but is rather a user-defined time that depends on the actual simulation being carried out. In view of this the triggering of voltage violation check will have to be done by the users.

The steps to be followed for performing voltage violation checks are as follows:

1. The first step is to select the required violation check – voltage recovery and/or the voltage dip from the Dynamics Simulation Options dialog and define the parameters V1, V2, V3, and t1, t2 and t3.

2. In order to trigger the voltage violation check functions during dynamic simulations, users have to select the Trigger Voltage Violation Check option, which is available under Disturbance menu.

The setting of voltage recovery and voltage dip checks as well as the triggering of violation check will be recordable.

Once the voltage check is triggered, the voltage recovery and/or voltage dip checks will be performed for all buses. When any bus has a criteria violation, PSS®E will print a message to the progress window. Additionally it will be possible to display the violation on the slider diagram.

25.4.2. Model SYSANG Called from CHSB

This model is extremely useful in monitoring the general results of a stability case. This model allows the user to put the following outputs in VARs for subsequent output:

1. Average angle.

2. Largest machine angle and its bus number.

3. Smallest machine angle and its bus number, and the angle spread — the difference between the largest and smallest machine angles.

The largest and smallest angle are extremely useful in helping to locate a machine going out of synchronism. Any of the subroutine arguments can be set to zero to bypass the logic and storage of that quantity.

When selected output channels from the activity CHSB dialog, channels are automatically created, the user can modify the names using *Edit>Dynamics/Network Date* dialog.

25.5. Playback Model 'TSTGOV1'

The TSTGOV1 model was developed to assist in the evaluation of the performance of the governor model. The model has two operational modes.

1. Determining the response of the governor model to a defined frequency input, such as specified in a grid code.
2. Determining the response of the governor model to a frequency input defined in a data file.

In either mode, the TSTGOV1 model injects the frequency into the simulation as the machine speed. The governor model will then see this frequency (speed) as its input signal and will respond according to the dynamics of the governor model.

This is accomplished by creating a simple one bus model as shown in Figure 25.4, "One Bus Test System". In this case, the bus number was chosen arbitrarily to be 101. In power flow, this bus must be a code 3 bus (i.e., a swing bus). A constant MW load must be added to the bus (the load should not be modeled as either constant current load or constant admittance load). The value of this load should be either the initial MW loading of the generator for test mode 1 above, or the value of the generator power at the beginning of the measurements for test mode 2. In either case, the bus voltage and load reactive power are not of concern. This is only a test of the power/speed loop and voltage does not play a role. Thus setting the generator scheduled voltage to 1.0 and the reactive power to zero is recommended, but not required. When the load flow is solved, the generator output will equal the load. Figure 25.4, "One Bus Test System" shows an initial loading of 264 MW on the generator.

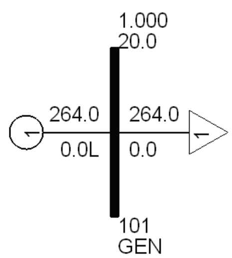


Figure 25.4. One Bus Test System

The TSTGOV1 model essentially simulates the governor response in an open-loop mode. That is, it breaks the accelerating power to speed loop by inserting the frequency deviation into the generator speed array at every time step. The governor model responds to this speed and adjusts mechanical power. To keep the system balanced, the bus load is adjusted at each time step in such a way that it follows the governor mechanical power output. This in turn ensures that the generator electric power output is the same as the mechanical power input minus any stator losses.

The TSTGOV1 model performs a linear interpolation to calculate the frequency at each time step in either operational mode. In test mode 2, the model will also calculate the value of the measured electrical power at each time step, also using linear interpolation. These values are stored in VARs allowing plotting if desired.

25.5.1. Use of TSTGOV1 to Simulate a Grid Code Frequency Shape

Primary reserves are intended to arrest the initial fall in frequency following a contingency (e.g. loss of a large unit or an interconnection tie). The ability of a unit to release primary reserves can be measured by artificially subjecting the unit to a test whereby "measured" frequency is of the form as illustrated in Figure 25.5, "Defined Frequency Excursion for Primary Response Calculation". Note that 60 Hz is used as the base frequency in Figure 25.5, "Defined Frequency Excursion for Primary Response Calculation", but the concept is equally applicable to 50 Hz systems.

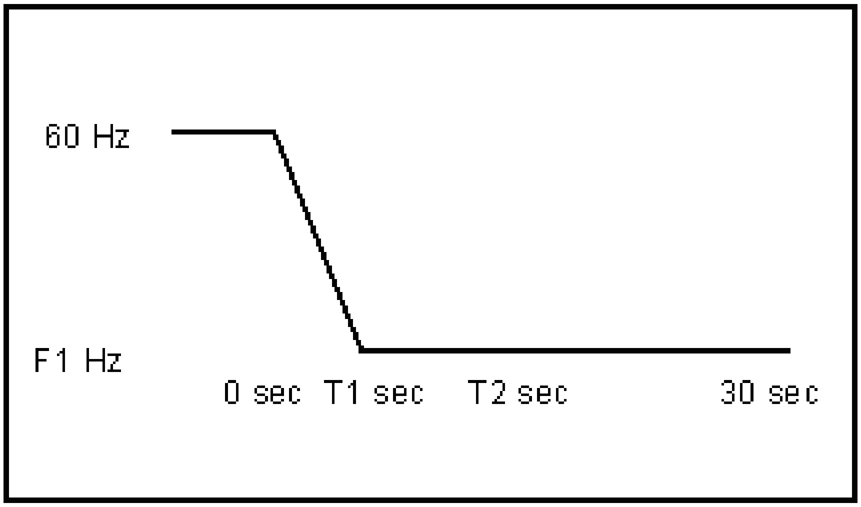


Figure 25.5. Defined Frequency Excursion for Primary Response Calculation

For example, one definition of primary response capability is defined as the unit's change in power output in response to this change in frequency, measured at T2 seconds and sustainable for an additional (30-T2) seconds. If the power output measured at T2 seconds is not sustained for the 30 second period, the primary reserve is the minimum power output reached during the period from T2 through 30 seconds. The frequency input curve is intended to represent the system's marginal frequency response following critical contingencies. Parameters in the frequency input curve would be selected to provide some margin to the frequency at which load shedding is initiated.

Secondary reserves are intended to bring frequencies back to acceptable levels following unit outages, i.e., frequencies at which most generating units are expected to be able to operate indefinitely, and high enough so as to reasonably overcome additional unit outages should they occur in the brief period before frequency is restored through AGC action. The ability of a unit to release secondary reserves is measured by extending the primary reserve test as shown in Figure 25.6, "Secondary Response Test", again using 60 Hz as the base frequency.

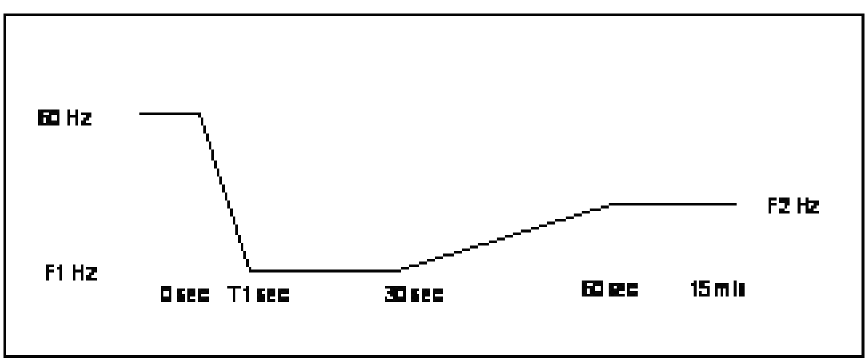


Figure 25.6. Secondary Response Test

Secondary response capability is determined, for example, by the lowest governor response throughout the 30 seconds to 15 minutes period, and is meant to bring the frequency back to F2 Hz within 1 minute after the contingency, and keep it there until AGC/operator action restore frequencies to nominal.

Of course, other definitions are used by different power systems. Other shapes can be represented by proper selection of the parameters. If a more complex shape is needed, it can also be defined using an input data file as explained below.

25.5.2. Use of TSTGOV1 to Simulate a Measured Frequency Response

The following sections illustrate the two methods to use the model and the data required to perform the respective simulations.

Model Data Input

Data records for user-written models of this type must be in the following format (see the section on Dynamics Model Raw Data File Contents in the PSS®E Program Operation Manual):

BUSID 'USRMDL' IM 'model name' IC IT NI NC NS NV data list /

Where:

BUSID and IM are the external bus number and the machine id of the machine that is being subject to test.

IC Is the user-model type code, which in this case would be 505 since the model is classified as a "Machine Other model".

IT determines the placement in CONET. In this case, IT is 0 since the model does not need to be called during dynamic simulation network solution.

NI Is the number of ICONs used by the model (NI = 2).

NC Is the number of CONs used by the model (NC = 6).

NS Is the number of STATEs used by the model. (NS = 0).

NV Is the number of VARs used by the model. (NV = 2).

data list specifies NI ICONs, followed by NC CONs.

The data record format for the TSTGOV1 model is thus:

Bus# 'USRMDL' GenID 'TSTGOV1' 505 0 2 6 0 2, ICON(M) to ICON(M+1), CON(J) to CON(J+5) /

Where the model uses 6 CONs:

CON(J) = TSTART1 (SECONDS)

CON(J+1) = TEND1 (SECONDS)

CON(J+2) = FREQUENCY1 (HERTZ)

CON(J+3) = TSTART2 (SECONDS)

CON(J+4) = TEND2 (SECONDS)

CON(J+5) = FREQUENCY2 (HERTZ)

The model uses 4 ICONs:

ICON(M) = Flag for grid code test or input from a file

= 0 for grid code test (trapezoidal frequency shape

= 1 to read frequency and power data points from a file

ICON(M+1) = LOAD ID (enter in single quotes, e.g., '1')

And the model uses 2 VARs:

VAR(L) = Measured frequency from file

VAR(L+1) = Measured Pelec of generator from file

As an example for operation in the grid code mode, the data record format for the TSTGOV1 model using the shape in Figure 25.6, “Secondary Response Test” is given below for a 50 Hz system where F1 is 49.4 Hz, F2 is 49.6 Hz and T1 is 5 seconds and the other times are shown in the figure. In this case, both the generator and load IDs are 1.

101 'USRMDL' 1 'TSTGOV1' 505 0 2 6 0 2 0 '1' 0.0, 5.0, 49.4, 30.0, 60.0, 49.6 /

As an example for operation in the mode to input data from a file and to determine the response of the governor model to this frequency input, the data record below can be used for the TSTGOV1 model. In this example, both the generator and load IDs are 1. Note that there is no need to input the constants to define the trapezoid and zeros are typically entered.

101 'USRMDL' 1 'TSTGOV1' 505 0 2 6 0 2 1 '1' 0.0, 0.0, 0.0, 0.0, 0.0, 0.0 /

When the model is used to read data from a file, the data has to be supplied in a file whose name is 'FTIME1.DAT'. The file must be present in the folder from where PSS®E is started. The format of this data file must be one data record per line, with each data record containing the measured data in this order:

Time, Frequency, Power

The data is read free format. The units of time should be seconds; the units of frequency should be Hz, and the units of power are MW.

There is no restriction in the number of data points supplied in the data file 'FTIME1.DAT'.

The user does not need to calculate and enter the number of data points as the program automatically reads until the end of the file is reached.

25.5.3. Example of the Use of TSTGOV1 to Simulate a Measured Frequency Response

The simulation is performed in the usual manner, bringing in a snapshot containing the model data and a load flow case with the one bus model of 1. Load conversion is not necessary and should not be performed. The load must be a constant MVA load. The snapshot should contain the generator, excitation, and governor models for the unit to be studied and the TSTGOV1 model.

When the simulation is initialized using activity STRT, PSS ®E will read the measurement data contained in the file FTIME1.DAT and perform an initialization. The user simply needs to run out to a time consistent with the length of time in the measured data. That is, there is no disturbance applied by the user - the disturbance is inherently a part of the frequency data driving the simulation.

25.6. Equipment Monitoring Models

There are several PSS®E models provided that monitor specific equipment for output purposes only; they do not affect its solution. These models are not recognized by activity DYRE; they are ignored and print an appropriate message if the equipment is not found.

25.6.1. Models Set Up by Activities CHAN and CHSB

Special subroutines have been set up for requesting certain output quantities, not normally stored by PSS®E. These subroutines are automatically called during a simulation if the output is requested by activities CHAN and CHSB.

Model VOLMAG

This voltage monitoring model (VOLMAG) calculates the magnitude and angle at a bus. Storage of either quantity can be bypassed by setting the calling argument for each to zero.

Model RELAY2

RELAY2 calculates the apparent impedance seen from the from bus bus side and checks to see if circuit is within circles defined in Figure 25.2, "Standard RELAY1 and RELAY2 Relay Circles". If the storage locations are not set to zero, the apparent impedance is saved in the appropriate loca tion.

Model FLOW1

FLOW1 calculates the MW, Mvar, and MVA flowing on the circuit specified out of the from bus. To calculate total flows, the user should enter a circuit of –1. Flows include line shunt component at the from bus end. By giving a zero storage location the storing is bypassed.

Model RELAY3

RELAY3 calculates the apparent impedance seen from the from bus side looking into a three-winding transformer and checks to see if the apparent impedance is within the circles defined in Figure 25.2, "Standard RELAY1 and RELAY2 Relay Circles".

Model FLOW3

FLOW3 calculates the MW, Mvar, and MVA flowing into the winding from the from bus on a three-winding transformer. Flows include the magnetizing admittance component at the from bus end.

25.6.2. Additional Monitoring Models

The following models can be added to subroutine CONET manually (see the *PSS®E Program Operation Manual*, Advanced Uses of CONEC and CONET).

Model FLOW2

FLOW2 is identical to FLOW1 except that line shunt components are not included in the calculation.

Model FLOW

FLOW combines the features of FLOW1 and FLOW2 by ICON(I+3), which can be set to 0 to ignore the shunt component or 1 to include it.

Model GENTMC

GENTMC calculates the current magnitude and angle on machine base, MBASE, at the machine terminals.

Model GENTMZ

GENTMZ calculates the apparent impedance on machine base, MBASE, from the machine terminals looking out into the system.

25.7. Reactive Switching Devices

Beyond the constantly varying reactive devices commonly called static var devices described in an earlier section, the use of high-speed switches and thyristors to gate on large blocks of either reactors or capacitors is becoming more common. Various unique schemes defining when these devices will surely be proposed and implemented. This section describes models provided in the PSS®E library.

25.7.1. Model SWCAP

SWCAP is a simple model of a capacitor bank that is switched onto a bus if its voltage falls below a setpoint. SWCAP is completely independent of the power flow switched shunt elements. The undervoltage relay picks up instantaneously when the bus voltage falls below the voltage setpoint, CON(J+1), and the circuit breaker closes after a delay specified in CON(J+2). The delay may be specified as zero to force instantaneous closure of the breaker when voltage falls below the setpoint.

The switched capacitor may be locked out by setting ICON(I) to a zero or negative value. After being switched on, the capacitor remains on until removed manually by the user. The capacitor may be switched off by setting ICON(I) to zero or a negative value and setting VAR(K) to 9999. Because the capacitor is off in the initial condition, SWCAP requires no special treatment in initialization, except that the setpoint voltage, CON(J+1), should be less than the initial condition voltage at the bus.

25.7.2. Model SWSHN1

SWSHN1 was designed to use the data stored in power flow switch shunt arrays. It requires the switch shunt to be at a step and the switch shunt control mode to be discrete (i.e., MODSW=1). To be consistent with generator and static var models, this model ignores the remote bus specified in the power flow.

Pickup timers initiation is dependent on data input. The model allows three different choices. If the user inputs 0 for the first quantity, the high-voltage pickup and low-voltage pickup will be the values specified in the power flow. The second input choice is to specify a voltage deviation of less than or equal to 0.5 for the first CON. The model expects a negative voltage deviation value for low-voltage switching. Finally, the input values can be per-unit voltages above and below which pickup times activate. The model prints the voltage deviation if the pickup timer is activated by deviation; otherwise, it prints the bus voltage. The pickup timer instantaneously resets if voltage comes within limits. After the switch timer is activated, it cannot be reset. Both the pick-up timer and the switch timer reset after each switching action.

The model allows only one timer to be activated at a time either for the pickup or the switch. One step at a time will be switched on and all steps at a block must be on (or off) before the model goes on to the next block. If it is intended that this model either trip all capacitors or apply all reactors at a bus in a single step, then the user must modify the switched shunt data in the power flow to have only one block with one step having the proper capacitive or reactive value.

The model allows a different time to be specified for closing and opening of switches, so a high-speed solenoid close can be represented. Finally, the user may enter a limit on the number of switches allowed. A large number should be entered (99) to deactivate this feature.

25.8. FACTS Devices

Flexible ac Transmission System (FACTS) devices constitute a not yet well-defined class of equipment that resulted from advances in the 80's and early 90's in the field of forced-commutated thyristors (gate turn-off (GTO), MOS-controlled transistors (MCT), and insulated gate bipolar transistors (IGBT)). As opposed to the conventional thyristors found in HVDC converters and static var devices, forced commutated thyristors allow switching at any point of the ac sine wave. The mechanics and control of such high-speed electronic switches is beyond the bandwidth of PSS®E and is therefore not modeled. Their application, however, is leading to a new generation of equipment that can have a significant impact on the rotor-angle dynamics of interest in PSS®E.

Because FACTS devices are only starting to make their way into the power industry, their configuration and control is still a matter of debate. For this reason, the models presented in this section are simplified versions of the actual equipment and are only applicable for feasibility or scoping studies. They do include, however, some of the main features and limitations that need to be considered by the system planner contemplating application of such devices.

25.8.1. CRANI (also known as TCSC)

In these devices, a branch impedance is adjusted by either quick connection and disconnection of series capacitor elements or by thyristor control of a series reactor that may or may not be in parallel with a series capacitor or reactor. The model assumes the impedance adjustment to be both continuous and linear.

The model can be applied to any branch in the network model except for transformers and zero-impedance lines. Compensation limits X_{max} and X_{min} can take any positive (reactor) or negative (capacitor) value, as long as their range includes the initial branch reactance.

Upon initialization, model output VAR(L+1) and VAR(L+2) are set equal to the power flow branch reactance. Because of the washout (T_W), controller output is zero in the steady-state. As the simulation progresses, the effective branch reactance is modified in response to changes in controller input VAR(L), which must be set by appropriate assignment statements in CONEC.

The user should be aware that changes in effective branch reactance are attained by a combination of both branch reactance changes and current injections at the to and from buses. It is therefore incorrect to monitor with calls from activity CHAN, branch magnitudes such as active and reactive power or apparent impedances across the device. Instead the user should instruct activity CHAN to monitor these magnitudes along branches in series with the CRANI model. These branches can include zero impedance lines on each end of the CRANI device and would render a true picture of the flows going into and out of the device.

25.8.2. Static Condenser Model - CSTATT and CSTCNT

In very simplified terms, a STATCON (Static Condenser) consists of a dc capacitor shunt-connected to the ac network by means of high-speed electronic switches. Given a sufficient number of thyristor bridges it is possible for a converter to synthesize a controlled ac voltage with acceptable harmonic content behind the converter transformer reactance.

For pure reactive control, this ac voltage is kept in phase with terminal voltage. Because ideally there is no net exchange of active power with the network, the dc capacitor remains charged at the desired level. In practice, converters have losses that tend to discharge the capacitor. In order to replenish the capacitor charging, the synthesized voltage is controlled to slightly lag the terminal voltage, and thus maintain a small flow of active power between network and condenser. By this same mechanism capacitor voltage is controlled, which in turn determines the magnitude of the internal voltage and thus determines the reactive exchange with the network. In CSTATT as well as CSTCNT these active power flows are assumed negligible, only reactive power exchanges are modeled.

The dynamic models of CSTATT and CSTCNT are the same. The difference between CSTATT and CSTCNT is that, for power flow CSTATT is modeled as a sychronous condenser (i.e., with no active power output), while CSTCNT is modeled as a FACTS device. Care must be taken to insure that the power flow current output does not exceed CSTATT current limitations. In order to prevent contributions to short-circuit, a high value of ZSORCE is recommended.

In the CSTATT and CSTCNT model, the Condenser is modeled as a controlled voltage behind a transformer reactance. The ac voltage is kept in phase with terminal voltage; i.e., a lossless STATCON is assumed. The resulting STATCON current is limited to the temporary and steady-state overload limitations of GTO converters.

The STATCON dynamic model (CSTATT and CSTCNT) follows the guidelines proposed in Reference [1] . Inputs to the model are voltage reference, and terminal voltage. Because CSTATT is modeled as a generator in power flow, this model can also accept power system stabilizer output (PSS_{out}). Output of the model is STATCON reactive current. Positive current corresponds to STATCON performance as a capacitor.

The model consists of a voltage regulator with transient gain determined by time constants T_1 through T_4 and, more importantly, the integrator gain K. Per-unit steady-state gain is equal to the inverse of Droop.

AVR gain can be adjusted to attain a conservative crossover frequency of 25 rad/sec:

$$K = \frac{25}{\Delta E_{term} / \Delta E_{int}}$$

$\Delta E_{term} / \Delta E_{int}$ is the sensitivity of terminal voltage to internal voltage, and is equal to:

$$\frac{\Delta E_{term}}{\Delta E_{int}} = \frac{Z_{thev}}{Z_{thev} + jX_{transf} \times \frac{SBASE}{STATCONBase}}$$

where Z_{thev} is equal to the inverse of the minimum expected per-unit (SBASE) short-circuit level at the unit terminals.

The model output is subject to limitations of internal voltage and converter current. Typical values for these limitations are:

I_{max}

= 1.25 pu (i.e., a 25% transient overload capability is assumed)

V_{cutout}

= 0.2 pu

E_{limit}

[1]"FACTS Device Benefit Assessment on Commonwealth Edison's Power System, Volume 2: A Study of STATCON Use to Improve Voltage Stability and Power Quality at Schaumburg Substation". EPRI TR-101933 Volume 2, by General Electric.

= 1.2 pu

Other typical model parameters are:

X_{transf}

= 0.1 pu

Droop

= 0.01 to 0.05 pu

$T_1 = T_2$

$= T_3 = T_4$

Accl

= 0.5

25.8.3. CSMEST

The EPRI CSMEST model was developed with EPRI sponsorship via RP2123-27. It simulates the dynamic characteristics of a SMES. A SMES can be used to improve first-swing (transient) stability, to provide damping, and/or to limit frequency excursions. Voltages are normally controlled by an AVR-driven reactive path.

First-swing stability applications will normally require stepping the supplementary signal (VAR(L)) either manually or by a relay model. Damping can be provided by modulation of SMES active and/or reactive powers. Active power modulation is attained by connection (via CONEC statements) with supplementary signal controller models such as CHAAUT. Reactive power modulation is attained from any PSS model such as model STBSVC. Finally, governor action can be obtained from properly adjusted HVDC controller models driving the active power path. Model CHAAUT, for example, allows simultaneous damping and governor control of the active power path.

Because the converter can handle active and/or reactive power but has a finite thermal capability, the question of sharing converter capability among active and reactive power arises. Because active power is the primary purpose of the SMES, it is given priority as shown in the block diagram.

Unlike battery devices, in which energy capacity is likely to be much larger than that required during a simulation, a SMES device may be precisely sized to a particular application. In the EPRI CSMEST model coil energy is modelled explicitly in terms of coil inductance and coil current. A trial and error process may be needed in SMES sizing studies to arrive at the appropriate coil energy capacity. Likewise, experimentation may also be necessary to size the converter.

The EPRI CSMEST model covers two basic types of SMES converters; the voltage-source and the current-source converters:

- The voltage-source type is characterized by having a chopper+capacitor interface between the coil and the converter. Much in the way of a STATCON converter, the SMES converter can be visualized as sequentially switching the dc voltage on the capacitor so as to synthesize a controlled ac voltage behind the converter transformer reactance. This internal ac voltage is controlled to regulate both magnitude and phase with respect to the device terminals. Control of internal voltage magnitude drives reactive power interchange with the network. Control of internal phase angle allows regulation of active power exchanges with the ac system.

Were it not for the chopper, active power exchanges between capacitor and network would quickly exhaust or overload the capacitor. It is the role of the chopper to maintain appropriate voltage (charging) levels on the capacitor by selectively redirecting current from the coil to the capacitor. The chopper can also be viewed as controlling coil average dc voltage by rapidly cycling between +/- applications of the capacitor dc voltage on the coil terminals. This voltage-source design has the advantage that its reactive power capability is independent of coil charging level, functioning as a Static Condenser (STATCON) in the event of complete exhaustion of the coil energy (current) levels.

- In a current-source SMES, coil and converter are connected without any interface. Such a design is best visualized as an extension of conventional HVDC technology. The main difference from HVDC converters is that application of self-commutating thyristor technology allows operation in any of the four power quadrants. While conventional HVDC converters can only consume reactive power, self-commutating converters can also *generate* reactive power. As in HVDC terminals, converter ac current is proportional to dc (coil) current. Ac current is controlled by having two bridges in series on the dc side but in parallel on the ac side of the converter. Zero current at the SMES ac terminals, for example, is attained by having the current on each of the two bridges 180 degrees out of phase from each other. Maximum ac current, however, is still dictated by coil dc current level. Therefore, one disadvantage of this design is that both active *and* reactive power capability are limited at low coil charge levels.

In both voltage- and current-source converters the speed of response is very high and a SMES can make corrections to the ac system much more quickly than synchronous machines and somewhat more quickly than conventional static var compensators.

The EPRI CSMEST model can simulate both voltage- and current-source SMES devices. The SMES is modeled as a generator in the power flow. As in the STATCON model, it is recommended that a high value of ZSORCE be used to eliminate contributions to short-circuit.

Referring to the block diagram:

- VAR(L) drives the SMES active power path and should be connected by the user to control logic or controller model output via CONEC assignments.
- P_{init} (VAR(L+1)) allows initialization of the model at other than zero active power output. This, however, will result in an `initial condition suspect` message that should be disregarded.
- IDC0 corresponds to initial dc current and, together with KR, drives a slow reset action that, for 0 power order (VAR(L)+VAR(L+1)=0.), will return the coil current to IDC0 with time.
- P_{max} is a power limit to be used at the user's discretion.
- VDCMAX and VDCMIN take into account the maximum voltage capability of the converter and coil. This block can also be used to model limitations on maximum rate of change of coil current; limitations than can be expressed in terms of maximum dc coil voltages.
- I_{dcmax1}, I_{dcmax2}, I_{dcmin1} and I_{dcmin2} limit coil currents to prevent coil overcharging (I_{dcmax}) or undercharging (I_{dcmin}). To prevent discontinuities, the limits are applied gradually.
- I_{acmax} models converter current limitations; similar to those modeled in a STATCON device. These limits are not applicable to current-source devices because, by design, the converter must withstand maximum dc current and its corresponding ac current.
- $K_x V_{acx} I_{dc}$ models low coil current limitations in current-source converters. Because for such converters maximum ac current is proportional to dc current both active and reactive power outputs are restricted

at low charge levels. In a voltage-source converter this factor is used to model the inability to sustain maximum dc voltages at low ac voltages.

- Active power output divided by coil current leads to actual (current-source converter) or average (voltage-source converter) dc voltage on the coil terminals. This dc voltage is integrated by inductance to obtain coil current.
- The reactive path is comprised of a voltage regulator model. The voltage regulator is similar to that employed in the STATCON model. Reactive current, instead of internal voltage, is under direct control of the regulator. Converter current limits are enforced by the nonwindup limits on the K/S integrator. These current limits are the reactive counterpart of the current limits in the active power path, and are designed to give priority to active over reactive power orders. As in the STATCON case, the gain K can be adjusted to attain a crossover frequency of 25 rad/sec:

$$K = \frac{25}{\Delta E_{term} / \Delta I_{reac}}$$

$\Delta E_{term} / \Delta I_{reac}$ is the sensitivity of terminal voltage to SMES reactive current, and is equal to:

$$\frac{\Delta E_{term}}{\Delta I_{reac}} = \frac{Z_{thev} \times SMESBase}{SBASE}$$

where Z_{thev} is equal to the inverse of the minimum expected per-unit short circuit level at the SMES terminals (on system base, SBASE).

Typical data for a voltage-source SMES can be derived as follows:

- MBASE is selected as maximum coil current times maximum coil voltage. Their product is typically much larger than the SMES MW rating. dc voltage and current bases are also set to their maximum permissible values at the coil.
- Inductance, L, is derived from the Power and Energy ratings of the device. Assuming a rated per-unit power of P_{max}, and that rated energy is defined as the maximum time, T, rated power can be delivered; inductance, L, can be derived from the energy balance equation:

  $0.5 \times L \times (I^2 - P^2max) = P_{max} \times T(sec)$

P_{max} is the SMES MW rating in pu on MBASE (typically much smaller than 1.), but is also equal to the minimum per-unit current at which rated power can be delivered (i.e., with maximum dc voltage (1 pu) applied to coil terminals).

- By definition of per-unit bases, VDCMAX and VDCMIN are 1, and -1, respectively.
- IDCMAX1, IDCMAX2, IDCMIN1, and IDCMIN2 are set to 1, 1.01, 0.02, and 0.01, respectively.
- I_{acmax} is calculated as P_{max}/Power Factor
- The K factor in $K_x V_{acx} I_{dc}$ is set to 1.
- In a SMES solely meant for damping system oscillations, IDC0 could be set midway between minimum and maximum energy levels available at rated power:

$$IDCO^2 = \frac{(P_{max}^2 + I^2)}{2}$$

- Other model parameters are typically set as follows:

  $K_R = 0$

  $T_1 = T_2 = T_3 = T_4$

  $V_{MAX} = 9999$, $V_{MIN} = -9999$

  Droop = (0.01 to 0.05)/I_{acmax}

25.8.4. CBEST (EPRI Battery Energy Storage)

The EPRI CBEST battery model was developed with EPRI sponsorship via RP2123-27. It simulates the dynamic characteristics of a battery. As in the case of SMES devices, batteries can be used to improve first-swing (transient) stability, provide damping, and/or limit frequency excursions. Like in the EPRI CSMEST model case, judicious selection of external signals is required to model battery performance in any of these functions.

A voltage-source converter is the natural choice for a battery energy system. Power into and out of the battery is controlled by adjusting battery terminal voltage. The converter design provides some degree of independence between dc voltage and synthesized voltage behind converter reactance. This allows independent control of active and reactive powers.

The active power path in the EPRI CBEST model simulates power limitations into and out of the battery as well as ac current limitations at the converter. The model assumes that the battery rating is large enough to cover all energy demands that occur during the simulation. Nevertheless, the model provides an approximate means of computing such requirements by separately computing energy out of and into the model, and by adding them in VAR(L+4). The computations take into account battery inefficiencies both in the retrieval and in the storage of energy.

The reactive power path is identical to that in the EPRI CSMEST model. AVR gain computation follows the same guidelines as those for the latter model.

The BES is modeled in the power flow as a generator with a large ZSORCE impedance. The EPRI CBEST model allows initialization at other than zero power factor but will alarm nonzero state derivatives on the energy-computing states.

If MBASE is set equal to the battery power rating, Pmax is set to 1. I_{acmax} is set to P_{max}/Power Factor. AVR parameters are set as in the SMES model.

Assuming an 80% turnaround efficiency, retrieval (OutEff) and storage (InpEff) efficiencies would typically be set to 1.1 and 0.9, respectively.

25.8.5. CDSMS1

The CDSMS1 model of a D-SMES (Distributed Superconducting Magnetic Energy Storage) device was developed by PTI in conjunction with American Superconductor Corporation (AMSC), the device's manufacturer. A D-SMES device, a combination of a SMES system with a voltage-source IGBT converter, is capable of fast, effectively controlled, and near instantaneous injection of both real and reactive power into the system. Using D-SMES is considered as a new option to solve plenty of transmission, generation, and distribution system problems, including improvement of voltage and angular stability, increasing power transfer capability of existing grids, damping oscillations, load leveling, etc.

As in the CSMEST model, in CDSMS1 there exists active (P-path) and reactive (Q-path) power paths. The model represents the device's capability of injecting or consuming active (POUT) and reactive (QOUT) power to hold the voltage at a controlled bus to a desired level (AVR function). The voltage at a controlled bus is compared against four threshold values V1, V2, V3, and V4. The device's controls monitor the voltage to be held, either at the D-SMES own bus (VDSMES) or remote (Vremote), and determine whether it is necessary to inject active and inject or consume reactive power. Active power injection can also be caused by an auxiliary damping signal, PAUX. In the future the device, following the damping signal, will also be able to absorb active power from the system and dissipate it in resistor banks. This device capability is under development, therefore only its simplified representation is provided.

Any active power injection is formed by discharging the D-SMES magnet. The process of discharge can be either uninterrupted or repetitive (see model diagram, *The Magnet Discharge Curve*, datasheet CDSMS1), but during any discharging interval the coil current IL is ramping down linearly having a given slope under a constant coil voltage VDC. Reactive power injection is formed by the device's IGBT voltage-source converter. Because the control of its high-speed electronic switches is beyond the bandwidth of PSS®E, it is not modeled. There also exists an overload capability activated when the controlled voltage is in a specific range; the capability's definition is given by the Overload Diagram of datasheet CDSMS1. To have the device's performance represented more accurately, some time constants (TON, TOFF) are taken into account that determine the minimum time intervals needed to activate the magnet or shut it down after the previous switching operation.

As the model is developed for the device manufactured by AMSC, recommended parameter values and ranges correspond to D-SMES systems currently in production. Comments are given with reference to the D-SMES Model Diagrams and Data Sheets and only for specific model parameters that may need clarifying.

Model ICONs:

Notation	Description	Application
CONV_TYPE	Converter type: 0 for current-source converter, 1 for voltage source converter	Set to 1 only.
IBUS_CONTR	Number of remote control bus.	Ignored if ICON(M+3) = 0
BOOST_CONTR	Boost control flag: 0 if no, 1 if yes	Yes allows the model to change the voltage set point.
VOLT_SEN_LOC	Voltage control sensor location flag: 0 for the IBUS, 1 for controlling the remote control bus	
TURN_ON_VOLT	Voltage control flag: 0 if no, 1 if yes	No means that the voltage thresholds V_i (i = 1, 2, 3, 4) are ignored by the active power path, normally set to 1.
TURN_ON_POWER	Active power (damping control) flag: 0 if no, 1 if yes	No means that PAUX signal is ignored. AMSC is looking to future technology where D-SMES systems can be used to dampen phase-angle swing and improve small signal stability. This application has not yet been examined deeply enough

Notation	Description	Application
		to provide commercial solution. Setting to 0 is recommended.
TURN_ON_P	Active power output flag: 0 if no, 1 if yes	No turns off the active power path (POUT=0).
TURN_ON_Q	Reactive power output flag: 0 if no, 1 if yes	No turns off the reactive power path (QOUT=0).

Model CONs (notation of the diagrams is used):

Notation	Description	Application
SRATED	rated D-SMES MVA, must be equal to MBASE	
VDC	nominal coin voltage (kV)	
IINIT	Initial dc coil current (kA)	Parameters of the Magnet Discharge Curve given in datasheet CDSMS1. INIT = 1.05 kA, IMIN = 0.4 kA, TDIS = 0.6 sec for AMSC systems currently in production.
IMIN	Minimum dc coil current (kA)	
TDIS	magnet full-discharge time (sec)	
TON	Minimum time (sec) that real power injection must remain off before it can be turned back on after being turned off.	A delay that is established to avoid 'ringing' in the magnet, i.e., quickly turning the real power injection on and off. TON = 0.1 sec for AMSC systems currently in production.
TOFF	Minimum time (sec) that real power injection must remain on after it is turned on.	A delay that is established to avoid 'ringing' in the magnet, i.e., quickly turning the real power injection on and off. TOFF = 0.1 sec for AMSC systems currently in production.
V1	voltage threshold (pu)	Voltage thresholds must be V1 > V2 > V3 > V4. Typical values in per units are 1.03 to 1.05 for V1, 0.95 to 0.97 for V2, 0.9 for V3, and 0.5 for V4.
V2	voltage threshold (pu)	
V3	voltage threshold (pu)	
V4	voltage threshold (pu) (>0)	
KAVR	AVR (Q-path) gain	Constants of the automatic voltage regulator that govern the response time of the model. To model quick response, a relatively high gain is required (about 700). This high gain has the effect of overrunning the effect of the time constants, therefore, for simplicity, it is recommended to set T1 = T2 = T3 = T4 = 1.0 sec.
T1	AVR time constant (sec)	
T2	AVR time constant (sec)	
T3	AVR time constant (sec) (>0)	
T4	AVR time constant (sec) (>0)	
AVRDROOP	AVR droop	Droop setting of the automatic voltage regulator.
PAUX_THRESH	PAUX threshold (MW) (>0)	A parameter that deals with the as of yet undeveloped small signal

Notation	Description	Application
		damping capability of the systems. Disabled if TURN_ON_POWER is set to 0. Set to 0.1 MW for all AMSC systems currently in production.
TOVLD	time interval of overload, when MVA output limit is maximum – SLIMMAX (sec)	Overload parameters referring to the Overload Diagram of datasheet CDSMS1. Recommended values are TOVLD = TBACK = 1.0 sec, KOL > 200%.
TBACK	time interval when MVA output limit SLIM is ramping from maximum value SLIMMAX to nominal value SRATED (sec)	
KOL	overload parameter (percent)	
TBOOST_BEG	boost control starting time (sec)	Boost voltage control parameters. Setting TBOOST_BEG to a value greater than the simulation time interval disables the two other parameters.
BOOST_DUR	time interval when the boost control is active (sec)	
STEP_VREF	voltage reference step used by the boost control (pu)	
KOV	parameter determines the step-up transformer voltage when the remote bus control is abandoned (percent)	The maximum over voltage level for the low-voltage winding of the D-SMES step-up transformer. If during a simulation the remote bus voltage Vremote is currently under control and the level of KOV is achieved, the device control abandons controlling the remote bus voltage and to starts controlling the D-SMES terminal voltage VDSMES. Recommended is the value of 110%.
VQMAX	maximum limit for AVR state 2 (pu)	
VQMIN	minimum limit for AVR state 2 (pu)	
IACMAX	maximum limit for the D-SMES ac current (pu)	The maximum ac current limit is determined mainly by the overload parameter KOL. IACMAX is an additional limit that helps to keep the output of the systems within capabilities. Recommended is a value slightly larger than the KOL.
PMAX	maximum limit for POUT (pu on MBASE)	
PMIN	minimum limit for POUT (pu on MBASE)	

An arbitrary number of D-SMES models may be connected to any bus. The model is provided with both state space and extended term simulation mode. The D-SMES device, although modeled as a FACTS device, is initialized like an electric machine and also treated as a machine in power flow calculations. In the power flow case MBASE = SRATED, ZSOURCE = 0 + j99999 to avoid inadequate device's contribution in short circuit currents of the system. PGEN must be set to 0, QGEN is set at user's discretion. However, the value of QOUT should be coordinated with the voltage thresholds V_i (i = 1, 2, 3, 4), otherwise it may adversely affect the initialization, and the IACMAC limit, otherwise QOUT will be changed during the initialization to match the limit.

25.8.6. SVSMO1U1 - Model of continuously controlled SVC

The block diagram of the PSS®E SVSMO1U1 model for a continuously controlled SVC is shown in Figure 25.7, "SVSMO1 Block Diagram".

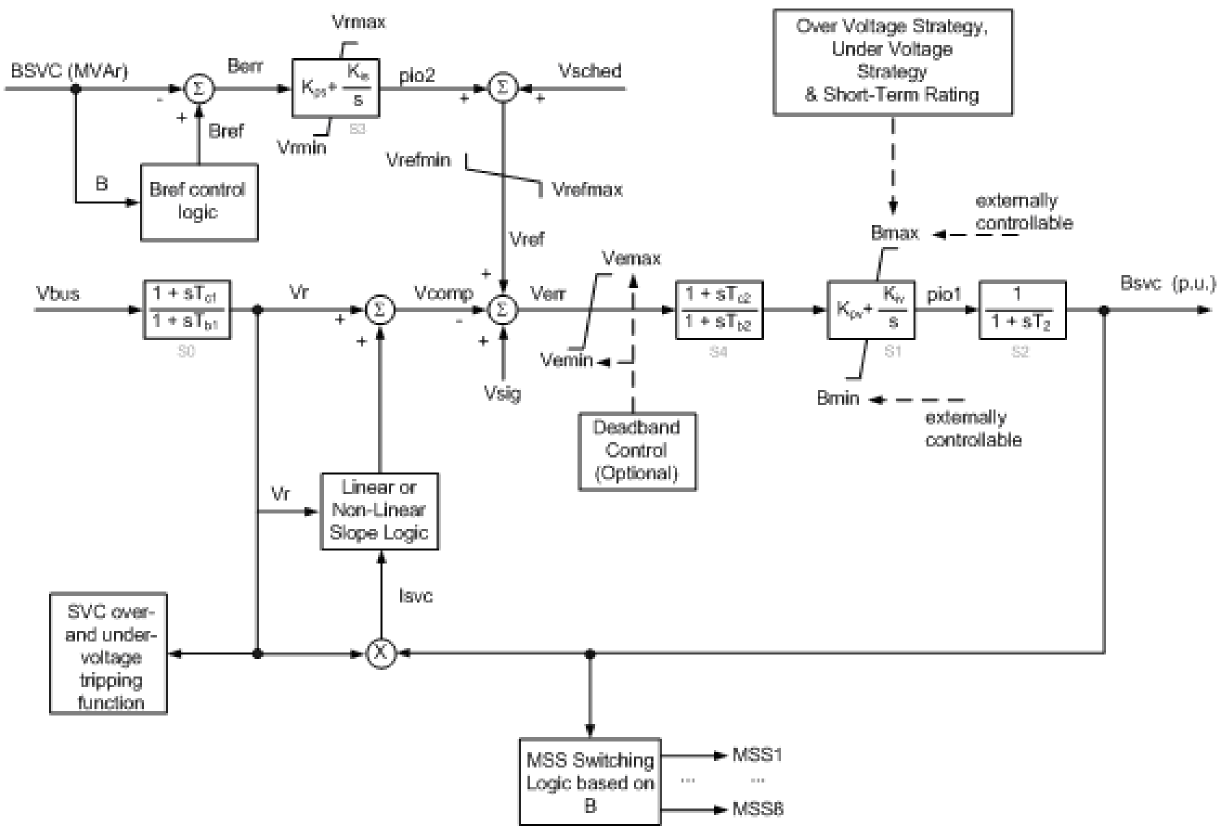


Figure 25.7. SVSMO1 Block Diagram

The main features of the model are:

- Proportional-Integral Primary Voltage Regulation Loop with gains Kpv and Kiv.
- Slow Susceptance Regulator: The PI regulator with gains Kps and Kis is the slow susceptance regulator which slowly biases the SVC reference voltage between the values of vrefmax and vrefmin to maintain the steady-state output of the SVC within the bandwidth of Bscs and Bsis.
- Non-Linear Slope/Droop: If the parameter flag2 is set to 0 then a standard linear droop of Xs1 is assumed, as is typically in most designs. Alternatively, by setting flag2 to 1, one can use a three piece piecewise

linear droop setting. This can be used to make the SVC non-responsive in a given bandwidth, similar to deadband control. This control, however, is more susceptible to limit cycling if not properly tuned.

- Optional Deadband Control.

Note: The deadband control, slow susceptance regulator, and non-linear droop are all intended for the same purpose - maintaining the SVC at a low steady-state output when the system voltage is within a given bandwidth. However, these three control strategies achieve this in quite different ways. Thus, for stable and suitable control response it is highly recommended to never use any combination of the deadband control, slow-susceptance regulation and non-linear slope/droop. Only one of the three should be used in the control strategy. The model checks for this condition during initialization and does not allow using combinations of these controls.

- Protection: The over/under-voltage strategies and over/under-voltage trip points.

- Short-term rating: the SVC output can exceed its continuous rating up to a given amount for a short time period.

- Mechanically Switched Shunt (MSS) Logic: detailed MSS logic is implemented which allows for automated MSS switching based on the SVC VAr output. Two thresholds (typically, one for fast switching and one for slower switching) are implemented with different delays on switching. The MS capacitor discharge time can also be set, i.e. time the MSC must be switched off before it can be switched back on. The MSS breaker delay is also modeled. The models can handle up to 8 MSSs: reactors and/or capacitors.

Note: the MSS switching must be properly coordinated with the slow-susceptance regulator, if used. Typically, to avoid excessive MSS switching, the slow-susceptance regulator time constant is chosen such that it acts first to bring the SVC to within the first threshold. If it is unable to achieve this, then the MSSs switch. Thus, the delay time on the first (smaller and slower) threshold for MSS switching is chosen to be significantly longer than the slow-susceptance time constant. Also, the slow-susceptance time constant is much longer than the primary voltage regulator loop response time.

- There is a provision to add the signal from the auxiliary control, e.g. for power oscillation damping.

- The upper and lower limits of the PI main controller Bmin/Bmax are parameters of the model that can be set by an auxiliary program outside of the model by means of the standard API function.

Load Flow Representation of SVSO1U1

A SVC modeled by the SVSMO1 model must be represented in PSS®E as a continuously controlled switched shunt.

In PSS®E, switched shunts may include up to 8 blocks with up to 9 steps in each of them, 72 steps total. Each step is sized in MVARs, negative for reactors and positive for capacitors.

The SVC is also capable to regulate voltage by controlling mechanically switched shunts (MSS), like mechanically switched capacitors (MSC) or reactors (MSR) available in the system around SVC. MSSs are represented in load flow as up to 8 fixed shunts connected to the same MSS bus. The status of fixed shunts in load flow can be either on-line or off-line.

Example Dynamic Data File for the SVSMO1U1 Model

```
7 'USRSWS' 'SVSMO1U1' 24 1 14 47 5 29
```

```
@!ICONs:
```

```
@!++++++++++++ SVC REMOTE BUS ++++++++++++

0

@!++++++++++++ MSS BUS ++++++++++++

3

@!++++ MSS SWITCH FLAG: 0 - NO SWITCH, 1 - SWITCH ON Q +++++++

1

@!+++ DROOP FLAG: 0 - LINEAR DROOP, 1 - NON-LINEAR DROOP ++++++

0

@!++++++++++ FLAGS: ++++++++++++++++++++++++++++++++++++++++

0 0 0 0 0

0 0 0 0 0

@!CONs:

@! CON(J ) = UVSBmax, max cap U/V limit

0.2000

@! CON(J+ 1) = UV1, undervoltage setting 1

0.5000

@! CON(J+ 2) = UV2, undervoltage setting 2

0.3000

@! CON(J+ 3) = UVT, undervoltage trip setting

0.5000

@! CON(J+ 4) = OV1, overvoltage setting 1

1.3000

@! CON(J+ 5) = OV2, overvoltage setting 2

1.5000

@! CON(J+ 6) = UVtm1, undervoltage trip time 1

1.0000

@! CON(J+ 7) = UVtm2, undervoltage trip time 2

7.0000
```

```
@! CON(J+ 8) = OVtm1, overvoltage trip time 1
1.0000
@! CON(J+ 9) = OVtm2, overvoltage trip time 2
0.2500
@! CON(J+10) = Xs1, slope/droop
0.0200
@! CON(J+11) = Xs2, slope/droop
0.0000
@! CON(J+12) = Xs3, slope/droop
0.0000
@! CON(J+13) = Vup, up volt break-point for non-linear droop
1.1000
@! CON(J+14) = Vlow,low volt break-point for non-linear droop
0.0000
@! CON(J+15) = Tc1, voltage measurment lead time constant
0.0000
@! CON(J+16) = Tb1, voltage measurment lag time constant
0.0100
@! CON(J+17) = Tc2, pre-controller lead time constant
0.0000
@! CON(J+18) = Tb2, pre-controller lag time constant
0.0000
@! CON(J+19) = Kpv, prop. gain of SVC PI-controller
50.0000
@! CON(J+20) = Kiv, integral gain of SVC PI-controller
250.0000
@! CON(J+21) = Vemax, voltage error max limit
0.5000
```

```
@! CON(J+22) = Vemin, voltage error min limit
-0.5000
@! CON(J+23) = T2, thyristor firing sequence control delay
0.0100
@! CON(J+24) = Bshrt, short-term max. suceptance of SVC
2.2000
@! CON(J+25) = Bmax, continuous max. suceptance of SVC
2.0000
@! CON(J+26) = Bmin, min. suceptance of SVC
-0.5000
@! CON(J+27) = Tshrt, duration of short-term rating
3.0000
@! CON(J+28) = Kps, prop. gain of SSC PI-controller
0.0000
@! CON(J+29) = Kis, integral gain of SSC PI-controller
0.0000
@! CON(J+30) = Vrmax, max. output of slow suceptance control
0.0000
@! CON(J+31) = Vrmin, min. output of slow suceptance control
0.0000
@! CON(J+32) = Vdbd1, steady-state voltage deadband
0.0000
@! CON(J+33) = Vdbd2, inner deadband
0.0000
@! CON(J+34) = Tdbd, recovery time to deadband
0.0000
@! CON(J+35) = PLLdelay, PLL delay in voltage recovering
0.1500
```

```
@! CON(J+36) =xeps, delta added to the susceptance bandwidth

0.5000

@! CON(J+37) = Blcs, larger threshold for switching MSCs

40.0000

@! CON(J+38) = Bscs, smaller threshold for switching MSCs

20.0000

@! CON(J+39) = Blis, larger threshold for switching MSRs

-40.0000

@! CON(J+40) = Bsis, smaller threshold for switching

-20.0000

@! CON(J+41) = Tmssbrk, time for MSS breaker to operate

0.1000

@! CON(J+42) = Tdelay1, time delay for larger threshold

0.5000

@! CON(J+43) = Tdelay2, Time delay for smaller threshold

3.0000

@! CON(J+44) = Tout, time MSC should be off before switch back

300.0000

@! CON(J+45) = Vrefmin, lower Vref limit

0.8000

@! CON(J+46) = Vrefmax, upper Vref limit

1.2000

/
```

25.8.7. SVSM02U1 - Model of discretely controlled SVC

To better understand the SVC model structure and the way of representing the SVC in load flow, it is reasonable to start with the description of the arrangement that was used to test this model. This is shown in Figure 25.8, “SVC arrangement used for testing SVSMO2”.

The SVC simulated by this model comprises discretely switched elements only, such as thyristor switched capacitors (TSC) and thyristor switched reactors (TSR). These elements are connected to two mid-voltage

(MV) SVC buses #991 and 992. A composition and a number of switched elements in both halves of the SVC connected to these two buses is the same, so both halves of the SVC are identical. The MV buses are connected via step-up transformers to the SVC high voltage (HV) bus #990 which, in turn, is connected to the system HV bus #154. This bus is a component of the standard example case SAVNW.SAV supplied with the PSS®E installation.

In load flow, both halves of the SVC are represented as switched shunts operating in the discrete mode. In PSS®E, switched shunts may include up to 8 blocks with up to 9 steps in each of them, 72 steps total. Each step is sized in MVARs, negative for reactors and positive for capacitors.

The SVC is also capable to regulate voltage by controlling mechanically switched shunts (MSS), like mechanically switched capacitors (MSC) or reactors (MSR) available in the system around SVC. The designated buses for MSS connection are shown in the diagram: 5 MSS buses connected to each of HV buses (#15401 through 15405 and 99001 through 99005) and MV buses (#99101 through 99105 and 99201 through 99205) SVC buses, i.e. up to 20 MSS designated buses total in the test case.

MSSs are also represented in load flow as switched shunts but, different from SVC discretely controlled elements TSCs and TSRs, MSSs controlled by the SVC operate in the fixed mode

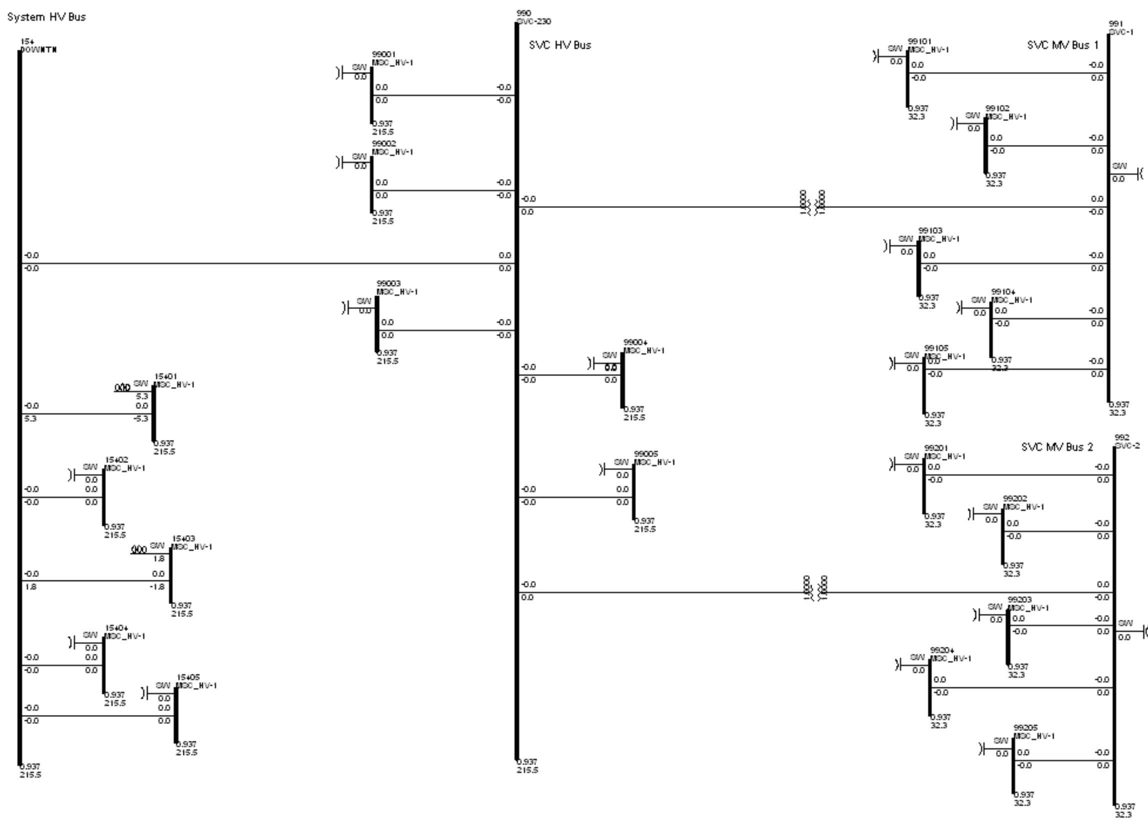


Figure 25.8. SVC arrangement used for testing SVSMO2

The block diagram of the SVC dynamic simulation model is shown in Figure 25.9, “SVSMO2U1 Block Diagram”.

This model includes following features:

- Three controllers, namely
- SVC voltage controller
- SVC slow susceptance controller (SSC)
- MSS controller
- The program reads the information from the dynamic data input file and performs a routine check of topology, data quality, similarity between two halves of SVC, and consistency between dynamic and load flow data.
- The controlled voltage error has a small deadband necessary for the discretely controlled equipment.
- The SVC voltage controller has a droop and a non-linear gain as a function of the controlled voltage. The output of the voltage controller is the demanded SVC susceptance.
- If the controlled voltage drops below the SVC cut-off voltage, the SVC voltage controller gets disabled.
- The demanded SVC susceptance is entered into the look-up table. This table is built by the program at initialization based on the information from the load flow.
- With the given delay, the output of the look-up table forms the model output that is used for updating the SVC current injection to the system which is used at each integration step to update the system voltage vector.
- A reference voltage of the SVC voltage controller Vref is the output of the SVC slow susceptance regulator. By changing the reference susceptance Bref it is possible to change Vref.
- The input from an auxiliary control is provided.

MSS bus numbers are entered into the program and checked for the consistency with the load flow. Also entered is the information of the available size of each MSS. At initialization, the program puts together this information with the load flow data and makes a judgment whether an MSS is ON or OFF. If, for example, the respective switched shunt size in load flow is zero but in dynamic data the available size is -0.05 the program figures out that there is a 5 MVAr reactor available that is off in the beginning of the simulation.

In the dynamic model the number of MSSs controlled by a SVC cannot exceed 8.

- The command for MSS switching comes from the output of the model BSVC.
- The MSS switching logic takes into account the following:
- different switching times for the first and subsequent on-operations and for the off-operation
- a permissible number of operations for a MSS
- a “cooling” time between switching off and subsequent switching on of a MSS
- reset of timers if the nature of a demand has changed during the switching cycle

- one switching at a time meaning that subsequent switching is allowed only after the previous switching has been completed

- in case of the positive MVAr demand, each MSS is checked: if this is a reactor and it is on it will be switched off; if this is a capacitor and it is off it will be switched on; vice versa in case of the negative demand.

- The “smoothing” mechanism implemented in the model meets two goals:

- Reduction of the system voltage excursion caused by a MSS switching

- better use of the SVC susceptance range available for control

This mechanism is simulated by means of a counter-action of the SVC immediately following a MSS switching. For example, when the 5 MVAR MSC is switched on the same portion, if available, is subtracted from the SVC demand.

- The overvoltage protection with regard to the SVC MV bus voltage. The SVC usually controls the HV SVC bus voltage. At the same time it monitors the SVC MV bus voltage and, if it exceeds the given threshold, the SVC susceptance demand immediately drops.

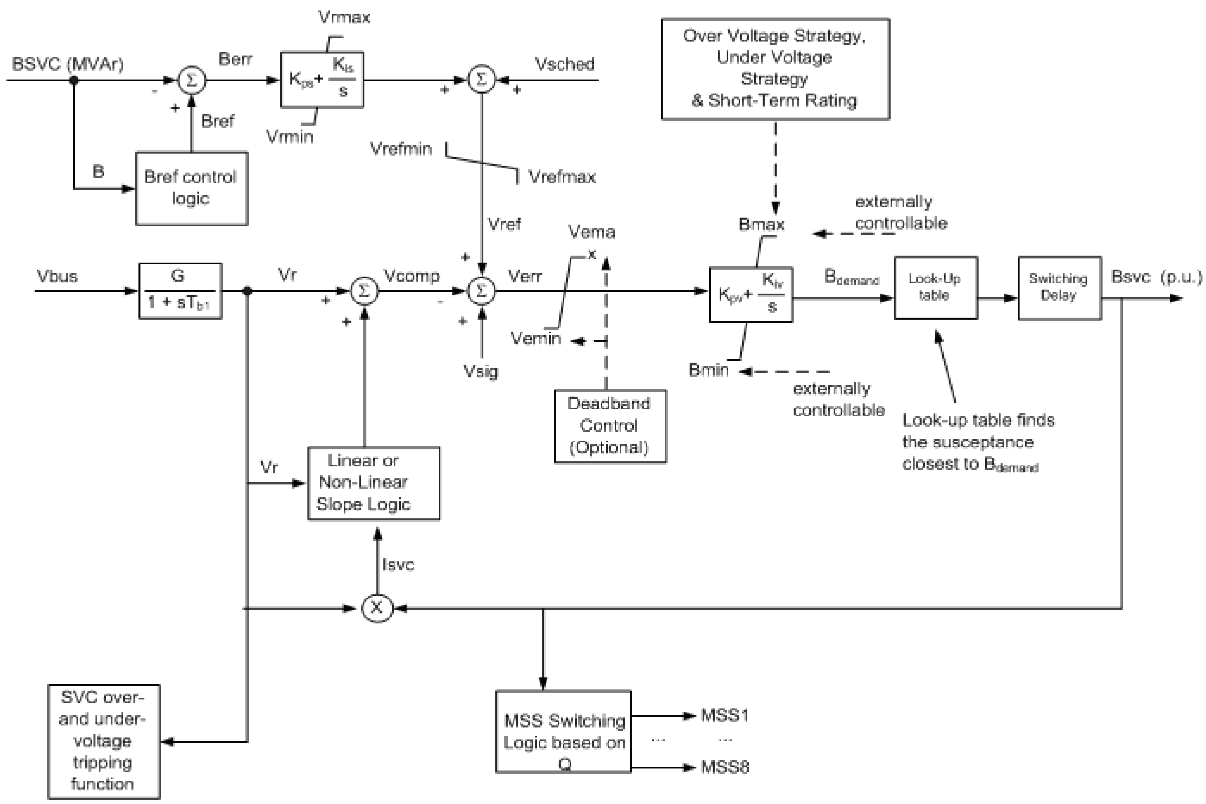


Figure 25.9. SVSMO2U1 Block Diagram

The example dynamic data input file for the SVSMO2 is given below.

```
991 'USRSWS' 'SVSMO2' 24 1 38 47 3 118
```

```
991 0 154 0 0

99101 99102 99103 99104

99201 99202 99203 99204

0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0

0.0200 0.0300 -0.0100 0.0100 0.9000

0.6000 1.1000 1.2000 0.0000 0.0000

0.0000 0.0000 20.0000 100.0000 20.0000

100.0000 0.0000 20.0000 0.0167 0.0000

0.1000 0.1000 -0.1000 1.1000 0.9000

1.0000 -1.0000 -0.5000 -0.0400 -0.0200

0.0200 0.0400 -0.0400 -0.0200 0.0200

0.0400 0.0000 0.0280 0.0500 0.0500

0.7000 0.0050 -0.0050 -0.0100 10.0000

0.0100 1.5000 /
```

25.8.8. SVSM03U1 - Model of VSC based SVC

SVSMO3 is a generic Static Var System (SVS) model for a Voltage Source Converter (VSC) based STATCOM. This model is coordinated with Mechanically Switched Shunt (MSS) devices.

The essential difference between the SVSMO3 and SVSMO1, the generic SVS model for a thyristor-controlled reactor (TCR)-based Static Var Compensator (SVC) is that the STATCOM is a constant current source once it reaches its limit while the SVC is a constant impedance device when it reaches its limit. Thus, the reactive power output of the STATCOM is proportional to voltage when it reaches limit. The block diagram of the PSS®E SVSMO3 model for of STATCOM is shown in Figure 25.10, “Block Diagram of SVSMO3”. The block diagram for modeling of short-term rating is shown in Figure 25.11, “Modeling of short-term rating”.

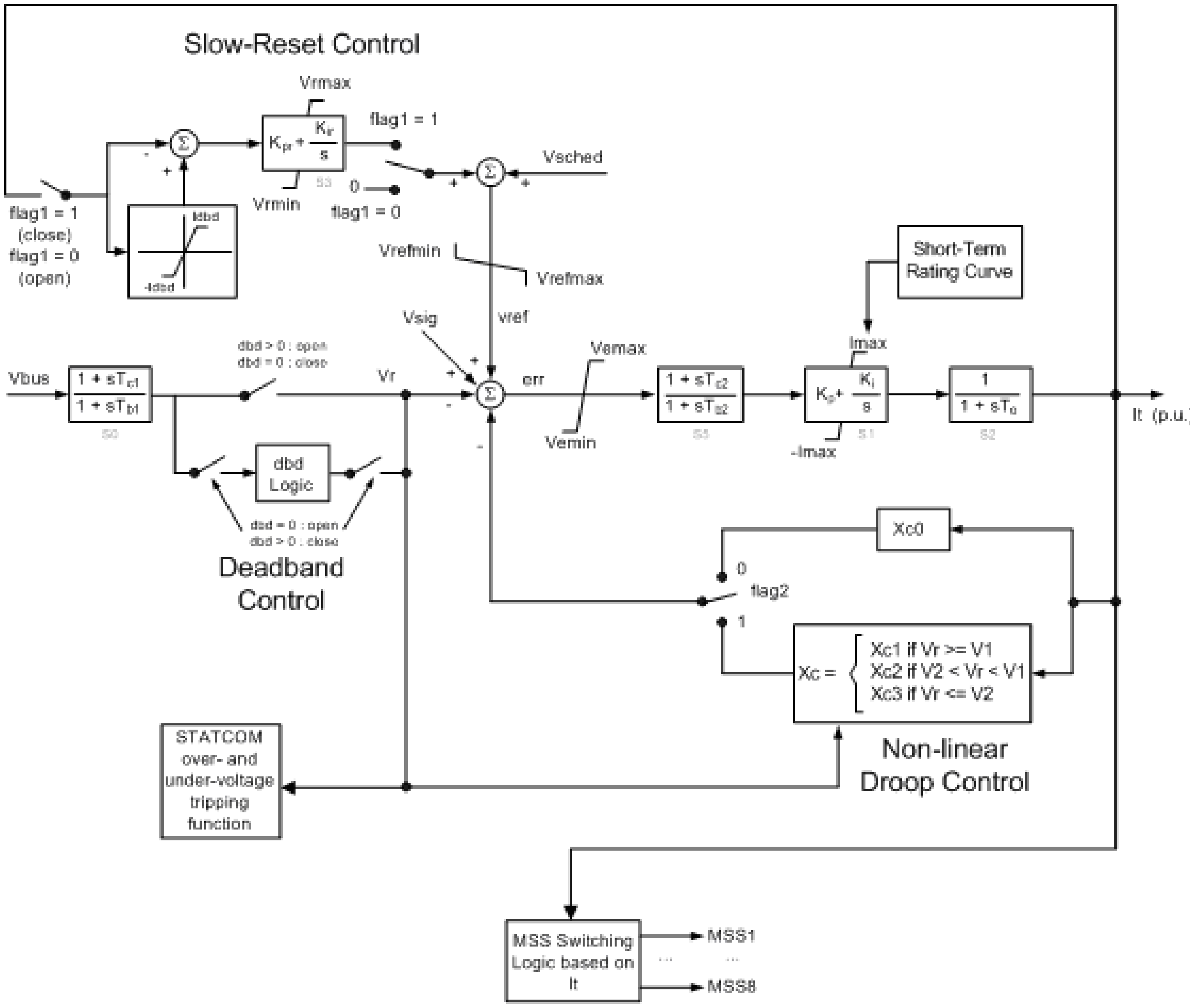


Figure 25.10. Block Diagram of SVSMO3

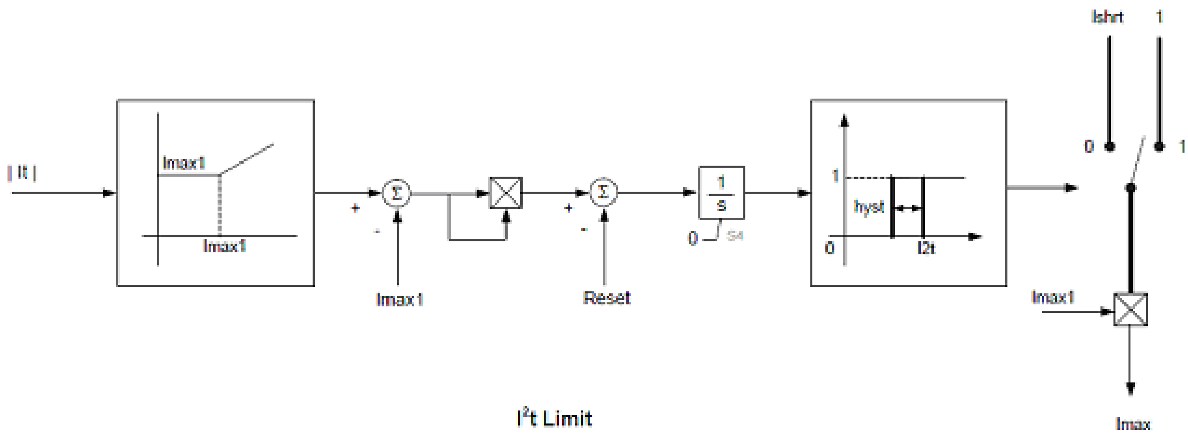


Figure 25.11. Modeling of short-term rating

The main objective of the STATCOM is the voltage control of the specified bus.

The main features the model are [2]

SVSMO3 Primary Control

- "Proportional-Integral Primary Voltage Regulation Loop with proportional gain, Kp and integral gain, Ki.

SVSM03 Secondary Control

- Slow-Reset Control: The PI regulator with gains Kpr and Kir is the slow-reset controller which very slowly biases the STATCOM reference voltage between the values of Vrefmax and Vrefmin to maintain the steady-state output of the STATCOM within the bandwidth of +Idbd and -Idbd. This control is enabled by setting flag1 as 1.

- Non-linear Droop Control: If the parameter flag2 is set to 0 then a standard linear droop of Xc0 is assumed, as is typically in most designs. Alternatively, by setting flag2 to 1, one can use a three piece piecewise linear droop setting. This can be used to make the STATCOM non-responsive in a given bandwidth, similar to deadband control. This control, however, is more susceptible to limit cycling if not properly tuned.

- Deadband Control: If the dbd parameter is set to 0 then deaband control logic is disabled. On the other hand if dbd is not equal to 0, the STATCOM main control acts only after the STATCOM bus voltage is outside the given deadband defined by Vref+dbd to Vref-dbd.

Note: The deadband control, slow-reset control, and non-linear droop are all intended for the same purpose - maintaining the STATCOM at a low steady-state output when the system voltage is within a given bandwidth. However, these three control strategies achieve this in quite different ways. Thus, for stable and suitable control response it is highly recommended to never use any combination of the deadband control, slow-

[2] P. Pourbeik, "User's Manual for ABB STATCOM Model in GE PLSF® and Siemens PTI PSS/E®", May 8, 2006. ABB Report No. 2006-11241-Rpt4-Rev2

reset control and non-linear droop. Only one of the three should be used in the control strategy. The model checks for this condition during initialization and does not allow using combinations of these controls.

Other features

- Protection: The over/under-voltage trip points.
- Short-term rating: the STATCOM output can exceed its maximum continuous current rating up to the maximum short-term current rating (=Ishrt*Imax1) for a short time period (= Tdelay1). Alternatively, the short-term rating can be based on the specified I2t limit.
- Mechanically Switched Shunt (MSS) Logic: detailed MSS logic is implemented which allows for automated MSS switching based on the STATCOM current output. The thresholds, Iupr and Ilwr are implemented for switching of capacitor or reactor. The MS capacitor discharge time can also be set, i.e. time the MSC must be switched off before it can be switched back on. The MSS breaker delay is also modeled. The model can handle up to 8 MSSs: reactors and/or capacitors.

Note: the MSS switching must be properly coordinated with the slow-reset control, if used. Typically, to avoid excessive MSS switching, the slow- reset control time constant is chosen such that it acts first to bring the STATCOM to within the two thresholds. If it is unable to achieve this, then the MSSs switch. Thus, the delay time for MSS switching is chosen to be significantly longer than the slow-reset time constant. Also, the slow-reset time constant is much longer than the primary voltage regulator loop response time.

Load Flow Representation

A STATCOM modeled by the SVSMO3 model must be represented in PSS®E as a FACTS device in load flow.

The STATCOM is also capable of regulating voltage by controlling mechanically switched shunts (MSS), like mechanically switched capacitors (MSC) or reactors (MSR) available in the system around STATCOM. MSSs are represented in load flow as up to 8 fixed shunts connected to the same MSS bus. The status of fixed shunts in load flow can be either on-line or off-line.

The example dynamic data input file is provided below, along with the example documentation of the dynamic parameters.

```
'STATCOM    '    'USRFCT' 'SVSMO3U1'  21  1  13  44  6  27
 0  1      6  0  0  0  0  0  2  0  0  0  0
0.10000E-01  0.0000     0.10000     0.0000     25.000
0.50000    -0.50000
0.50000E-02  1.0000
 0.0000     10.000     0.10000
 0.0000     0.10000E-02  0.10000E-01
0.10000    -0.10000
 1.4000
0.50000     0.20000     1.0800     1.2000     1.3000     1.0000     0.80000E-01
 1.0000     1.0500     0.95000
 0.0000     0.0000
 0.0000     0.0000     0.0000
0.10000E-01  1.0000     0.10000E-01  1.0250     0.97500
0.10000     300.00     0.50000
0.30000    -0.30000
 10.000   /
```

Figure 25.12. Example Dynamic Data Input File, SVSMO3

25.9. Under(Over) Voltage(Frequency) Relay Models

The under/over frequency models (FRQDCA and FRQTPA) and under/over voltage models (VTGDCA and VTGTPA) are protection models, located at the generator bus, that continuously monitor the frequency/voltage on that bus or a remote bus specified by the user. They trip the generator for under- and over- frequency/voltage conditions on the generator (or remote bus).

Both voltage and frequency protection relay models have two entries:

- FRQDCA and VTGDCA relays disconnect generator bus, i.e., disconnect all equipment attached to generator bus.
- FRQTPA and VTGTPA relays disconnect generators only.

The relay timer is started during under/over frequency/voltage conditions, i.e., when frequency/voltage is less/greater than or equal to the corresponding pickup threshold. The relay resets instantaneously if the frequency/voltage restores within the two pickup thresholds. If the relay is not reset, a trip signal is sent to the circuit breaker if the timer reaches its setting. Frequency/voltage must have remained in an under/over frequency/voltage condition for the entire time delay for generator tripping to occur. Generator tripping is delayed by the circuit breaker time.

Several relays can be used to simulate the coordinates of the protection system with the voltage/frequency versus time function.

25.10. Voltage Source Converter DC Line Dynamic Model

This section describes the dynamic model for a two-terminal, Voltage Source Converter (VSC) based HVDC system. The model has been developed for the PSS®E dynamics software in coordination with the associated VSC DC line power flow PSS®E model.

25.10.1. VSC Dynamic Model Overview

The model described herein is general performance class model developed to evaluate the interaction of a VSC based HVDC system with the ac network(s) to which it is interconnected. As with other PSS®E HVDC models, the objective is to represent the transient behavior of the outer, or supervisory controls, because these control actions have the most influence on the connected ac network. Controls that have been explicitly represented in the model take into consideration the 0-30 radians/second bandwidth over which PSS®E is applicable. Other controls and response, particularly those associated with the HVDC side of the system, have not been specifically modeled due to their rapid response in relation to the time scale of most PSS®E simulations. Rather, an approximate representation of DC characteristics has been implemented.

Control of a pair of VSCs and the fundamental dynamic interaction between the pair is accomplished in the PSS®E representation through the use of a Power Control Order function. This Power Control Order function utilizes the voltage-sensitive current limits of the VSCs to coordinate active power transfer across the HVDC system when either VSC goes into limitation. It should be noted that the model implies direct communication between VSCs. In the actual system, coordination is accomplished through monitoring and high-speed control of DC voltage, no direct communication is used.

The dc transmission line dynamics model (VSCDCT) in PSS ®E is composed by the integration of three modules, two voltage source converter modules (VSCDYN) for the VSCs at each dc line terminals and one dc transmission line module (DCLINE) for the dc link. VSCDCT is a current injection model. Figure 25.13, “VSCDCT PSS®E Model” shows schematically the modules for the VSCDCT PSS®E Dynamic model. The data sheet for this model with typical values for the input parameters is given in the *PSS® E Model Library*, (Model Configuration). Please note that an integration time step of ¼ cycle or less should be used when PSS ®E simulation cases include a VSC with typical time constants as listed.

A VSC module can operate in stand-alone mode or in conjunction with a second VSC. In the latter case, the pair of VSCs is coordinated via a separate module named DCLINE. This module is discussed subsequently. Stand-alone mode of operation can be set by taking out of service one of the VSC via power flow parameter input data. Specifying TYPE = 0, sets the converter out of service. Stand-alone operation may be used if the VSC is operating as an independent SVC, or when a user is only interested in studying the ac network on one side of a VSC dc system that has no parallel ac ties.

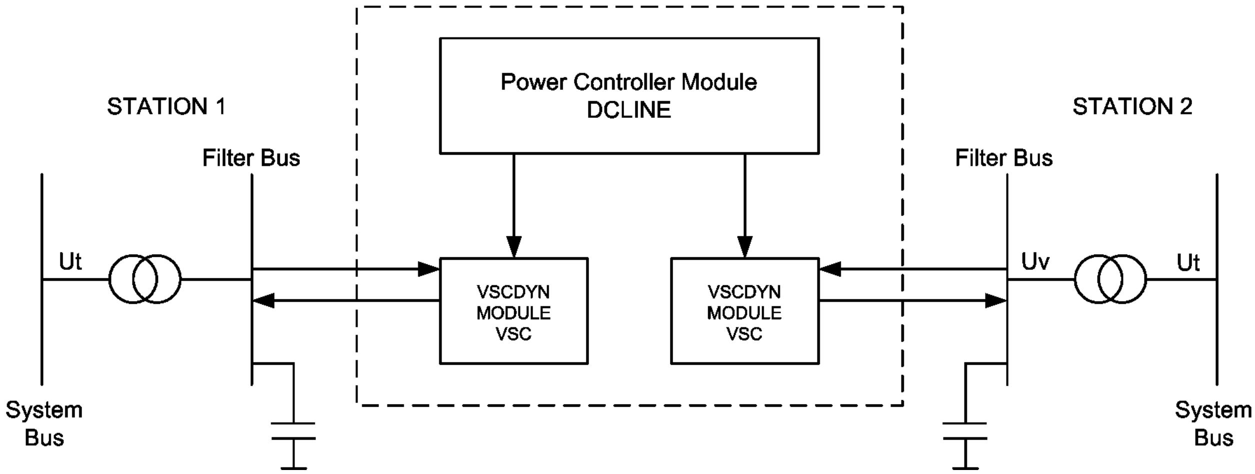


Figure 25.13. VSCDCT PSS®E Model

25.10.2. VSCDYN Module

The VSCDYN module has been developed to represent the control functions of a VSC converter. The VSCDYN module recognizes the following actions by the controls:

- AC voltage control or reactive power control,
- Active power control or DC voltage control, and
- Current output limitation.

Additionally, the VSCDYN module accommodates the following actions by the user:

- Power ramping, and
- Converter blocking.

Active Power Reference Regulation

Typically, the active power order is set manually and power stepping unit carries out the ramping of power order reference. The VSCDYN module has provision for accepting a power order directly (P_aux) via VAR(L) for VSC # 1 or VAR(L+12) for VSC #2. The model also has provision for receiving a power order from the DCLINE module via VAR(L+7) for VSC # 1 or VAR(L+19) for VSC # 2. When in the stand-alone operating mode, this power order value remains constant, as set during initialization.

In normal operation of a two-terminal VSC dc system, active power is controlled in one station while the other converter controls dc voltage. The user specifies whether a VSC is in active power or dc voltage control by the TYPE parameter in power flow input data.

AC Voltage Control

The AC Voltage Control function varies the reactive power order to control the ac voltage at the regulated bus. The regulated bus is the ac filter bus by default, however, the user can specify any remote bus by entering the bus number via ICON(M+1) for VSC # 1 and ICON(M+3) for VSC # 2. If these values are zero, the model takes the bus numbers from the power flow input data, REMOT parameter. In a VSC dc system, the AC Voltage Control is independent in each VSC.

The AC Voltage Control has the provision for droop (CON(J+6) for VSC # 1, or CON(J+19) for VSC # 2), to be included in the function to effectively alter the voltage reference point. This feature allows two or more VSCs to regulate the same bus voltage by sharing reactive power. Without the droop, it would be possible for the reactive output of the VSCs to drift apart and run the VSCs up to their maximum current limits.

In the VSC power flow data, the parameter MODE could be set to 1 for ac voltage control or 2 for fixed ac power factor. This information is passed to the VSCDCT model during dynamics simulations except that when MODE is equal to 2, the VSC holds a constant reactive power order, rather than ac power factor. If the model is initialized in reactive power control, the value of reactive power is determined from the power flow conditions. A VSC can be switched between ac voltage and reactive power control during a simulation. The reactive power order is maintained in VAR (L+6) for VSC # 1 or VAR(L+18) for VSC # 2 during the course of a simulation. These VARs are updated appropriately when in ac voltage control.

Current Order Limiter

This model converts the active and reactive power orders to current orders by dividing the values by the magnitude of the ac filter bus voltage.

The function of the Current Order Limiter (COL) is to limit the amplitude of phase current of the fundamental component to the rated current of the converter. This concept is illustrated in Figure 25.14, “Characteristic of Current Order”.

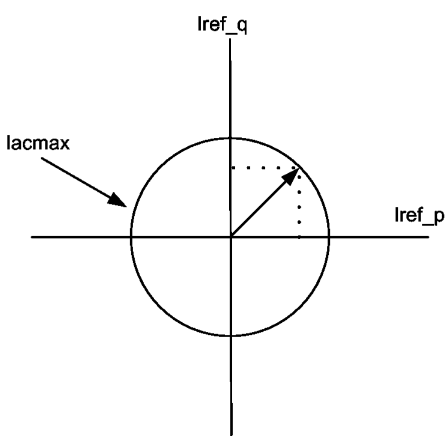


Figure 25.14. Characteristic of Current Order

If the amplitude of the current order is lower than the maximum current (Iacmax), (CON(J+5) for VSC # 1 or CON(J+18) for VSC # 2), the outputs of the COL will be the same as the corresponding inputs. If the amplitude of the current order is higher than Iacmax, the outputs of the COL will be reduced and a feedback signal is sent to the Voltage Controller to limit wind-up of the integrator.

The reduction of the active and reactive current order is accomplished by using the Power Weighting Factor (0.0 = PWF = 1.0) fraction. The value for the PWF is taken from the power flow input data. When PWF is 0.0, only the active current order is reduced; When PWF is 1.0 only the reactive current order is reduced; otherwise, a weighted reduction of both active and reactive current order is applied by solving a quadratic constraint and accepting the minimum real root. When roots are not real values, the reactive current order is set to zero and the active current order is set to the limit (Iacmax), (CON(J+5) for VSC # 1 or CON(J+18) for VSC # 2).

If the input setting for the maximum current (Iacmax) [CON(J+5) for VSC # 1 or CON(J+18) for VSC # 2] is zero then the power flow input data IMAX is used in per-unit of the converter base. If again, IMAX is zero in the power flow input data (default value) then unlimited loading is allowed in the VSCDCT model.

VSC Blocking

A VSC can be blocked by setting ICON(M) for VSC # 1 or ICON(M+2) for VSC # 2 equal to 1. Blocking a VSC instantly changes the active and reactive current orders to zero. In a VSC dc transmission system, one converter can be blocked and the remaining converter can continue controlling ac voltage.

25.10.3. DCLINE Module

The DCLINE module coordinates the active power flow between a pair of VSCs. The module import from the power flow input data the reference value of DC voltage (pole-to-pole, DCSET for TYPE 1) to be maintained at the DC voltage controlling VSC. Additionally, the DCLINE module import from the power flow input data the series DC resistance of transmission system (RDC in ohms). That information is used to estimate the series current dependent system losses. Fixed losses are determined at initialization based on the power difference between the two converters and the calculation of series losses. Both the fixed (Pzero_loss) and total (Pdc_loss) are routed to VAR(L+32) and VAR(L+33), respectively, in the model for the user's information.

During a simulation run, the DCLINE module produces a power order for each of VSCs of a two-terminal transmission system accounting for the losses in the HVDC system. The system losses are always compensated for at the DC voltage controlling VSC except for the condition of a severe current limitation at this station.

In a two-terminal HVDC Light system, the current limitations in the two converters work independently. When a limitation is encountered, a difference in active power between converters can result. In the actual system, this difference creates an error in the DC voltage and a fast acting regulator is activated to regulate the power reference in such a way that the unbalance is eliminated. In the simulation model, this procedure is simplified by directly controlling the power order reference; the model assumes a fast well-tuned DC control system. The references are reduced to the minimum value for the power transmission capacity of the two VSCs. These values are sent to the DCLINE module from each of the VSCDYN modules, again by utilizing the VAR(L+7) for VSC # 1 and VAR(L+19) for VSC # 2, PM variables. If one of the converters is blocked, the DCLINE module is ignored.

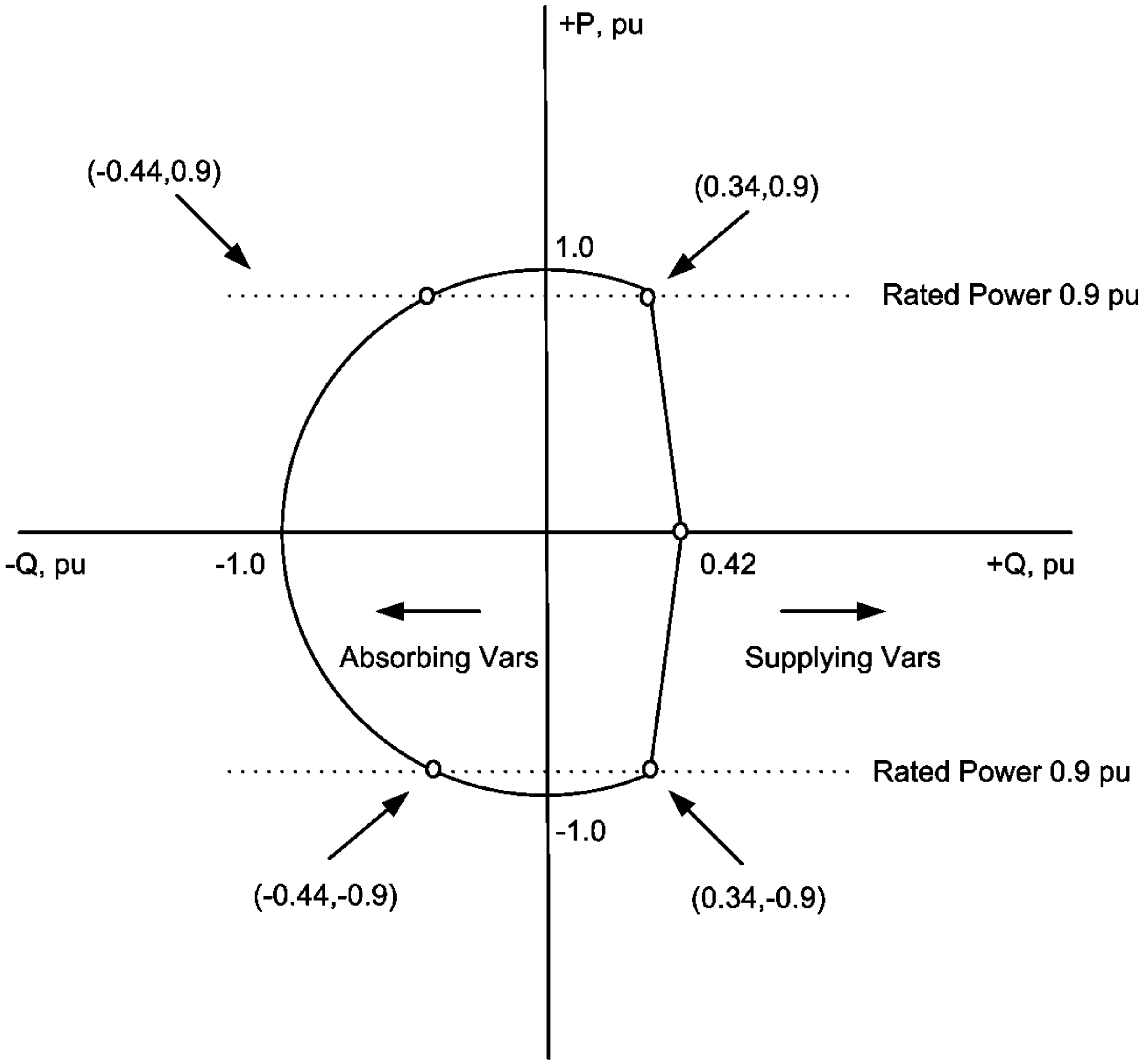
Active Power Ramping

Power transfer across a two-terminal, VSC based HVDC system can be changed in a simulation run by altering VAR(L+24) of the model. At initialization, VAR(L+24) will be set equal to the network active power injection at the power controlling VSC. The active power transfer can be ramped up (within the appropriate system limits) by increasing the absolute value of this variable and applying the same sign. A positive sign indicates power flow across the HVDC system from the voltage controlling VSC (TYPE 1) to the power controlling VSC (TYPE 2).

25.10.4. VSC DC Power Flow Representation

One model is required for each HVDC Light Transmission line in the power flow network to be analyzed. Any transformer associated with the VSC DC line should be modeled by an explicit transformer record in the PSS®E power flow data. The power flow data provides the initial conditions for the dynamic simulation of the model. The VSCs that make up an HVDC system should be dispatched in the PSS®E power flow program assuming a power transfer from one VSC to the other. Additionally, the converter MVA rating should be specified in the power flow input data as a non-zero parameter SMAX (*Program Operation Manual*, Voltage Source Converter (VSC) DC Transmission Line Data), when this VSCDCT model is used for dynamics simulations.

AC filters corresponding to a VSC can be modeled as fixed or switched capacitive shunt at the ac bus to which the VSC is connected. Figure 25.15, “VSC Steady-State Reactive Capability Curve” illustrates the typical reactive capability of a VSC assuming a nominal ac bus voltage (1.0 per unit). The curve that cuts off the right hand side of the circular characteristic is the limit due to the maximum steady-state internal VSC voltage. As the ac filter bus voltage decreases below 1.0 per unit, this portion of the curve will shift to the right allowing for more reactive support from the VSC. This overall capability curve can be used as reference for specifying the VSC reactive power limits in the dyre file, [CON(J+9), CON(J+10), CON(J+22), and CON(J+23)]. Keep in mind, reactive power of one VSC of a HVDC system can operate independent of the reactive power output of the other.



Typical VSC Steady-State Reactive Capability
(excluding the ac shunt filter, assumes 1.0 pu ac voltage)

Figure 25.15. VSC Steady-State Reactive Capability Curve

25.11. Variable Frequency Transformer (VFT) Model

The Variable Frequency Transformer (VFT) is a power system device developed by GE to either interconnect two asynchronous AC power systems or to control the flow on an AC transmission path. This device has a 3-phase winding on the stator and a motor-driven rotor which also has a 3-phase winding. This rotary transformer can continuously adjust the phase shift between the stator and rotor to any desired angle.

The VFT is a medium voltage device with a typical terminal voltage rated at 17kV. Generator step-up transformers are required on both sides of the VFT to connect it to the transmission system.

Note that this device consumes reactive power. As a consequence, shunt reactive power compensation might be required for voltage control.

This user guide details the use of the PSS®E dynamic simulation model for the GE VFT developed by Siemens PTI based on technical information in the GE report "VFT Modeling for Planning Studies" Rev. 3, dated June 3, 2009 and previous work from Hydro-Québec-IRÉQ.

25.11.1. Limitations

Note that PSS®E does not presently distinguish a VFT from a standard phase-shifting transformer, in particular, the VFT's capability of coupling two asynchronous networks.

When using this device to couple two asynchronous power systems, a swing bus (Type 3 bus) is required in EACH island. Without a swing bus in each island, the power flowing across the VFT would not be regulated. However, if the VFT is used to regulate flow within a synchronous network (functioning similar to a standard phase shifting transformer) only one swing bus is needed in this synchronous system.

When a VFT is used to connect two asynchronous systems, two PSS®E features are impacted as result of modeling the VFT as a standard phase shifting transformer.

1. Activity TREE
2. The Inertial Power Flow

Activity TREE finds the number of asynchronous islands in a network and verifies that every island has a swing bus. Since the VFT is represented as a phase-shifting transformer, it links its two terminals as an AC branch. Hence, in terms of activity TREE, the VFT would link the two asynchronous islands into a single island. As a result the output of activity TREE would not recognize the existence of the two islands and would report them as one island containing two swing buses.

Activity TREE is implicitly called when solving the inertial power flow to determine the "synchronous island" that shares the same steady state frequency. Due to the VFT being modeled as a phase-shifting transformer, the inertial power flow can not distinguish between the two systems and hence would assume that the two asynchronous systems share the same frequency and, for example, all generators of both "islands" would contribute to frequency control.

It is presently planned that this limitation will be addressed in a future release of PSS®E. That is, logic will be added such that activity TREE, and other activities that use it, will recognize the VFT as a device capable of linking two asynchronous islands and adjust their calculations appropriately.

25.11.2. Example

Figure 25.16, "Single Line Diagram of the VFT and Associated GSU and Capacitor Bank" shows a single line diagram of the VFT example system. In this diagram, the VFT is connected between buses 99003 and 99004.

The transformers between 99006 and 99003, and 99007 and 99004 represent the step-up transformers. When entering the transformer data, the phase shifting element is defined to be on the winding 1 bus. Note the selection of the tapped bus is arbitrary and the power can flow in either direction.

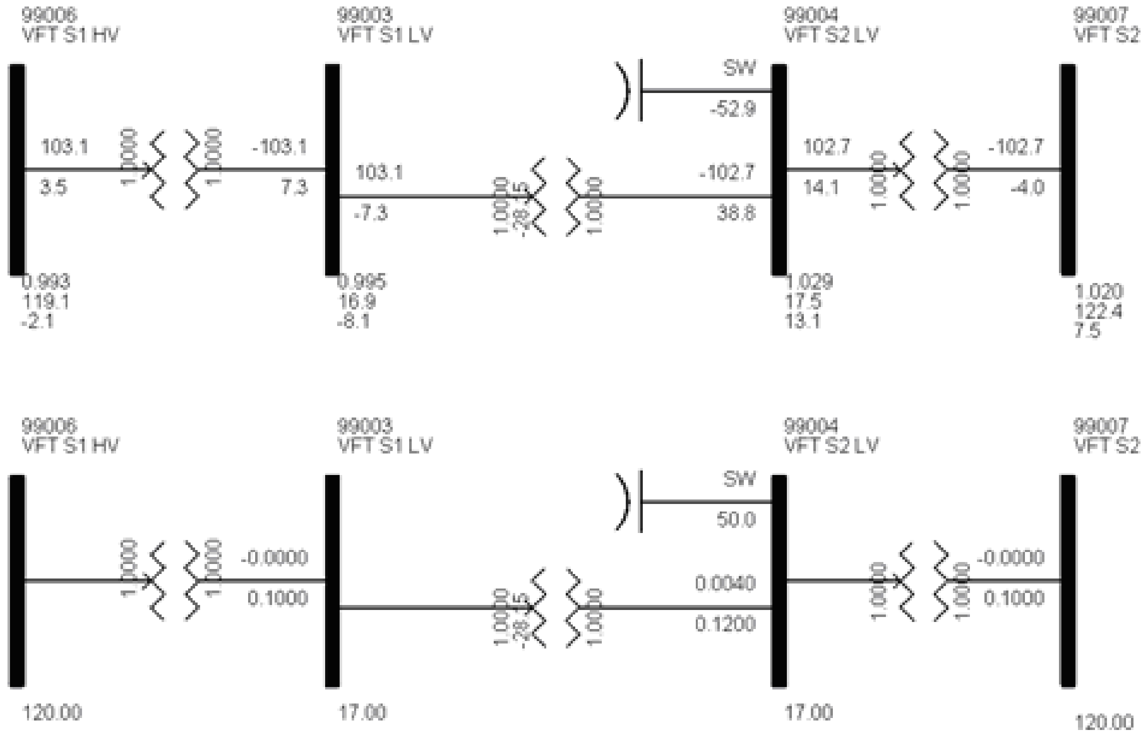


Figure 25.16. Single Line Diagram of the VFT and Associated GSU and Capacitor Bank

For the phase-shifter to control active power flow, the transformer must be selected as "Auto Adjust" and the control variable as "Active". as shown in Figure 2 2.

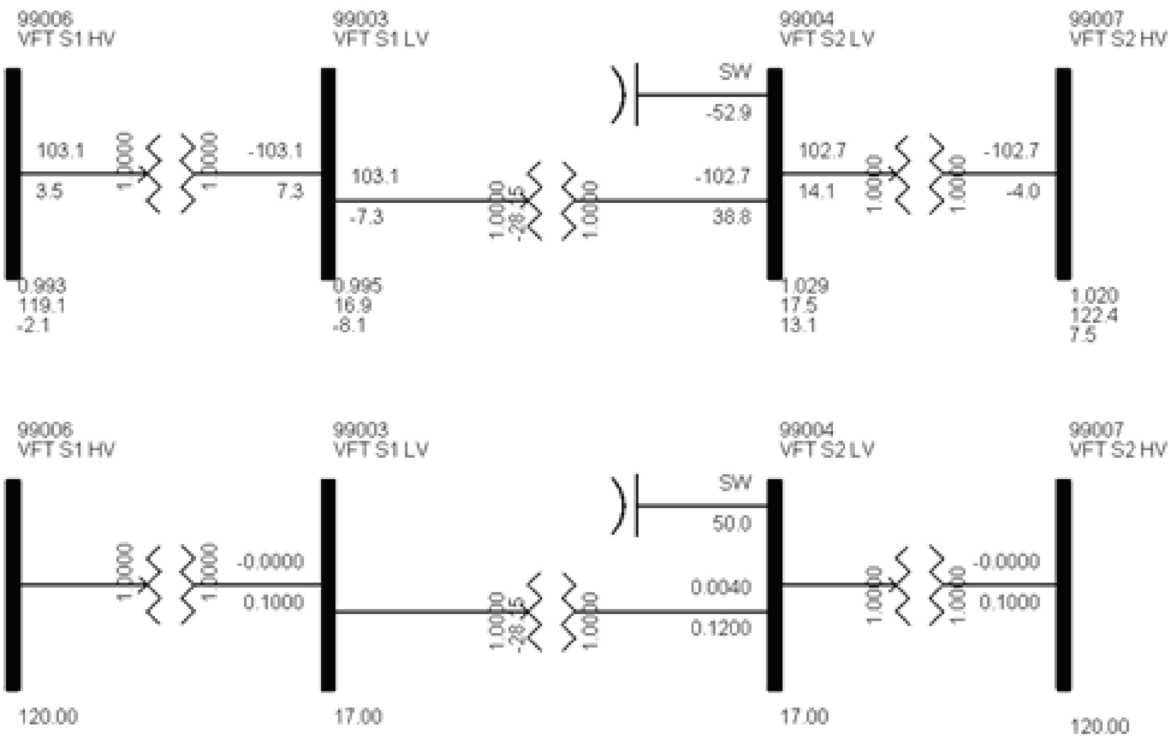


Figure 25.17. Data Record in PSS®E Power Flow Interface

Typical parameters are shown in Table 25.1, " Power Flow Parameter for the VFT". These typical parameters are given in per unit on the rating of the VFT. This rating must be specified under the entry "Winding MVA". Typically, it is 100 MVA per VFT.

It is important to note that the VFT has a large magnetizing current, typically consuming 18 Mvar per VFT. Therefore, it is important that the magnetizing branch be included in the transformer model.

Also note that the solution option "Adjust phase shift" needs to be selected when solving the power flow solution to enable the VFT to control the flow.

Table 25.1. Power Flow Parameter for the VFT

Parameter	Typical Value (Based on VFT rating)	Note:
RVFT	0.4 %	VFT Series Resistance
XVFT	12 %	VFT Series Reactance
Xmag	-18%	VFT Magnetizing Reactance
Xt1 , Xt2	10 %	Step-up Transformer Reactance
C1 , C2	20% to 80% depending on needs	Shunt Capacitors at VFT Terminals

25.12. Modeling for Stability Analysis

The model of the VFT is suitable for studies of transient stability and other events where the frequency of the power system or between the two systems, if modeling an asynchronous connection, remains within a few percent of nominal.

The VFT consists of a three-phase stator, a three-phase rotor driven by a DC motor, and the control system.

Figure 25.18, "Block Diagram of the VFT Drive System" shows the block diagram of the rotor and the motor-drive system. The input command (desired rotor speed, Spd Cmd), is the output of the control system shown in Block Diagram of the VFT Drive System.

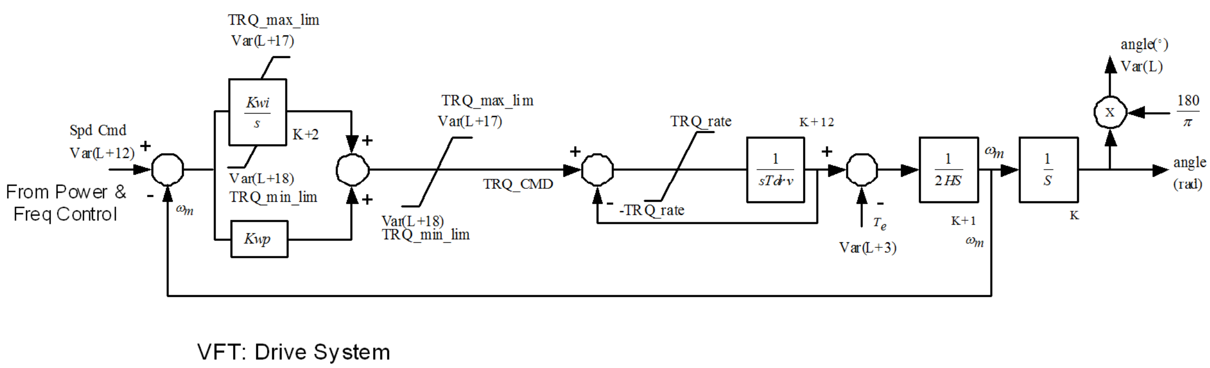


Figure 25.18. Block Diagram of the VFT Drive System

The block diagram of the main controller of the VFT is shown in Figure 25.19, "Block Diagram of the Main Controller of the VFT". It has three branches:

- a P-I controller that regulates the VFT power,
- a frequency control that regulates a speed input from the difference in Thevenin frequency between the two terminals,
- a speed feedback stabilizing path.

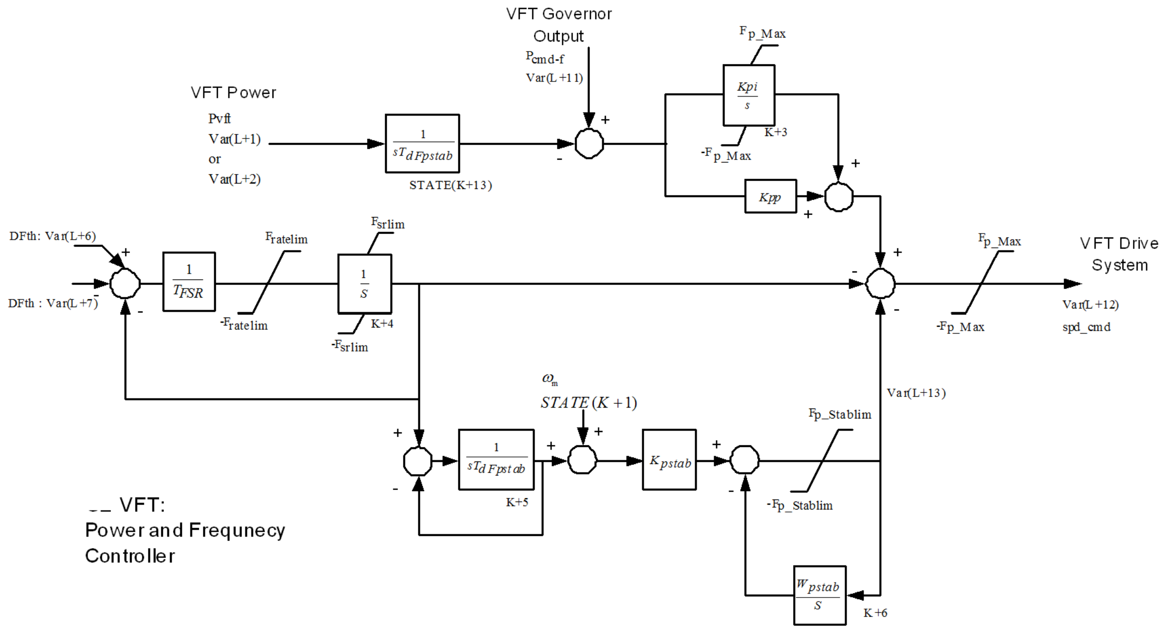
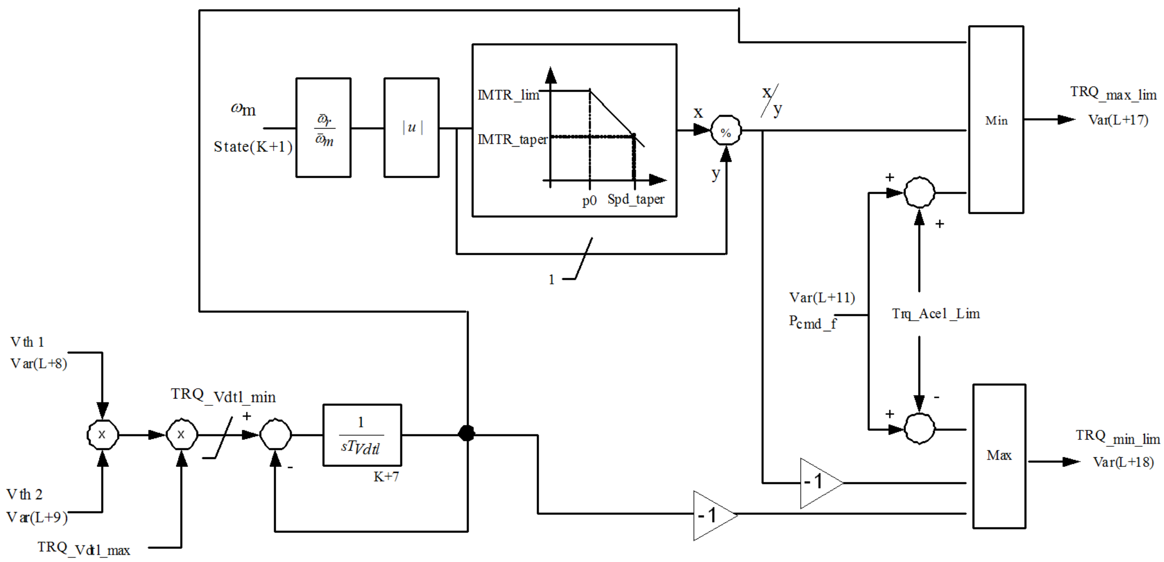


Figure 25.19. Block Diagram of the Main Controller of the VFT

The torque of the DC motor can be limited due to its rotational speed and/or the terminal voltages. The Drive Motor Torque Limit prevents windup of the speed regulator by limiting its output torque command when the rotor speed is high. The Voltage Dependant Torque Limit prevents the control from making excessive change when the voltage is low. The driving torque is also limited by an acceleration limit (Trq_Acel_Lim) which limits the torque to be within a band around the per-unitized Power Command. The block diagram of these limits is shown in Figure 25.20, “Block Diagram of the Torque Limiter of the VFT”.



VFT:
Torque Limiter

Figure 25.20. Block Diagram of the Torque Limiter of the VFT

The VFT has a controller that can be used to emulate governor action when connecting asynchronous systems. If the frequency on one side of the VFT deviates beyond the deadband FDB1 on the system 1 side or FDB2 on system 2, the VFT would modulate the power order command according to the droop settings R1 for system 1 or R2 for system 2.

The VFT also has a Voltage Dependent Power Limiter (VDPL) which limits power transfer during a low voltage event in order to, for example, prevent voltage collapse. This limiter also modulates the power order command. The block diagram of the VFT governor and the VDPL are shown in Figure 25.21, “Block Diagram of the VFT Governor”.

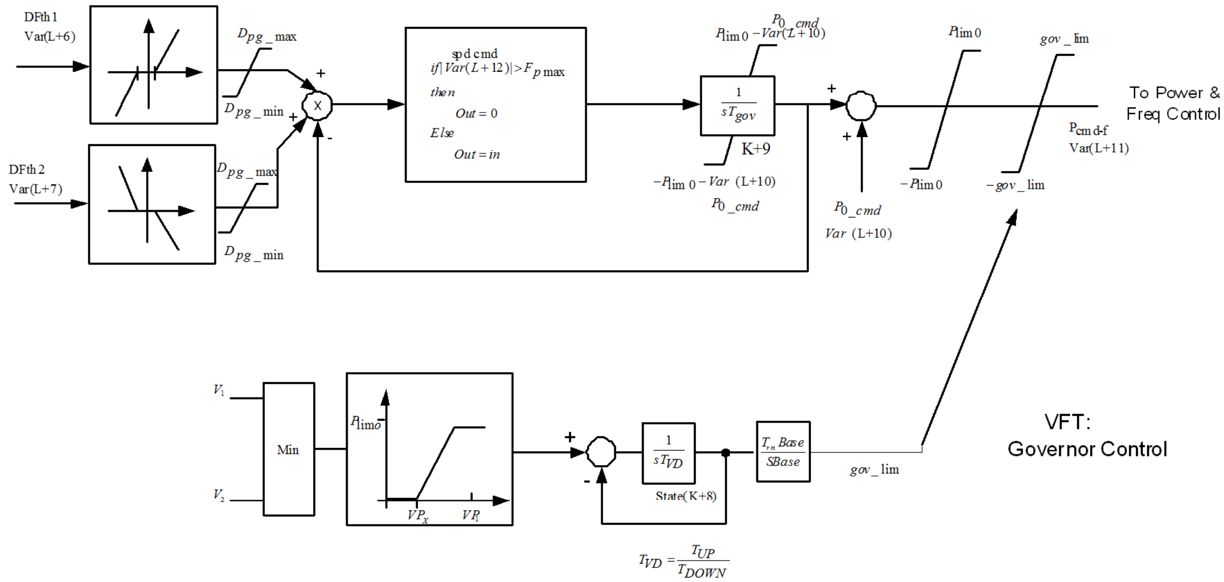


Figure 25.21. Block Diagram of the VFT Governor

At model initialization, the VFT model assumes that the VFT is operating in steady state under nominal voltages. The VFT angle in VAR(L) is initialized as the absolute VFT angle in degrees and the VFT Power Feedback Pfbk is measured from the tapped side bus as the power in MW into the VFT.

The VFT adjusts the power flow by rotating its rotor. As this rotation angle becomes large, the current flowing across the VFT could significantly deviate from the initial value. When the rotation exceeds the VFT factorizing angle, CON(J+40), the power flow admittance matrix will be re-factorized. This re-factorization speeds up the network solution and prevents a potential divergent solution when the VFT alters the power flow significantly from the initial conditions. As a starting point, Siemens PTI recommends a value of 20 degrees for this re-factorization angle, but this angle may need to be adjusted based on the characteristics of the power system modeled.

When connecting asynchronous systems, the VFT links the two systems with different frequencies by rotating its rotor to follow the calculated Thevenin Frequency on each side. The Thevenin Frequency is calculated at both ends of the VFT.

For side 1:

$$\overline{Vth1} = \left[V1 - \frac{Q1 \cdot Xth1}{V1}\right] - j\left[\frac{P1 \cdot Xth1}{V1}\right]$$

$$Vth1 = \min[Mag(\overline{Vth1}), 0.1]$$

$$Ath1 = Ang(\overline{Vth1})$$

$$Fth1 = \frac{sAth1 + f1}{1 + sTfx}$$

$$DFth1 = Fth1 - Fbase$$

The same calculation is performed for side 2. These signals are the inputs to the Main Controller of Figure 25.19, “Block Diagram of the Main Controller of the VFT”.

The real power flowing across the VFT is stored in VAR(L+1) and VAR(L+2) for the from and to side flows respectively, with the convention of positive flow from the bus into the VFT. Similarly the reactive power is stored in VAR(L+4) and VAR(L+5). Note that the default channels for branch flow for the VFT should NOT be used as they do not generally take into account the movement in VFT. That is, if plotting the VTF flow is desired, the VFT model VARS should be used.

At initialization, the initial active power flow is stored in Pcmd. To change the active power flow to a new setpoint, Pcmd, VAR(L+10), can be changed to the new setpoint. Note that the relative direction of the power flow must be taken into account.

A sample PSS®E Dynamic Data Input File for Activity DYRE and DYRE,ADD is shown below:

```
99003 'VFT1' 99004 1

26.200 0.15000 0.30000 0.20000E-01 0.20000E-01

0.30000E-02 0.52000E-01 0.20000E-01 0.10000 0.55000E-01

0.60000E-01 1.0000 0.10000 0.50000E-01 0.50000E-01

500.00 500.00 0.20000E-01 75.000 4.0000

0.20000 0.25000E-01 1800.0 48.000 3.1500

2.7300 2.5000 5.0000 0.70000 0.95000

3.0000 0.30000 1.1500 0.10000E-01 0.10000E-01

0.10000E-01 0.10000E-01 0.30000 1.5000 1.5000
```

```
20.000 0.25000E-01 /
```

Chapter 26
Data Verification

26.1. General Approach

26.1.1. Stages of Verification

One of the most difficult aspects of power system dynamic simulation work is obtaining complete and valid data. Problems arise both because of errors in data files and because parameter values are simply not given by many of the usual sources of data.

Because the data that is normally available on generators, excitation systems, and other equipment is unreliable in many cases, it is essential to make a careful check of the data values entered on the model data sheets. The first and most obvious approach to data verification is to check all parameters for reasonableness after they have been established in the PSS®E database. This will detect many simple errors, particularly transcription errors, but is not a conclusive indication of validity of the data.

The second, and most effective, way to check data is to make special simulations of the response of the generating units in hypothetical isolated operating conditions. Saturation, excitation system response, and governor effects are then not masked by the electrical synchronization effect but are clearly and unambiguously visible. These special simulations correspond to the tests that can be made on the generating units in actual practice and, because the form of the test result needed for satisfactory performance of the unit is well understood in practice, they assist greatly in detecting those insidious situations where parameter values appear to be reasonable but are actually incorrect. PSS®E includes activities for both levels of data checking.

26.1.2. Parameter Range Checking

The PSS®E activity DOCU allows the checking of data for gross errors such as misplaced decimal points, improper relationships between parameters, and so on. Activity DOCU lists the parameters and calling arguments of each model. The output listing of DOCU, a sample is shown in Figure 26.1, “Typical Output from Activity DOCU”, confirms that the model-calling arguments and parameters were actually loaded into the PSS®E program and memory arrays as intended.

Critical examination of the output of DOCU for a large system is difficult because of its volume. Activity DOCU provides an initial editing of the DOCU output and restricts it to machines where the values of parameters are suspect. DOCU compares each parameter with a representative range of values and lists output for a machine only if it has a parameter outside the representative range. A typical output of DOCU is shown in Figure 26.2, “Typical Output from Data Checking Mode of Activity DOCU”.

```
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU JAN 11, 1996  15:19
SAMPLE SYSTEM FOR PSS®E MANUAL
1100KV DC CASE

REPORT FOR ALL MODELS                                  BUS   200 [HYDRO    345]

        ** GENSAL **  BUS   NAME  BSKV MACH    C O N ' S     STATE'S
                      200 HYDRO    345   1    29-   40     13-   17

          MBASE      Z S O R C E          X T R A N        GENTAP   From load
         1750.0  0.00000+J 0.25000   0.00000+J 0.10000   1.02500    flow case

 T'DO   T''DO    T''Q0      H      DAMP    XD      XQ      X'D     X''D     XL      From
5.000   0.050    0.200    5.00     0.00  1.0000  0.7500  0.4000  0.2500  0.1000     CON
                                                                                    data
                                    S(1.0)  S(1.2)                                  array
                                    0.1100  0.6200

     ** SCRX **  BUS   NAME  BSKV MACH    C O N ' S     STATE'S   SOLID
                 200 HYDRO    345   1    153-   160    62-   63    FED

       TA/TB     TB      K       TE     EMIN   EMAX  SWITCH  RC/RFD
       0.100  10.000  200.0   0.050   -5.00   5.00    1.0    10.00

   ** HYGOV **  BUS   NAME  BSKV MACH    C O N ' S     STATE'S    V A R ' S
                200 HYDRO    345   1    215-   226    80-   83     5-    6

 R-PERM R-TEMP   TR    TF    TG    VELM  GMAX  GMIN   TW    AT DTURB  QNL
  0.050  0.300  5.00 0.050 0.500  0.200  1.00  0.00  1.25  1.20 0.50 0.080
```

Figure 26.1. Typical Output from Activity DOCU

```
      PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU JAN 11, 1996   15:23
SAMPLE SYSTEM FOR PSS®E MANUAL
 1100KV DC CASE

 DATA CHECK FOR ALL MODELS                                BUS    100 [NUCLEAR   345]

 BUS    100   MACHINE 1:
 T'Q0=      0.1500
```

Suspicious value of T'_{qo}; that's right! It should be 1.5.

```
         ** GENROU **  BUS    NAME  BSKV MACH    C O N ' S      STATE'S
                       100 NUCLEAR  345    1      1-   14       1-    6

             MBASE      Z S O R C E          X T R A N       GENTAP
            1100.0  0.00000+J 0.20000  0.00000+J 0.15000  1.02500

  T'D0 T''D0  T'Q0 T''Q0     H    DAMP   XD      XQ      X'D     X'Q    X''D     XL
  6.50 0.060  0.15 0.050   4.00   0.00 1.8000 1.7500 0.6000 0.8000 0.2000 0.1500

                                S(1.0)  S(1.2)
                                0.0900  0.3800
```

Warnings! Excitation system data corresponds to a rather high transient gain

```
 BUS    100   MACHINE 1:
 TF1=          2.0000
 KF=           0.1000    TF1=          2.0000    TRANSIENT GAIN=    20.0000

       ** IEEEX1 **  BUS    NAME  BSKV MACH   C O N ' S      STATE'S    VAR
                     100 NUCLEAR  345    1    121-  136      52-   56      1

   TR       KA      TA      TB      TC    VRMAX    VRMIN     KE      TE      KF     TF1
  0.000   46.00   0.060   0.000   0.000   1.000   -0.900   0.000   0.460   0.100   2.000

          SWITCH          E1      S(E1)     E2      S(E2)          KE VAR
             0.0        2.3000   0.1000   3.1000   0.3300          -0.0155

 BUS    100   MACHINE 2:
 T''Q0=     0.0020
 X''D=      0.2000    XL=        0.2300
```

T''_{qo} too small in relation to time step

Something wrong! X_l cannot be larger than X''

```
         ** GENROU **  BUS    NAME  BSKV MACH    C O N ' S      STATE'S
                       100 NUCLEAR  345    2     15-   28       7-    12

             MBASE      Z S O R C E          X T R A N       GENTAP
            1100.0  0.00000+J 0.20000  0.00000+J 0.15000  1.02500

  T'D0 T''D0  T'Q0 T''Q0     H    DAMP   XD      XQ      X'D     X'Q    X''D     XL
  6.50 0.060  0.20 0.002   4.00   0.00 1.8000 1.7500 0.6000 0.8000 0.2000 0.2300

                                S(1.0)  S(1.2)
                                0.0900  0.3800
```

Figure 26.2. Typical Output from Data Checking Mode of Activity DOCU

This example warns of an unacceptably small value of q-axis subtransient time constant and an impossible situation where the value of leakage reactance exceeds that of the subtransient reactance. Both parameters must be reviewed and corrected before PSS®E can give meaningful results. DOCU does not necessarily indicate that parameter values are wrong; it simply indicates that they deserve to be checked. Conversely, the absence of warning messages from DOCU *does not indicate that all data are valid*. Most power system parameters can fall within reasonable normal value ranges and still be invalid. For example, the field rheostat parameter, K_e, of the IEEE type 1 excitation model is often assigned a value of -0.05 in manufacturers' listings of typical excitation system parameters. But this parameter changes as the plant operator changes the manual-mode voltage setpoint of the excitation system, and hence it can vary widely from the typical value, not only between different plants, but as the loading of a given plant is adjusted. Many other excitation system parameters are field adjustable, with the normal adjustment ranges being more than sufficient to cause serious variation of system performance. Section 26.5, "Parameter Ranges for Activity DOCU" contains the parameter range values used by activity DOCU for the various models in the PSS®E model library.

26.1.3. Performance Verification

The proper criterion for the correctness of generator, excitation system, and turbine governor data is not that all parameter values lie within typical ranges but rather, that the parameter values entered for each item correspond to correct performance of that unit under test conditions. After data has been checked for gross errors by activity DOCU, the user should verify that the sets of parameter values correspond to the following:

1. Correct steady-state values of all quantities that are normally measured or documented in normal operation of a generating unit.

2. Correct reproduction of standard dynamic response tests that may be run on generating units or their control systems in isolation.

The testing of data with respect to these criteria is handled by running PSS®E simulations of standard test conditions, observing the steady-state and transient results, and comparing these with either actual test results if available, or with typical unit performance if test data is unavailable. Individual unit operating conditions for which actual or typical performance data are available for the majority of generating units include:

1. Steady-state generator operation at defined load; measurement of steady-state excitation voltage.

2. Exciter response to step change in voltage regulator reference with voltage feedback signal held constant; recording of transient exciter output voltage and of response ratio.

3. Excitation system and generator response to step change in regulator reference point setting with generator at rated speed on open circuit; recording of excitation voltage, E_{fd}, and generator terminal voltage.

The simulation of these test conditions is facilitated by PSS®E activities ESTR, ERUN, GSTR, and GRUN and the support program VCV. No special data or setup is needed; just execute simulation runs using ESTR/ERUN or GSTR/GRUN in place of the normal STRT/RUN combination. The special activities temporarily override the user's channel assignments to place the appropriate unit response quantities into the output channels. These special data verification simulations are used each time a new set of excitation system or governor data is introduced into a study. It is impossible to interpret the results of a simulation of many interconnected machines without the prior knowledge that the individual generators, excitation loops, and governing loops are properly modeled with data values corresponding to an acceptably tuned response for each unit.

26.2. Generator Data

26.2.1. Reactances and Saturation Function

PSS®E requires the specification of *unsaturated* synchronous machine reactances together with specification of two points on the machine's open circuit saturation curve. The correct specification of the saturation data is necessary for the generator field voltage, E_{fd}, to take its correct value at all loadings. The correct initial value of E_{fd} is of major importance in any simulation run where the excitation system ceiling is a significant parameter; that is, in virtually all transient stability runs. Any error in the initial value of E_{fd} in such a simulation produces a corresponding error in the maneuvering range available to raise field flux linkages following a fault. Because this field-forcing effort is a key factor in determining transient stability limits, a correct initial value of E_{fd} is just as important as correct specification of excitation ceiling and generator reactances.

26.2.2. Generator V-Curves

The best form of verification of generator reactance and saturation data is the machine V-curves that plot generator terminal current versus excitation voltage, E_{fd}, over the machine's entire operating range. These curves are commonly provided by generator manufacturers, along with open-circuit saturation curves, as standard design documentation. Typical manufacturers' data is shown in Table 26.1, "Typical Generator Reactance and Time Constant Data, Rated Output 69 MW, 0.9 pf" as well as Figure 26.4, "Saturation Curve as Supplied by Manufacturer; Corresponds to Table 26.1, "Typical Generator Reactance and Time Constant Data, Rated Output 69 MW, 0.9 pf"" and Figure 26.3, "Typical Generator V-Curves as Supplied by Manufacturer Corresponds to Table 26.1, "Typical Generator Reactance and Time Constant Data, Rated Output 69 MW, 0.9 pf"". Figure 26.5, "VCV Graphical Output for Case Where Full Machine Data is Known" shows program VCV graphic output used to verify that a set of data extracted from Table 26.1, "Typical Generator Reactance and Time Constant Data, Rated Output 69 MW, 0.9 pf" and Figure 26.4, "Saturation Curve as Supplied by Manufacturer; Corresponds to Table 26.1, "Typical Generator Reactance and Time Constant Data, Rated Output 69 MW, 0.9 pf"" does correctly reproduce the generator's steady-state characteristics.

Table 26.1. Typical Generator Reactance and Time Constant Data, Rated Output 69 MW, 0.9 pf

Reactance or Time Constant	Unsaturated	Saturated
x_d	1.974	
x'_d	0.26	0.196
x''_d	0.171	0.128
x_q	1.882	
x'_q	0.41	
x_l	0.141	
T'_{do}	6.6	
T''_{do}	0.023	
T'_{qo}	0.48	
T''_{qo}	0.049	

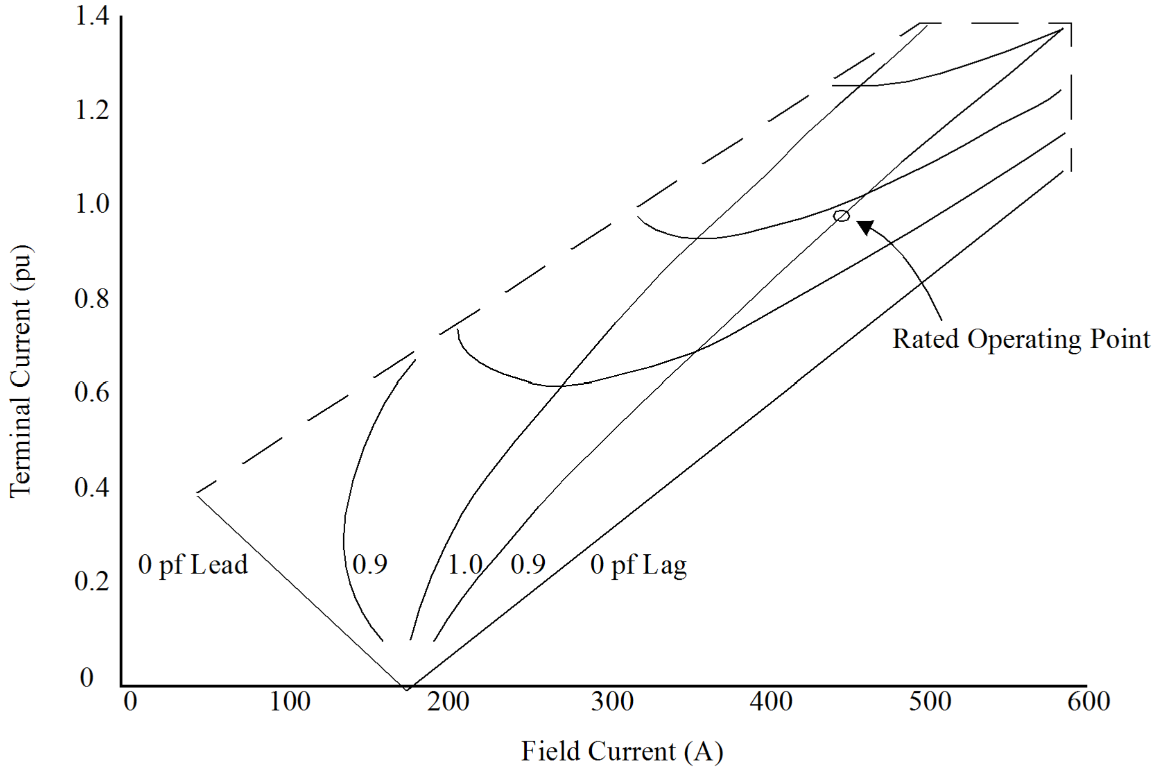


Figure 26.3. Typical Generator V-Curves as Supplied by Manufacturer Corresponds to Table 26.1, "Typical Generator Reactance and Time Constant Data, Rated Output 69 MW, 0.9 pf"

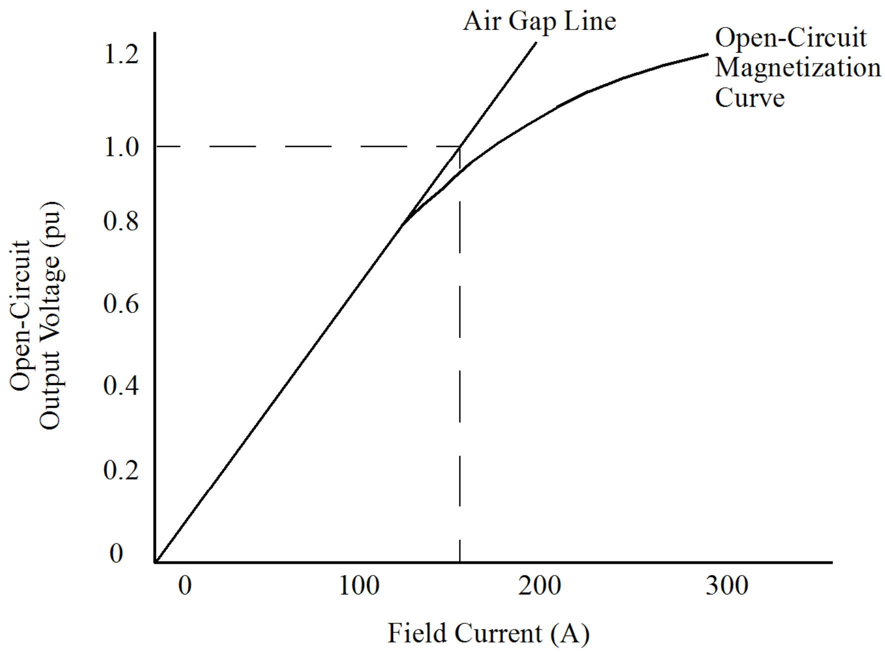


Figure 26.4. Saturation Curve as Supplied by Manufacturer; Corresponds to Table 26.1, “Typical Generator Reactance and Time Constant Data, Rated Output 69 MW, 0.9 pf”

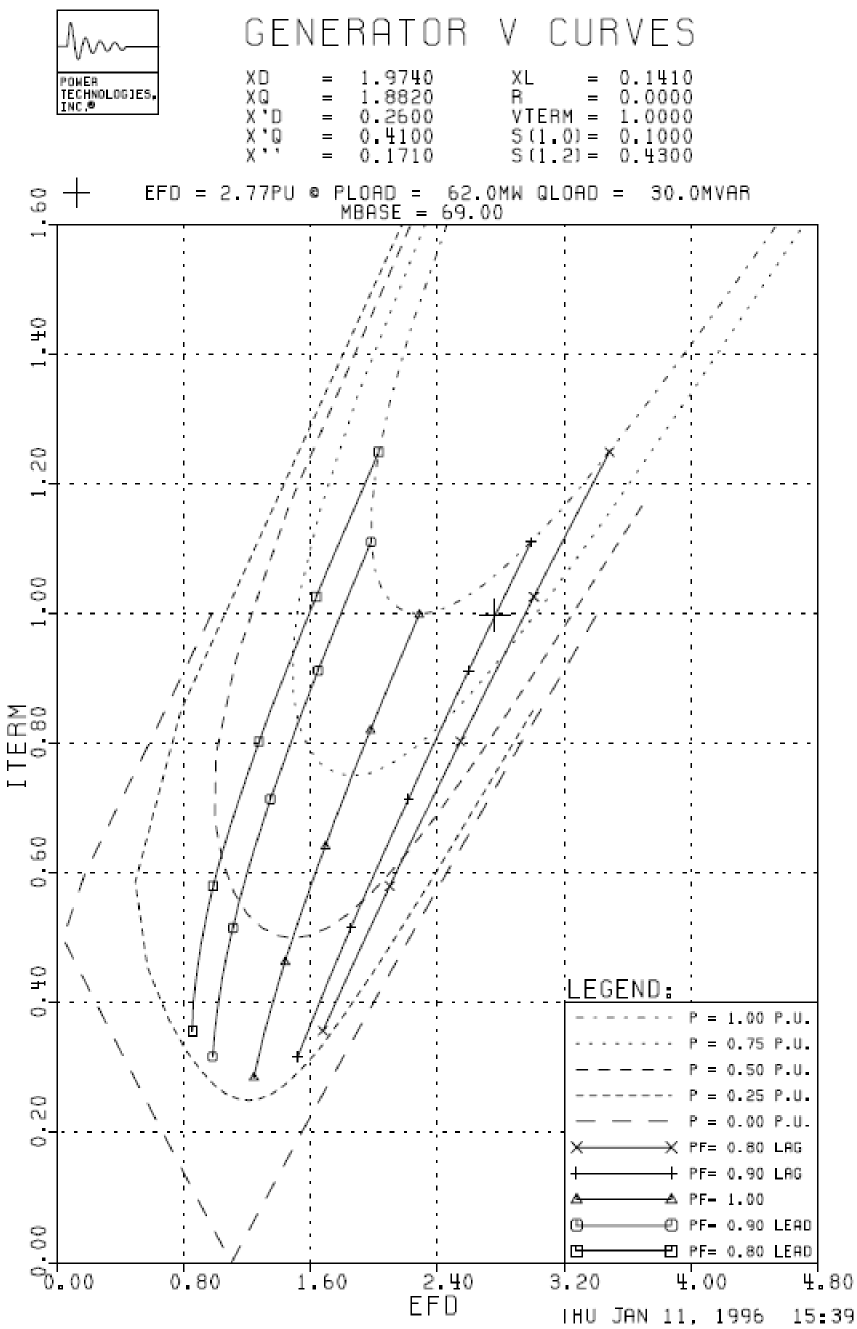


Figure 26.5. VCV Graphical Output for Case Where Full Machine Data is Known

Examining Figure 26.3, “Typical Generator V-Curves as Supplied by Manufacturer Corresponds to Table 26.1, “Typical Generator Reactance and Time Constant Data, Rated Output 69 MW, 0.9 pf”” shows that the air gap line field-current for rated voltage, open circuit is 162 A, and field current at rated load, rated power factor = 448 A. Hence, E_{fd} at rated output 448/162 = 2.77 per unit. The results computed by VCV on the basis of the proposed generator data agrees with this value. VCV also allows the user to enter specific loading information. It calculates and prints the E_{fd} at that loading, as well as the internal machine angle relative to the terminal voltage assumed at a zero angle. The typical PSS®E user would not normally use the angle but someone doing machine testing could find it valuable.

26.2.3. Use of Typical Machine Data

While the complete data of Figure 26.5, "VCV Graphical Output for Case Where Full Machine Data is Known" is the ideal, it is often necessary to set up machine data on the basis of a much less detailed machine specification. The traditional approach in the face of minimal or incomplete machine data abandons the properly detailed synchronous machine models such as GENROU and GENSAL and uses the classical machine model, as implemented by GENCLS in PSS®E. This approach was justified with previous generations of stability programs, largely by the argument that the widespread use of detailed machine models would involve an unacceptable penalty in computational efficiency. The use of the GENCLS classical model offers no significant computational advantage in PSS®E, however. More importantly, the use of GENROE, GENSAE, GENROU and GENSAL for the majority of machines involves no significant penalty in PSS®E. Correspondingly, no justification exists for use of GENCLS to model incompletely specified machines in PSS®E. Such an approach forces the simulation of these machines to neglect all generator damping effects, indicate incorrect machine internal voltage and reactive power output in the postdisturbance steady state, and neglect both steady-state and dynamic effects of voltage regulators.

It is perfectly reasonable to assume that the majority of machines for which complete data is unavailable are basically of conventional design, that they do contribute damping torques, that they are subject to voltage regulator action, and that they do adopt postdisturbance conditions according to synchronous reactance values. It follows, therefore, that the preferred approach to the representation of incompletely specified machines is to use the detailed machine models GENROE, GENSAE, GENSAL, and GENROU with typical data that represents the principal response characteristics of normal generators. Furthermore, voltage regulator action at these machines should be represented by a simple excitation system model with data set to give typical conservative response characteristics; a special excitation system model, SEXS, is provided in the PSS®E model library for this purpose.

The user can conveniently characterize generator reactance values by the value they imply for field voltage, E_{fd}, at full load in the absence of saturation. Figure 26.6, "Excitation Voltages at Rated MVA Using Typical Generator Data (Saturation Neglected)" shows the values of E_{fd} corresponding to full load and various power factors. The plot in Figure 26.6, "Excitation Voltages at Rated MVA Using Typical Generator Data (Saturation Neglected)" reveals slight difference in the calculated E_{fd} due to variation in X_q for unity and leading power factors. Rated lagging power has a difference of about 25%. Figure 26.7, "Estimation of SE(1.2) for Use with Typical Generator Data of and Figure 26.8, "Typical Salient Pole Generator Data"" shows the value of SE(1.2) needed to give a value of E_{fd} exceeding the unsaturated value of Figure 26.6, "Excitation Voltages at Rated MVA Using Typical Generator Data (Saturation Neglected)" by 25% at rated load and 0.9 (lagging) power factor. Figure 26.6, "Excitation Voltages at Rated MVA Using Typical Generator Data (Saturation Neglected)" and Figure 26.7, "Estimation of SE(1.2) for Use with Typical Generator Data of and Figure 26.8, "Typical Salient Pole Generator Data"" apply only for the typical machine reactance ratios of Figure 26.8, "Typical Salient Pole Generator Data" and Figure 26.9, "Typical Solid Rotor Generator Data". For machines with known specific reactances, but no saturation curve, the values of $S_E(1.0)$ and $S_E(1.2)$ can be estimated by program VCV. The value of $S_E(1.2)$ is dependent upon the generator synchronous reactance because increasing machine reactance requires a higher internal flux level to support a given terminal voltage and loading. Figure 26.6, "Excitation Voltages at Rated MVA Using Typical Generator Data (Saturation Neglected)" and Figure 26.7, "Estimation of SE(1.2) for Use with Typical Generator Data of and Figure 26.8, "Typical Salient Pole Generator Data"" may be used to estimate a proper value of $S_E(1.2)$ and of exciter ceiling level when using the typical data of Figure 26.8, "Typical Salient Pole Generator Data" through Figure 26.10, "Typical Excitation System Model and Data for Use when Detailed Data is Not Available", which show data forms for models GENSAL, GENROU, and SEXS listing suitable sets of typical data for salient pole generators, turbine generators, and excitation systems, respectively.

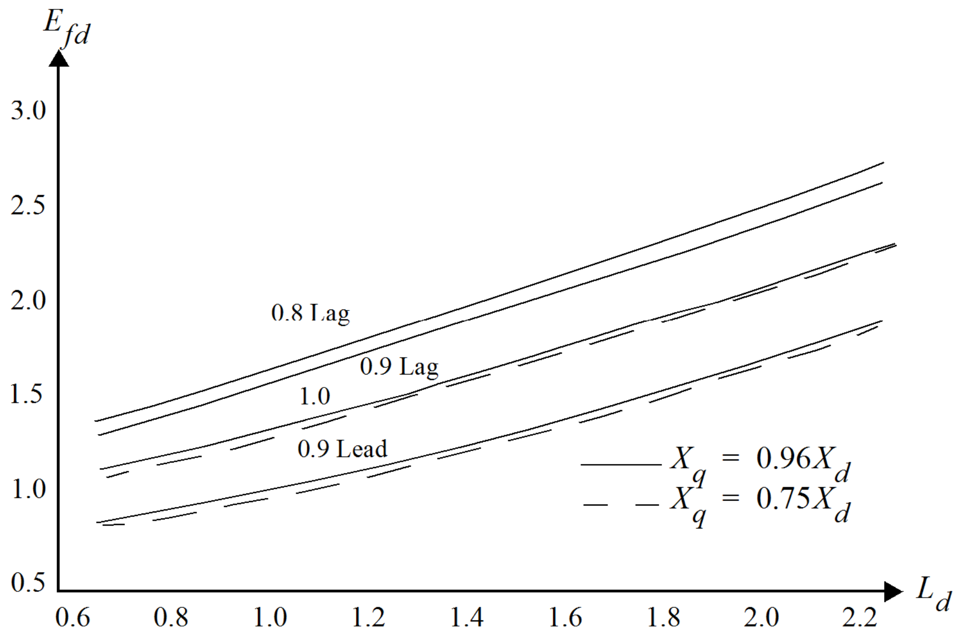


Figure 26.6. Excitation Voltages at Rated MVA Using Typical Generator Data (Saturation Neglected)

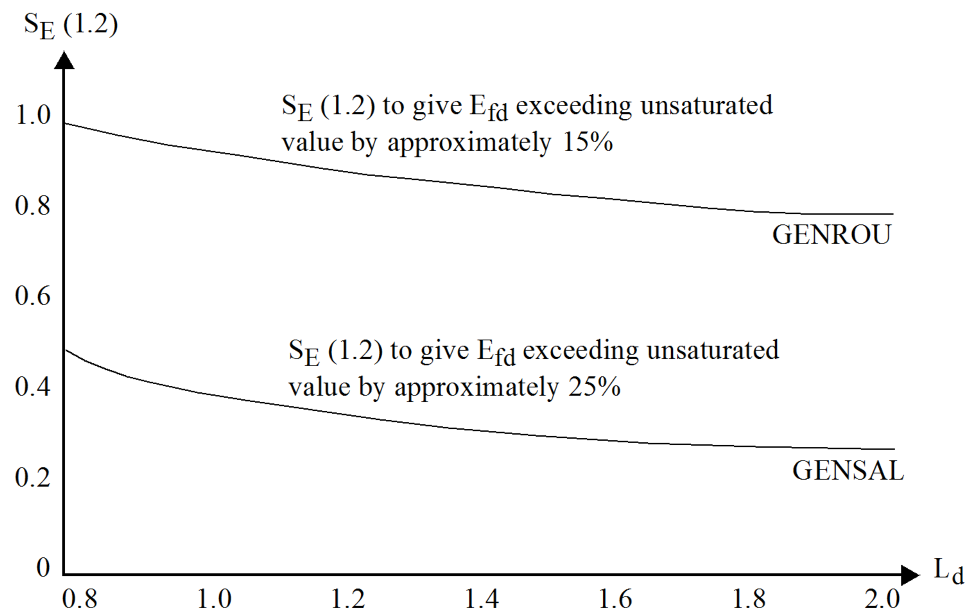
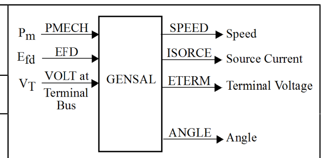


Figure 26.7. Estimation of SE(1.2) for Use with Typical Generator Data of Figure 26.7, "Estimation of SE(1.2) for Use with Typical Generator Data of and Figure 26.8, "Typical Salient Pole Generator Data"" and Figure 26.8, "Typical Salient Pole Generator Data"

GENSAL

Salient Pole Generator Model (Quadratic Saturation on d-Axis)

This model is located at system bus	# 100 [a]	IBUS,
machine	# 1*	I.
This model uses CONs starting with	#_____	J,
and STATEs starting with	#_____	K.
The machine MVA is 5* for each of 1* units = 5* MBASE.		
ZSORCE for this machine is 0* + j 0.25* on the above MBASE.		



[a]See power flow data, Figure 13-4.

CONs	#	Value	Description
J		5	T'_{do} (>0) (sec)
J+1		0.05	T''_{do} (>0) (sec)
J+2		0.06	T''_{qo} (>0) (sec)
J+3		5.084	Inertia, H
J+4		1	Speed damping, D
J+5		1.5	X_d
J+6		1.2	X_q
J+7		0.4	X'_d
J+8		0.25	$X''_d = X''_q$
J+9		0.12	X_l
J+10		0.03	S(1.0)
J+11		0.25	S(1.2)

X_d, X_q, X'_d, X''_d, X''_q, X_l, H, and D are in pu, machine MVA base.

X''_q must be equal to X''_d.

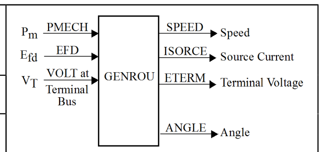
STATEs	#	Description
K		E'_q
K+1		ψ''_q
K+2		ψ kd
K+3		Δ speed (pu)
K+4		Angle (radians)

IBUS, 'GENSAL', I, T'_{do}, T''_{do}, T''_{qo}, H, D, X_d , X_q, X'_d, X''_d, X_l , S(1.0), S(1.2)/

Figure 26.8. Typical Salient Pole Generator Data

GENROU

Round Rotor Generator Model (Quadratic Saturation)

This model is located at system bus	# 100 [a]	IBUS,	
machine	# 1*	I.	
This model uses CONs starting with	#_____	J,	
and STATEs starting with	#_____	K,	
The machine MVA is 5* for each of 1* unit = 5* MBASE.			
ZSORCE for this machine is 0 + j 0.25 on the above MBASE			

[a]See power flow data, Figure 13-4.

CONs	#	Value	Description
J		6	T'_{do} (>0) (sec)
J+1		0.05	T''_{do} (>0) (sec)
J+2		1	T'_{qo} (>0) (sec)
J+3		0.05	T''_{qo} (>0) (sec)
J+4		3	Inertia, H
J+5		0	Speed damping, D
J+6		1.4	X_d
J+7		1.35	X_q
J+8		0.3	X'_d
J+9		0.6	X'_q
J+10		0.2	$X''_d = X''_q$
J+11		0.1	X_l
J+12		0.03	S(1.0)
J+13		0.4	S(1.2)

X_d, X_q, X'_d, X'_q, X''_d, X''_q, X_l, H, and D are in pu, machine MVA base.

X''_q must be equal to X''_d.

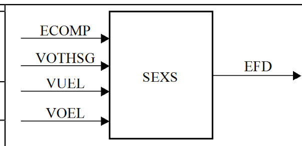
STATEs	#	Description
K		E'_q
K+1		E'_d
K+2		ψ kd
K+3		ψ kq
K+4		Δ speed (pu)
K+5		Angle (radians)

IBUS, 'GENROU', I, T'_{do}, T''_{do}, T''_{qo}, T''_{qo}, H, D, X_d , X_q, X'_d, X'_q , X''_d, X_l, S(1.0), S(1.2)/

Figure 26.9. Typical Solid Rotor Generator Data

SEXS

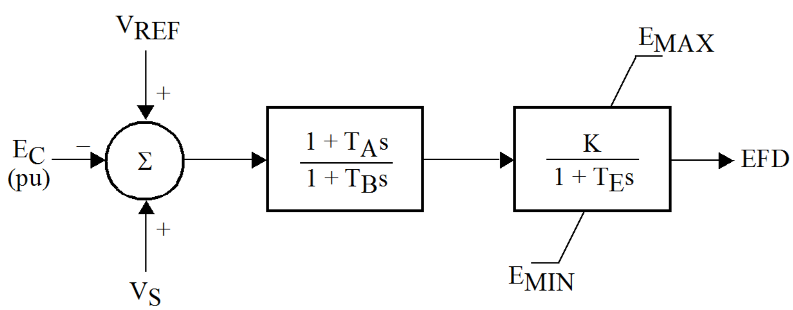
Simplified Excitation System

This model is located at system bus	# 201	IBUS,	
machine	# 1	I,	
This model uses CONs starting with	#____	J,	
and STATEs starting with	#____	K.	

CONs	#	Value	Description
J		0.1	T_A/T_B
J+1		10	T_B (>0) (sec)
J+2		100	K
J+3		0.1	T_E (sec)
J+4		0	E_{MIN} (pu EFD base)
J+5		3	E_{MAX} (pu EFD base)

STATEs	#	Description
K		First integrator
K+1		Second integrator

IBUS, 'SEXS', I, T_A /T_B, T_B, K, T_E , E_{MIN}, E_{MAX}/



V_S = VOTHSG + VUEL + VOEL

Figure 26.10. Typical Excitation System Model and Data for Use when Detailed Data is Not Available

26.3. Excitation System Data

26.3.1. General Considerations

The verification of excitation system data is complicated by several factors: the existence of a wide variety of types, the fact that key parameter values may depend upon the reactances of the generators to which they are applied, and operating conditions. Checking parameter values against typical values is unrewarding in many cases, but useful checks can be made by using activities ESTR and ERUN to simulate excitation system tests. The use of these tests can best be illustrated by example.

26.3.2. Exciter Ceiling

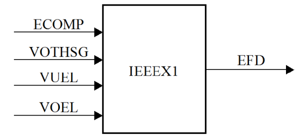
The ceiling field voltage obtainable from many excitation systems is determined largely by the saturation characteristic of the exciter and, to a secondary extent, by the maximum output available from the excitation control source, particularly in the case of dc exciter systems. Figure 26.11, "Sample Data for Excitation System Data Verification" shows the transfer function diagram of a fairly typical dc excitation system from the 1950s. This system, represented by the model IEEEX1, uses a dc generator as its main exciter, with control being exerted by an amplidyne. The excitation system is presumed, on the basis of contract documents, to have a specified response ratio of 1.0 and a specified ceiling of twice rated excitation. An initial estimate of the data for this exciter, taken from manufacturer's typical data, is shown in Figure 26.11, "Sample Data for Excitation System Data Verification". A run of ESTR/ERUN is used to check that this data corresponds to the specified performance of this excitation system. (This method leaves open the question of whether the actual performance matches the specification, but is better than using typical data with no check at all.Interest centers first on the saturation curve parameters and the amplidyne output limit, V_{RMAX}. Activity ESTR determines the value of the exciter field resistance parameter K_e. The amplidyne output limit V_{RMAX} is fixed at 1.05 in the initial trial by setting the constant, CON(J+7), corresponding to K_e, to zero and allowing the initialization to determine K_e as a variable in each run. Curve A of Figure 26.12, "Saturation Curves of Initial dc Exciter Model, (A) and Proposed Model of Larger Exciter, (B)" represents the saturation curve used in the first trial.

The first step in checking the excitation system data, after the use of DOCU,CHECK, is to confirm that the exciter saturation curve data is properly related to the excitation requirement of the main generator. It is good practice to assign E_1 a value close to rated load excitation voltage, and E_2 a value close to ceiling excitation voltage. (The excitation voltage at rated load is not 1.0; unity excitation voltage gives rated main generator voltage on open circuit in the absence of saturation.) The Response Ratio Test option of activity ESTR is used to initialize the generator at rated output. The preceding DOCU output confirms that the K_e constant has been set to zero to tell the model to calculate its own value for K_e, and that this value will be placed in VAR(1). The ESTR output for the unit at bus 1 shows a rated load value of E_{fd} of 2.6665 and thus confirms that the value, 2.47, specified for E_1 in the exciter data is well placed relative to the rated output of the exciter. A value of E_1 that is not close to rated exciter output should be reviewed because it is likely that it was obtained from data on an exciter different from the one under consideration. After initializing for the response ratio test, activity DOCU would show the value of K_e determined by the model for the rated operating condition (see Section 16.2.4). The K_e value, –0.599, is quite reasonable. Furthermore, activity DLST would confirm that the amplidyne control element, which is shown by Figure 26.11, "Sample Data for Excitation System Data Verification" to be STATE(K+2), has been initialized at 10% of its positive range.

IEEEX1

IEEE Type 1 Excitation System

This model is located at system bus	#_____	IBUS,
machine	#_____	I,
This model uses CONs starting with	#_____	J,
and STATEs starting with	#_____	K,
and VAR	#______	L.



CONs	#	Value	Description
J		0	T_R (sec)
J+1		40	K_A
J+2		.06	T_A (sec)
J+3		1.	T_B (sec)
J+4		1.	T_C (sec)
J+5		1.05	V_{RMAX} or zero
J+6		-1.05	V_{RMIN}
J+7		*	K_E or zero
J+8		.5	T_E (>0) (sec)
J+9		.08	K_F
J+10		2.	T_{F1} (>0) (sec)
J+11		0	Switch
J+12		2.47	E_1
J+13		.035	$S_E(E_1)$
J+14		3.5	E_2
J+15		.6	$S_E(E_2)$

STATEs	#	Description
K		Sensed V_T
K+1		Lead lag
K+2		Regulator output, V_R
K+3		Exciter output, EFD
K+4		Rate feedback integrator

VAR	#	Description
L		K_E

IBUS, 'IEEEX1', I, T_R, K_A, T_A, T_B, T_C, V_{RMAX}, V_{RMIN}, K_E, T_E, K_F, T_{F1}, 0., E_1, $S_E(E_1)$, E_2, $S_E(E_2)$/

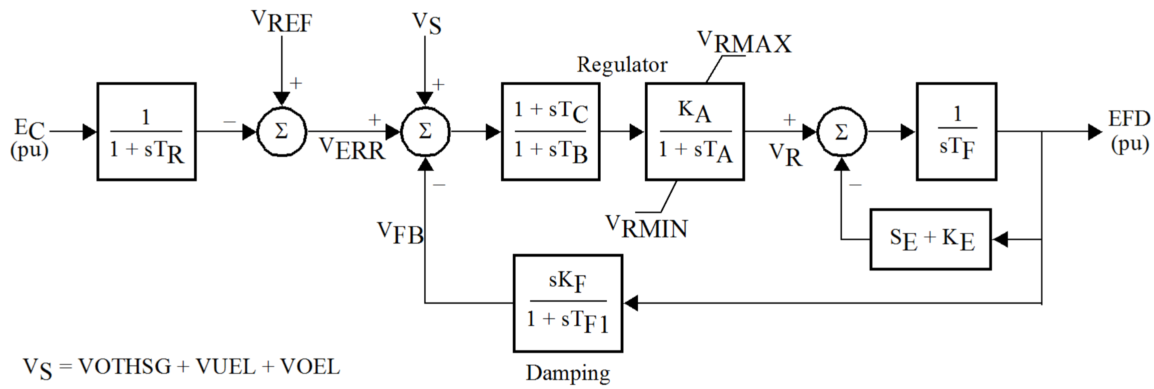


Figure 26.11. Sample Data for Excitation System Data Verification

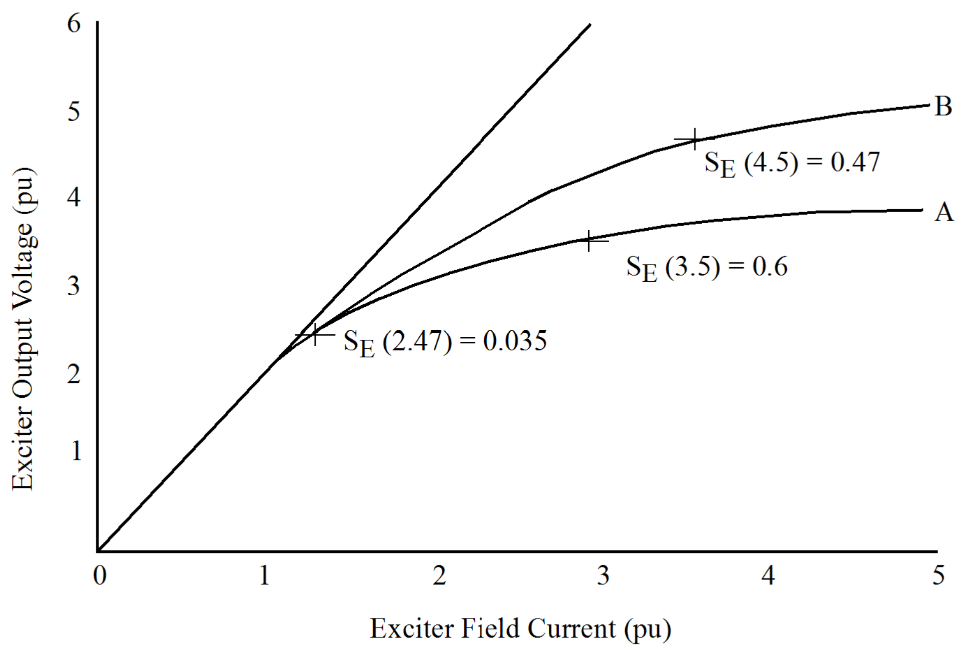


Figure 26.12. Saturation Curves of Initial dc Exciter Model, (A) and Proposed Model of Larger Exciter, (B)

The foregoing confirms that the excitation system data is reasonable with regard to the steady state. The next step is to run activity ERUN. When run after activity ESTR in response ratio mode, ERUN automatically steps the voltage regulator reference upward by a large amount, forcing the excitation system as rapidly as possible to ceiling. The ESTR/ERUN combination automatically overrides existing channel assignments and places machine field voltages in the first n channels where n is the number of units in the power flow case. The output of ERUN shows the rise of units excitation and at t = 0.5 sec automatically records the response ratio of each exciter. The response ratio, as defined in the IEEE Transactions, Volume PAS-88, 1969, is then defined. This area is shown in Figure 26.13, "Evaluation of Response Ratio by Activity ERUN". After an adequate time, the ERUN simulation settles with each exciter at its ceiling.

Using curve A of Figure 26.12, "Saturation Curves of Initial dc Exciter Model, (A) and Proposed Model of Larger Exciter, (B)" for saturation, ESTR would show that the response ratio is 0.456 and the ceiling is 3.1957.

Both values are far below the target values of 1.0 and 2 × 2.67 = 5.34, respectively. Examination of the IEEEX1 block diagram shows that

- The initial rate of rise of excitation voltage is determined principally by the maximum output, V_{RMAX}, of the control element.
- The excitation ceiling is determined principally by saturation of the exciter and, secondarily, by the value of V_{RMAX}.

The low values of response ratio and ceiling shown by an initial ESTR/ERUN test indicate that both V_{RMAX} and the exciter saturation curve must be revised.

Doubling the size of the amplidyne by changing V_{RMAX} to 2.1 raises the response ratio from 0.456 to 0.832 and ceiling from 3.1957 to 3.52, which is insufficient. The added effect of changing the exciter saturation characteristic from curve A to curve B of Figure 26.12, "Saturation Curves of Initial dc Exciter Model, (A) and Proposed Model of Larger Exciter, (B)" raises the response ratio to 1.126 and ceiling to a value somewhat above 4.34 per unit. These values are close, but not yet at the target values. Another trial should bring the test performance very close to target. Figure 26.14, "Exciter Responses in Response Ratio and Ceiling Tests for IEEEX1" summarizes the results of the three response ratio tests.

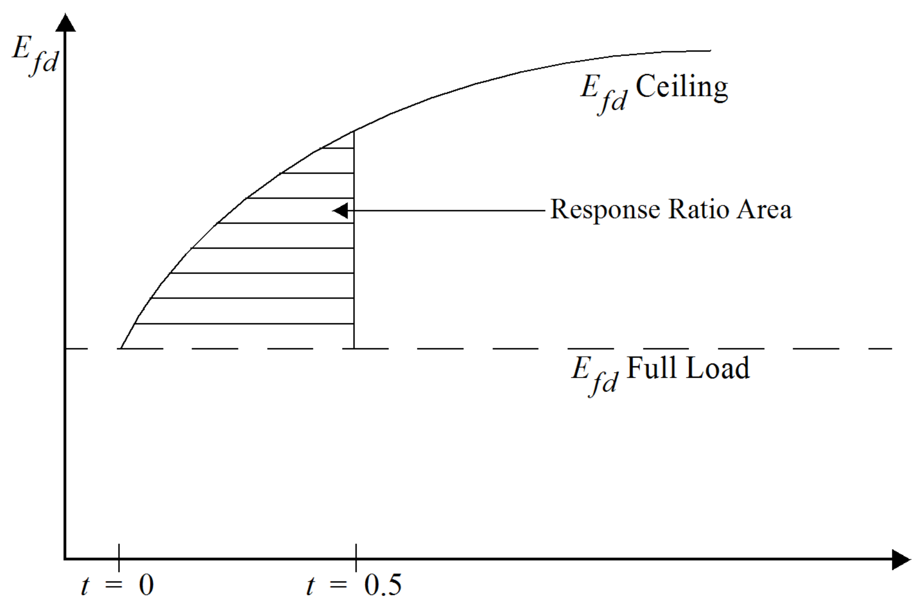


Figure 26.13. Evaluation of Response Ratio by Activity ERUN

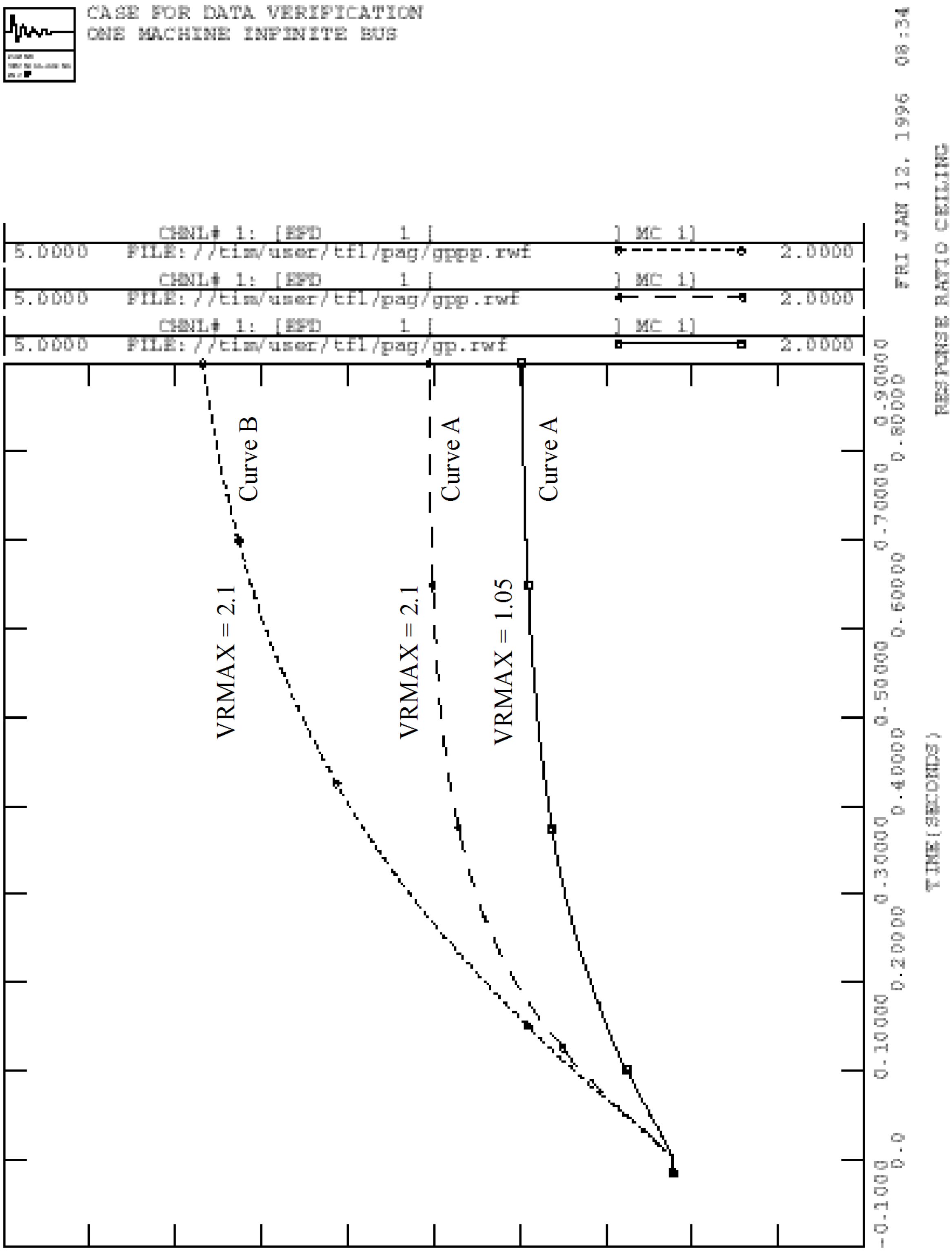


Figure 26.14. Exciter Responses in Response Ratio and Ceiling Tests for IEEEX1

26.3.3. Checking of Automatically Initialized Parameters

Example Based on Model IEEEX1

The automatic calculation of those excitation system parameters that are dependent on generator loading is intended to handle the task in a reasonable manner in the majority of plants in a large system study. It is emphasized, however, that it is the implementation of reasonable assumptions only, and that the results should be checked by the engineer in critical situations.

An example of the need for a specific check arises in the example completed above. Here the size of the amplidyne represented by the IEEEX1 model was doubled and the model was reinitialized at full load with automatic calculation of the parameter, K_e. A DOCU output obtained just after activity ESTR shows a positive value of K_e, $K_e = 0.168$. A positive value of K_e implies that the manual setting of the exciter field resistance is above the self-excitation limit and hence that the exciter is dependent upon the amplidyne to maintain its steady state. This implication is not necessarily incorrect, but is contrary to the normal intention that the exciter should be in self-excited mode with the amplidyne providing only a trimming effect.

The questionable situation can be corrected by recognizing that the key item in determining K_e is not the value of K_e itself but, rather, is the value of the amplidyne output signal. The model data sheet, Figure 26.11, "Sample Data for Excitation System Data Verification", shows that this quantity is available as STATE(K+2). The criterion for correctness of the parameter, K_e, is that the value of this state should be near to the middle of its range. A K_e value requiring K_e to be near the upper end of its range would correspond to an operation where the control system is using nearly all of its control effort capability to maintain a steady state and hence has little capability to increase excitation when this is required. (The converse applies with regard to excitation decrease.) Such operation is bad practice and would surely not be intended. The recommended approach in this case of a positive value of K_e would be to:

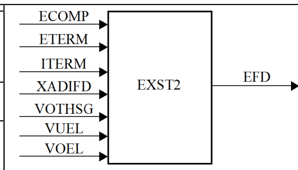
- Change K_e from the positive value as calculated by the IEEEX1 model to a proper negative value by placing the desired nonzero value in CON(J+7); see Figure 26.11, "Sample Data for Excitation System Data Verification".
- Rerun activity ESTR or STRT to reinitialize all state variables.
- Recheck the amplidyne output signal, STATE(K+2), to ensure that it is reasonably placed in the range between V_{RMAX} and V_{RMIN}.
- Adjust the value of K_e in CON(J+7) and repeat the process if necessary.

Example Based on Model EXST2

A second example of the importance of checking automatically calculated parameters is provided by the setup of model EXST2 to represent an SCPT-type excitation system where exciting power is obtained from compounded potential and current transformers. Figure 26.15, "Initial Data Estimate for Compounded Transformer-Type Excitation System (Sheet 2 of 2)" shows the EXST2 data sheet filled in with representative first trial data. The value of K_I, CON(J+10), has been set to zero to tell the model to determine a value for K_I. K_I, unlike K_e in model IEEEX1, is a design constant and does not vary with machine loading or operator action. The value of K_I should, therefore, be determined once and then fixed by placing an appropriate positive value in CON(J+10)

EXST2

IEEE Type ST2 Excitation System

This model is located at system bus	#_____	IBUS,	
machine	#_____	I,	
This model uses CONs starting with	#_____	J,	
and STATEs starting with	#_____	K,	
and VAR	#_____	L.	

CONs	#	Value	Description
J		0	T_R (sec)
J+1		120	K_A
J+2		.15	T_A (sec)
J+3		1.2	V_{RMAX}
J+4		-1.2	V_{RMIN}
J+5		1.0	K_E
J+6		0.5	T_E (>0) (sec)
J+7		.02	K_F
J+8		1.	T_F (>0) (sec)
J+9		1.19	K_P
J+10		0	K_I or zero
J+11		.7	K_C
J+12		4.5	EFD_{MAX}

STATEs	#	Description
K		Sensed V_T
K+1		Regulator output, V_R
K+2		Exciter output, EFD
K+3		Rate feedback integral

VAR	#	Description
L		K_I

IBUS, 'EXST2', I, T_R, K_A, T_A, V_{RMAX}, V_{RMIN}, K_E, T_E, K_F, T_F, K_P, K_I, K_C, EFD_{MAX}/

Initial Data Estimate for Compounded Transformer-Type Excitation System

(Sheet 1 of 2)

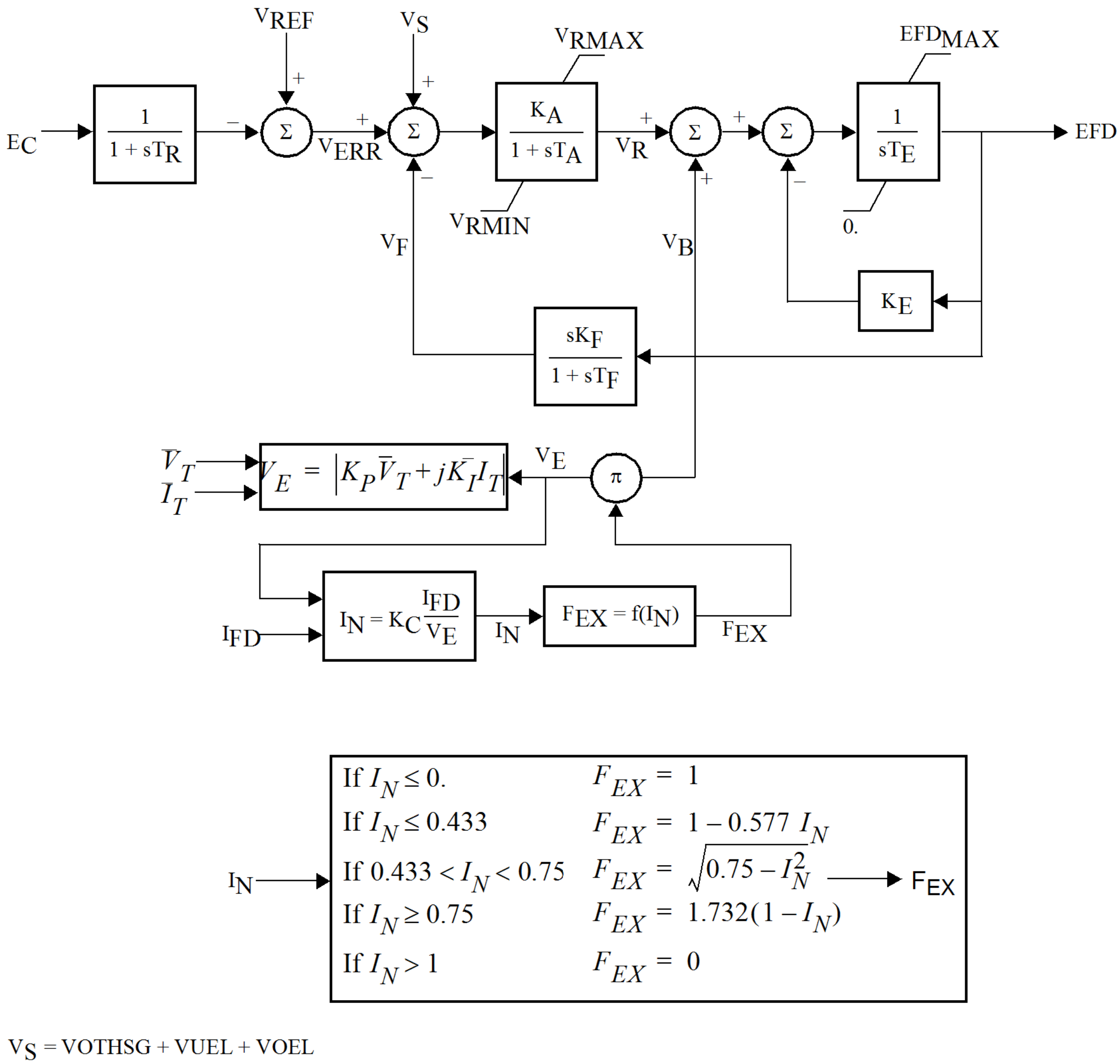


Figure 26.15. Initial Data Estimate for Compounded Transformer-Type Excitation System (Sheet 2 of 2)

Figure 26.16, "Use of ESTR to Determine Value of EXST2 K_I Parameter Corresponding to Different Generator Rated Power Factors" shows the first execution of ESTR to initialize a generator at 0.9 power factor. The resulting value is shown by DOCU to be 3.084, which is nearly twice the main generators quadrature synchronous reactance; a high value for K_I. The second execution of ESTR, also shown in Figure 26.16, "Use of ESTR to Determine Value of EXST2 K_I Parameter Corresponding to Different Generator Rated Power Factors", initializes the generator at unity power factor. The ensuing DOCU output shows that K_I is calculated at 2.78 in this condition. These two automatically calculated values of K_I indicate what K_I would have to be to produce the required excitation voltage at full load with zero output, V_r, from the voltage regulating element. This assumption is now overridden and, in Figure 26.17, "Presetting of K_I = 2.5 and Checking for Reasonableness of Required Voltage Regulator Output", the K_I constant (CON(J+7) or CON(27), in this setup, is set to 2.5; a value that will require some output from the regulating element in the steady state at high generator loads. Figure 26.17, "Presetting of K_I = 2.5 and Checking for Reasonableness of Required Voltage Regulator Output" next shows a reinitialization at 0.9 pf to determine the value of regulating element output required by the value K_I = 2.5. The following DLST output shows that V_R (STATE(10) in this setup) has the initial steady-state value of 0.6146. This is above one half of the regulating elements operating range; it draws attention to the value of the parameter, K_C, which characterizes commutating drop in the excitation rectifier.

Figure 26.18, "Change of KC Parameter of EXST2 Model to 0.5 to Reduce Commutation Drop Modeled in Excitation Rectifier Unit, and Recheck of Steady-State Values of Excitation System Variables" shows the effect of changing K_C, CON(28) in this setup, from 0.7 to 0.5. Initialization at 0.9 pf now results in a very reasonable value of 0.2328 for the output of the regulating element and suggests that a reasonable set of data values has been reached.

A statement of typical excitation system parameters is of little value in this example unless it is coordinated with data on the reactances and rated power factor of the main generator. As a general rule, excitation system data stated in isolation from corresponding main generator data should be treated with considerable distrust.

26.3.4. Excitation Loop Tuning

The data checks and excitation system ceiling tests described above pertain mainly to the sizing and output limits of the excitation system power components; they reveal little about the correctness of parameters, such as KA and KF in IEEEX1 or EXST2, involved in the voltage regulator loop. These parameters must be checked by a test where the result depends on the inherent dynamic characteristics of the regulator loop, rather than on equipment ratings and limits.

Voltage regulator parameters can be checked readily by simulating the response of the excitation system and generator to a step change in voltage regulator reference when the generator is running at rated speed on open circuit. This test is simulated automatically by ESTR and ERUN when the OPEN CIRCUIT SETPOINT STEP TEST option of activity ESTR is selected. Its use is best illustrated by an additional example.

The open-circuit step test on the generator and EXST2 excitation system model combination was run on the data refined in the section called "Example Based on Model EXST2". The plotted result of the test is shown in Figure 26.19, "Plotted Response from Open-Circuit Step Test of Model EXST2". The excitation system is much too oscillatory. A review of Section 16.4.1 suggests that the voltage regulator gives too high a gain at the frequency of the oscillation, about 1 Hz, and that an increased value of the rate feedback gain, K_F, in the EXST2 model would improve the tuning of the system. Figure 26.20, "Plotted Response of Open-Circuit Step Test for Model EXST2 but with Rate Feedback Gain, K_F, Increased to 0.05" shows the plotted result from re-execution of the open circuit step test with the value of K_F increased from 0.02 to 0.05. The increased rate feedback gain produces the desired result of quenching the oscillatory behavior while retaining a quick, well-tuned tracking of the step change.

```
ACTIVITY? estr
```

Use ESTR to initialize generators at rated load

```
ENTER 0 FOR RESPONSE RATIO TEST
      1 FOR OPEN CIRCUIT SETPOINT STEP TEST: 0

ENTER DEFAULT POWER FACTOR: .9
```

0.9 pf for first trial

```
ENTER BUS NUMBER, MACHINE ID, POWER FACTOR:

    PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI JAN 12, 1996  10:35
CASE FOR DATA VERIFICATION
ONE MACHINE INFINITE BUS

INITIAL CONDITION LOAD FLOW USED  0 ITERATIONS

--------------------------MACHINE INITIAL CONDITIONS--------------------------
X------ BUS -----X ID  ETERM   EFD     POWER    VARS   P.F.   ANGLE    ID     IQ
    1               1 1.0000 2.6665   90.00    43.59 0.9000  38.19 0.8990 0.4379

ENTER CHANNEL OUTPUT FILENAME:
```

E_{fd} = 2.67 defines rated size of excitation system if generator is rated for 0.9 pf

```
ACTIVITY? docu
```

DOCU is convenient way to examine value of K_I as calculated by EXST2 model

```
        ** GENROU **  BUS    NAME  BSKV MACH    C O N ' S      STATE'S
                        1                 1      1-   14      1-    6

            MBASE      Z S O R C E          X T R A N       GENTAP
            100.0  0.00000+J 0.19800  0.00000+J 0.00000  1.00000

 T'DO T''DO  T'QO T''QO     H   DAMP   XD     XQ    X'D    X'Q   X''D    XL
 5.00 0.050  1.00 0.050   3.50  0.00 1.8000 1.7280 0.2700 0.4500 0.1980 0.0800

                               S(1.0)  S(1.2)
                               0.1000  0.5000
```

K_I is calculated as 3.084 to hold required excitation voltage with zero voltage regulator output

```
      ** EXST2 **  BUS    NAME  BSKV MACH  C O N ' S      STATE'S   VAR
                     1                 1   15-   27      7-   10     1

            TR       KA       TA     VRMAX   VRMIN     KE       TE
           0.000   120.0    0.150    1.200  -1.200    1.000    0.500

            KF       TF       KP      KI      KC    EFDMAX   KI VAR
           0.020   1.000    1.190    0.000   0.700   4.500    3.084
```

K_I CON is zero to force automatic calculation

```
ACTIVITY? estr

ENTER 0 FOR RESPONSE RATIO TEST
      1 FOR OPEN CIRCUIT SETPOINT STEP TEST: 0

ENTER DEFAULT POWER FACTOR: 1
```

Second trial with generator operated at unity power factor

```
ENTER BUS NUMBER, MACHINE ID, POWER FACTOR:

    PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI JAN 12, 1996  10:36
CASE FOR DATA VERIFICATION
ONE MACHINE INFINITE BUS

INITIAL CONDITION LOAD FLOW USED  0 ITERATIONS

--------------------------MACHINE INITIAL CONDITIONS--------------------------
X------ BUS -----X ID  ETERM   EFD     POWER    VARS   P.F.   ANGLE    ID     IQ
    1               1 1.0000 2.1452  100.00     0.00 1.0000  57.36 0.8421 0.5394

ENTER CHANNEL OUTPUT FILENAME:
```

E_{fd} = 2.15 defines smaller rating required of excitation system if generator rated power factor is raised to unity

```
ACTIVITY? docu

      ** EXST2 **  BUS    NAME  BSKV MACH  C O N ' S      STATE'S   VAR
                     1                 1   15-   27      7-   10     1

            TR       KA       TA     VRMAX   VRMIN     KE       TE
           0.000   120.0    0.150    1.200  -1.200    1.000    0.500

            KF       TF       KP      KI      KC    EFDMAX   KI VAR
           0.020   1.000    1.190    0.000   0.700   4.500    2.780
```

Unity of main generator operation would require K_I = 2.77 to hold required excitation with zero regulator output

Figure 26.16. Use of ESTR to Determine Value of EXST2 K_I Parameter Corresponding to Different Generator Rated Power Factors

```
ACTIVITY? estr

ENTER 0 FOR RESPONSE RATIO TEST
      1 FOR OPEN CIRCUIT SETPOINT STEP TEST: 0

ENTER DEFAULT POWER FACTOR: .9
```

Reinitialize at 0.9 pf to check steady-state values of all excitation system variables

```
ENTER BUS NUMBER, MACHINE ID, POWER FACTOR:

    PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI JAN 12, 1996  10:55
CASE FOR DATA VERIFICATION
ONE MACHINE INFINITE BUS

INITIAL CONDITION LOAD FLOW USED  0 ITERATIONS

--------------------------MACHINE INITIAL CONDITIONS--------------------------
X------ BUS -----X ID  ETERM   EFD    POWER    VARS   P.F.  ANGLE   ID     IQ
    1              1 1.0000 2.6665  90.00   43.59 0.9000  38.19 0.8990 0.4379

ENTER CHANNEL OUTPUT FILENAME:

ACTIVITY? docu

      ** EXST2 **  BUS    NAME   BSKV MACH  C O N ' S     STATE'S   VAR
                     1                1     15-   27     7-   10     1

              TR       KA       TA     VRMAX    VRMIN      KE       TE
            0.000    120.0    0.150    1.200   -1.200    1.000    0.500

              KF       TF       KP      KI       KC     EFDMAX   KI VAR
            0.020    1.000    1.190    2.500    0.700   4.500    2.500
ACTIVITY? dlst

ENTER CON RANGE: 0
ENTER VAR RANGE: 0
ENTER STATE RANGE: 7 10
ENTER ICON RANGE: 0
ENTER OUTPUT CHANNEL RANGE: 0
ENTER CRT PLOT CHANNEL RANGE: 0

STATES:

    7:   1.000          8: 0.6146          9:   2.667          10: 0.5333E-01
```

With K_I = 2.5, voltage regulator must have nonzero steady-state output to hold required

Nonzero K_I CON forces K_I to its value

DOCU shows that voltage regulator output

Figure 26.17. Presetting of K_I = 2.5 and Checking for Reasonableness of Required Voltage Regulator Output

```
ACTIVITY? estr

ENTER 0 FOR RESPONSE RATIO TEST
      1 FOR OPEN CIRCUIT SETPOINT STEP TEST: 0

ENTER DEFAULT POWER FACTOR: .9

ENTER BUS NUMBER, MACHINE ID, POWER FACTOR:

    PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI JAN 12, 1996  11:43
CASE FOR DATA VERIFICATION
ONE MACHINE INFINITE BUS

INITIAL CONDITION LOAD FLOW USED   0 ITERATIONS

--------------------------MACHINE INITIAL CONDITIONS--------------------------
X------ BUS -----X ID  ETERM   EFD    POWER    VARS    P.F.   ANGLE    ID      IQ
    1               1 1.0000 2.6665   90.00    43.59 0.9000  38.19 0.8990 0.4379

ENTER CHANNEL OUTPUT FILENAME:

ACTIVITY? docu

      ** EXST2 **  BUS   NAME  BSKV MACH  C O N ' S     STATE'S   VAR
                    1               1     15-   27     7-   10     1

            TR      KA      TA     VRMAX   VRMIN     KE      TE
          0.000   120.0   0.150   1.200  -1.200   1.000   0.500

            KF      TF      KP      KI      KC     EFDMAX  KI VAR
          0.020   1.000   1.190   2.500   0.500   4.500   2.500

ACTIVITY? dlst

ENTER CON RANGE:
ENTER VAR RANGE:
ENTER STATE RANGE: 7 10
ENTER ICON RANGE:
ENTER OUTPUT CHANNEL RANGE:
ENTER CRT PLOT CHANNEL RANGE:

STATES:

    7:  1.000        8: 0.2328           9:   2.667          10: 0.5333E-01
```

Initialize again at 0.9 pf to recheck voltage regulator output needed in steady state

Required excitation voltage is now maintained with voltage regulator output of 0.24 pu

Figure 26.18. Change of KC Parameter of EXST2 Model to 0.5 to Reduce Commutation Drop Modeled in Excitation Rectifier Unit, and Recheck of Steady-State Values of Excitation System Variables

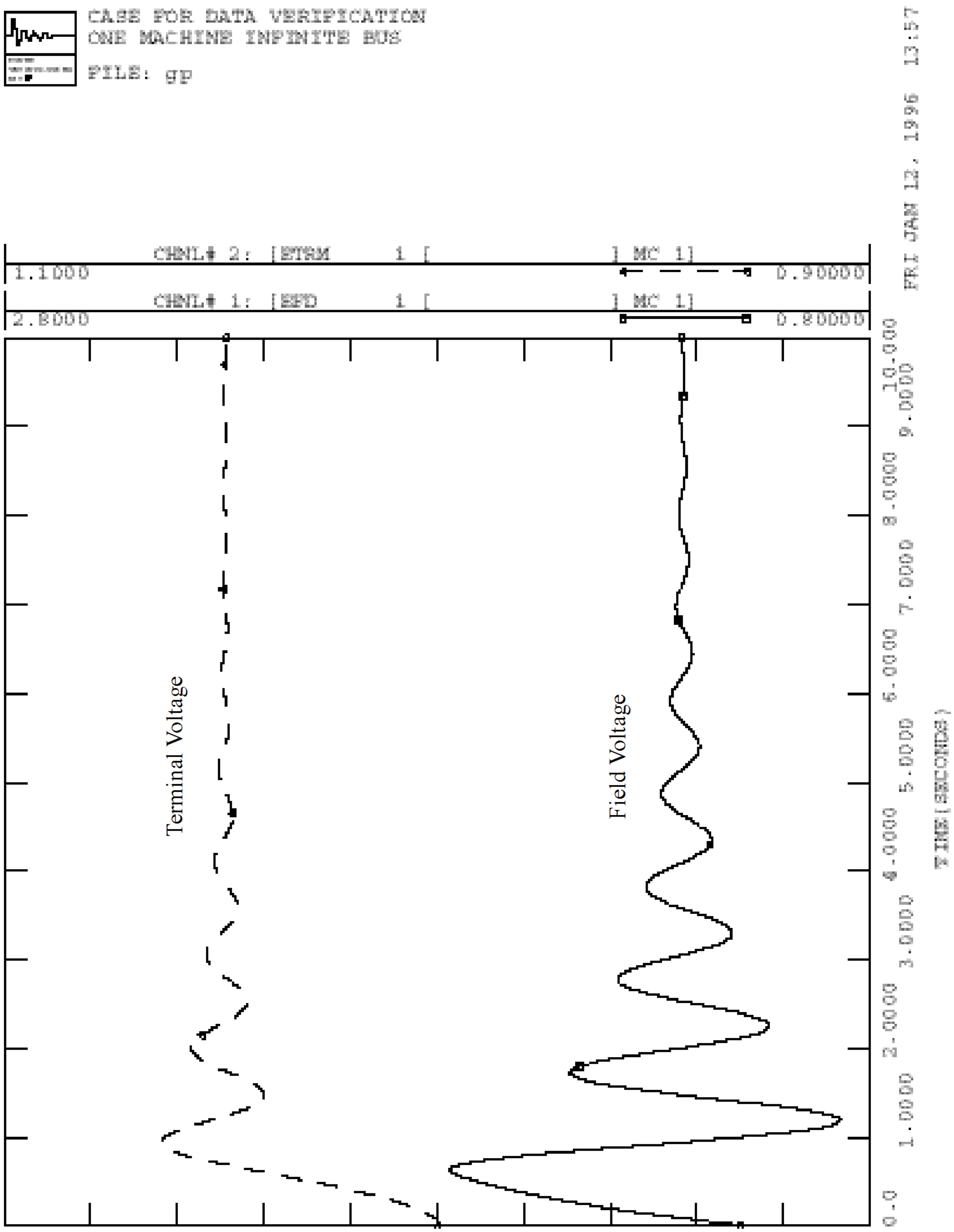


Figure 26.19. Plotted Response from Open-Circuit Step Test of Model EXST2

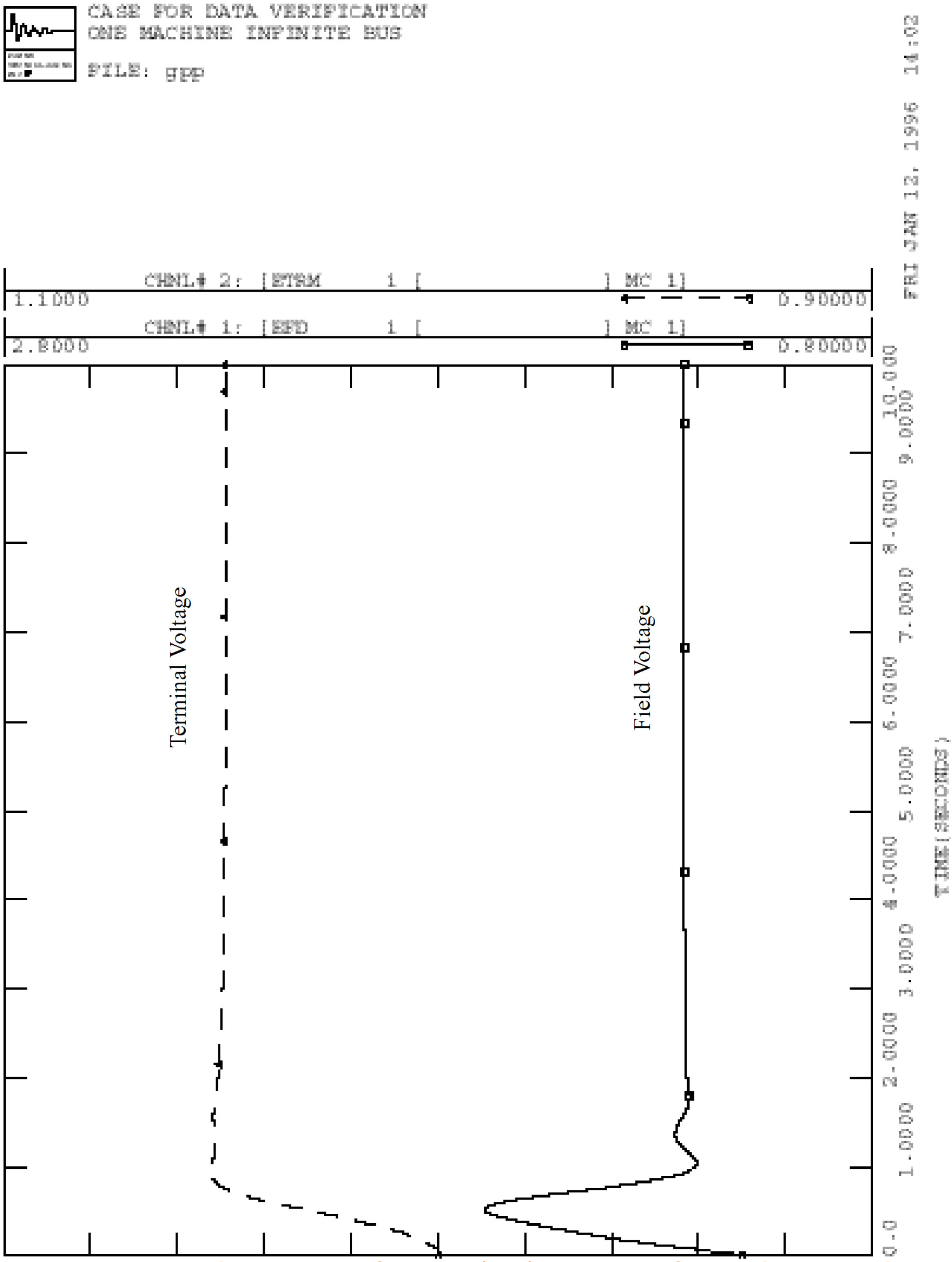


Figure 26.20. Plotted Response of Open-Circuit Step Test for Model EXST2 but with Rate Feedback Gain, K_F, Increased to 0.05

26.3.5. General Notes on Excitation System Data Review

The examples illustrate the principles of excitation system data checking. The following notes summarize a number of points to consider when using ESTR and ERUN.

1. ESTR overrides channel assignments, placing field voltages and terminal voltages in output channels. Consequently, while it is valid to make a snapshot after use of ESTR, channel assignments made by the user will be lost. Do ESTR/ERUN work before the setup of channels for output of study results; use of activity CHAN then overrides the assignments that have been made by ESTR.

2. Activity ERUN automatically prints out the response ratio of all exciters at time 0.5 sec, but its main significance is for rotating machine exciters. SCR-bridge type exciters (as modeled by SCRX for example) will generally exhibit very high response ratios because of their ability to reach ceiling output practically instantaneously.

3. Response ratio/ceiling tests should be run for at least 1 sec; 2-sec runs may be needed to allow older, slower responding excitation systems to settle at their ceilings.

4. Open-circuit step response tests should be run for at least 5 sec to allow slower responding excitation systems to reveal their dynamic behavior.

5. A final value of E_{fd} exceeding 1.3 pu for a 1.05 pu terminal voltage in the open-circuit step response test usually indicates suspect main generator saturation data.

26.4. Turbine Governor Data Verification

26.4.1. Governor Response Test

Activity GSTR and GRUN run simulations of governing response of individual units in isolation. The principal purpose of the governor response test is to ensure that the governor gain and time constant parameters correspond to correctly tuned well-damped response. The user initiates the governor test with activity GSTR, which initializes each governor to a load level specified by the user. Activity GRUN is then used to simulate the response of the governors to a step change in load. The load electrical power is held constant (independent of frequency) after the step so that the response indicates the damping due to the turbine and governor loop only. The governors should be initialized to about 0.8 per-unit load and the load step should be approximately 0.1 per unit. The damping of hydro governing loops is usually decreased with increasing load and hence that response tests should normally be made near full load for these units.

Governor response tests should be run for at least 5 sec for steam turbine units (TGOV1) and for at least 15 sec for gas turbine (GAST) and hydro units (HYGOV). All three types of units should have well damped response. Hydro governors will generally show a somewhat greater overshoot than steam turbine governors, but should still be well damped, showing no persistent oscillations. The governor testing simulation output shows the transient variation of turbine power. A small negative change in hydro turbine power before it follows a positive change of load power is normal and does not indicate incorrect governor tuning.

26.4.2. Governor Data Verification Example

For an example of governor data verification, consider that the data for the governor of generator 1 was entered according to Figure 26.21, "Initial Trial Data for Hydro Turbine Governor", passed checking by DOCU, and must be verified. Hydro governors always require careful attention to the values of temporary droop (CON(J+1)) and relaxation time constant (CON(J+2)), because the values required for these parameters vary over quite wide ranges depending upon the civil engineering characteristics of the plant.

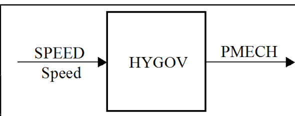
Figure 26.22, "Use of Activity GSTR/GRUN to Check Hydro Turbine Governor Data by Simulation of Isolated Load Step Response Test" shows output from activity DOCU when the check option was chosen, which indicates nothing unusual about the data assigned to the hydro turbine governor model, HYGOV. The DOCU data review is followed in Figure 26.22, "Use of Activity GSTR/GRUN to Check Hydro Turbine Governor Data by Simulation of Isolated Load Step Response Test" by the use of GSTR to initialize the unit at 80% load in preparation for simulation of a test where the electrical load is suddenly increased to 90% of unit rating. GSTR is followed by GRUN to run the simulation. Figure 26.23, "Plotted Response of Governor Step Load Test Corresponding to Figure 26.22, "Use of Activity GSTR/GRUN to Check Hydro Turbine Governor Data by Simulation of Isolated Load Step Response Test"" shows the plotted response of the turbine-governor to the test and reveals oscillatory performance. This response is unsatisfactory to the point where plant operators would not tolerate it. It indicates that the governor temporary droop, CON(J+1), and/or relaxation time constant, CON(J+2), are incorrect even though their values fall within reasonable ranges. Figure 26.24, "Plotted Response of Governor Step Load Test with Revised Governor Tuning" shows the plotted response of the same GSTR/GRUN test made after changing:

```
CON(J+1) from 0.25 to 0.5
CON(J+2) from 5.0 to 7.5
```

The step change response is now much improved, although the return of speed to nominal is more sluggish than may be desired. It would be interesting to try another test with temporary droop increased still further to 0.75 and the relaxation time returned to 5.0 sec.

HYGOV

Hydro Turbine-Governor

This model is located at system bus	#_____	IBUS,	
machine	#_____	I,	
This model uses CONs starting with	#_____	J,	
and STATEs starting with	#_____	K,	
and VARs starting with	#_____	L.	

CONs	#	Value	Description
J			R, permanent droop
J+1			r, temporary droop
J+2			T_r (>0) governor time constant
J+3			T_f (>0) filter time constant
J+4			T_g (>0) servo time constant
J+5			± VELM, gate velocity limit
J+6			G_{MAX}, maximum gate limit
J+7			G_{MIN}, minimum gate limit
J+8			T_W (>0) water time constant
J+9			A_t, turbine gain
J+10			D_{turb}, turbine damping
J+11			q_{NL}, no power flow

STATEs	#	Description
K		e, filter output
K+1		c, desired gate
K+2		g, gate opening
K+3		q, turbine flow

VARs	#	Description
L		Speed reference
L+1		h, turbine head

IBUS, 'HYGOV', I, R, r, Tr, Tf, Tg, VELM, GMAX, GMIN, TW, At, Dturb, qNL/

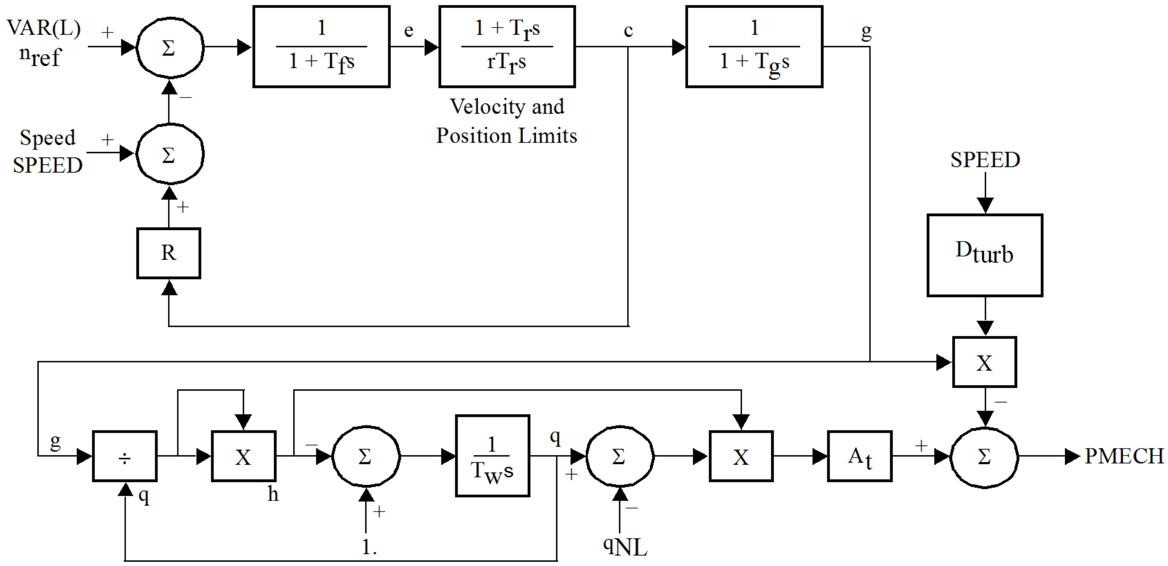


Figure 26.21. Initial Trial Data for Hydro Turbine Governor

```
                         DATA CHECK FOR GOVERNOR MODELS


BUS     1  MACHINE 1:                    Reminder only, OK for medium head hydro turbine
DTURB=    0.5000
                                 Governor adjustable parameters (always deserve careful review)

   ** HYGOV **  BUS   NAME  BSKV MACH  C O N ' S    STATE'S   V A R ' S    DOCU,CHECK shows
                  1                 1    28-   39    11-   14     2-    3    nothing suspicious in
                                                                             hydro turbine governor
 R-PERM R-TEMP   TR    TF    TG     VELM  GMAX  GMIN   TW    AT DTURB   QNL
  0.050  0.250  5.00 0.050 0.500   0.200  1.00  0.00  1.75  1.15 0.50 0.080
ENTER UP TO 20 BUS NUMBERS
0

ACTIVITY? gstr                    Activity GSTR to run hydro plant isolated step load test

ENTER INITIAL LOADING, STEP (P.U.): .8 .1   Run test from 80% load with 10% increase

    PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI JAN 12, 1996  16:28
CASE FOR DATA VERIFICATION
ONE MACHINE INFINITE BUS

INITIAL CONDITION LOAD FLOW USED  0 ITERATIONS

--------------------------MACHINE INITIAL CONDITIONS--------------------------
X------ BUS -----X ID  ETERM   EFD    POWER    VARS   P.F.  ANGLE   ID     IQ
    1              1 1.0000 1.8371   80.00    0.00 1.0000  51.53 0.6264 0.4977

ENTER CHANNEL OUTPUT FILENAME: gs

ACTIVITY? grun                     Activity GRUN to run the test simulation

AT TIME =  -0.017 ENTER TPAUSE, NPRT, NPLT, CRTPLT: 0 2 2

CHANNEL OUTPUT FILE IS gs  Print/plot intervals commensurate with slow response characteristic of governors

   TIME X- VALUE --X X--------- IDENTIFIER ---------X X- VALUE --X X--------- IDENTIFIER ---------X
-0.0167  0.00000     SPD      1 [               ] MC 1  0.80000     PMEC     1 [               ] MC 1

 0.0000 -0.88697E-10  0.80000
                                                                       Note that GSTR overrides
ACTIVITY? grun                                                         prior channel assignments

AT TIME =   0.000 ENTER TPAUSE, NPRT, NPLT, CRTPLT: 20 240 5

CHANNEL OUTPUT FILE IS gs

   TIME X- VALUE --X X--------- IDENTIFIER ---------X X- VALUE --X X--------- IDENTIFIER ---------X
 0.0000 -0.88697E-10 SPD      1 [               ] MC 1  0.80000     PMEC     1 [               ] MC 1

 2.0000 -0.28219E-01  0.79830

 4.0000 -0.33245E-01  0.91676

 6.0000 -0.70223E-02   1.0034
```

Figure 26.22. Use of Activity GSTR/GRUN to Check Hydro Turbine Governor Data by Simulation of Isolated Load Step Response Test

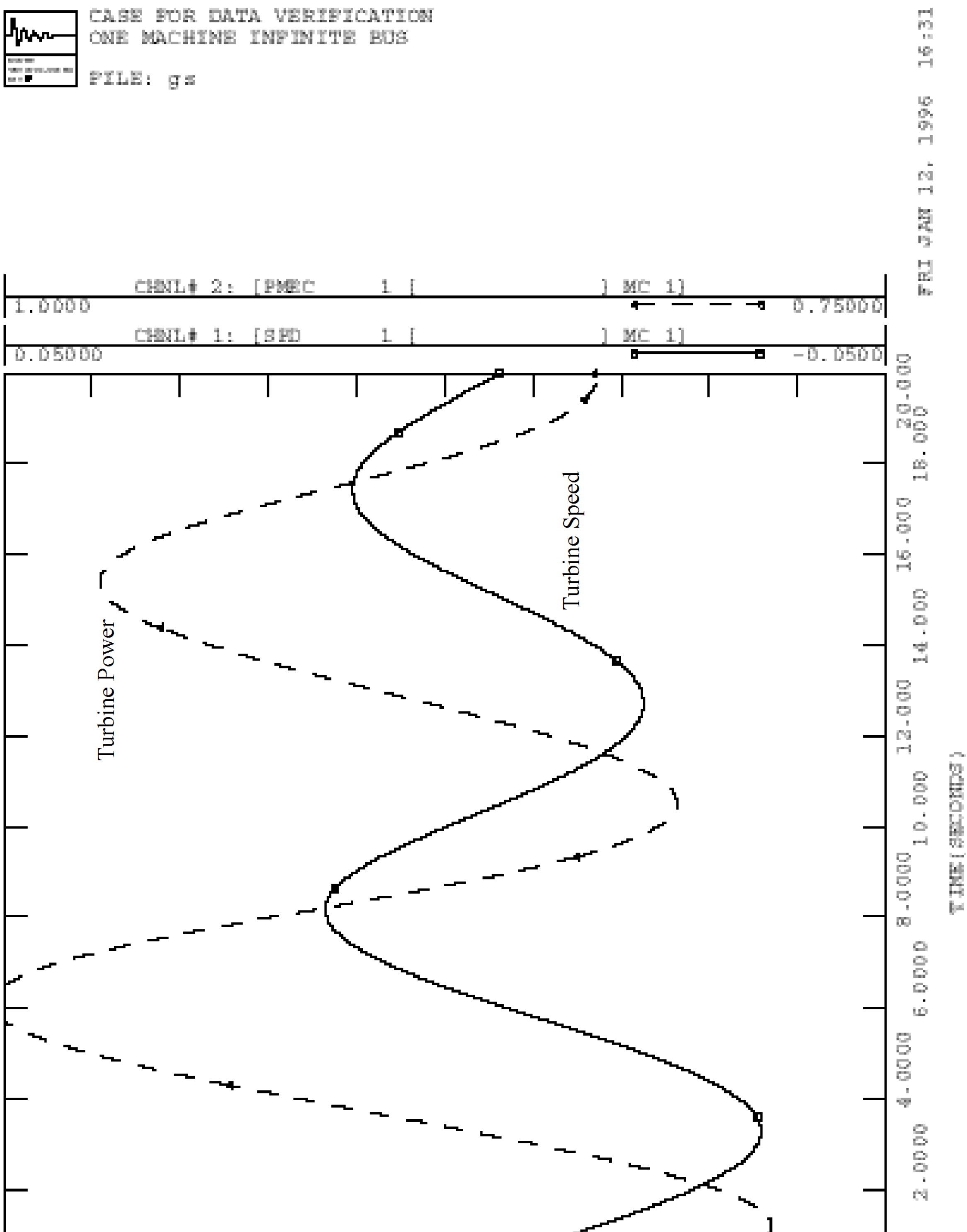


Figure 26.23. Plotted Response of Governor Step Load Test Corresponding to Figure 26.22, "Use of Activity GSTR/GRUN to Check Hydro Turbine Governor Data by Simulation of Isolated Load Step Response Test"

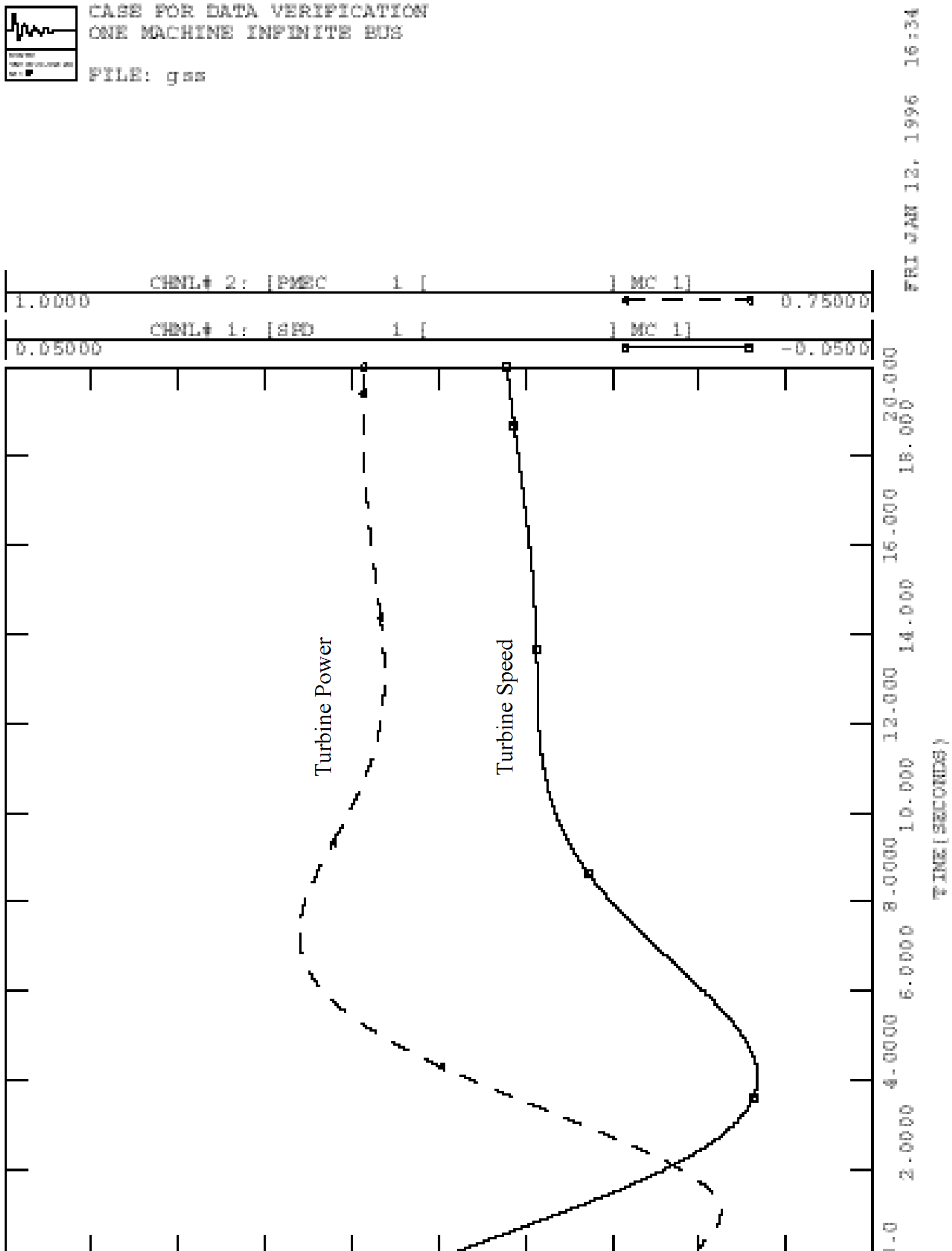


Figure 26.24. Plotted Response of Governor Step Load Test with Revised Governor Tuning

26.5. Parameter Ranges for Activity DOCU

DOCU, when in the checking mode, assumes that data is specified on machine base. The user will probably see generator inertias, damping factors, reactances, turbine governor limits and regulating gains flagged for machines not on machine base. The following checks are made by each standard PSS®E equipment model:

- BBGOV1
- BBSEX1
- CDC1
- CDC4 and CDC6 for Appropriate Data
- CIMTR1, CIMTR2, CIMTR3 and CIMTR4 for Appropriate Data
- CLOAD
- COMP
- COMPCC
- CPAAUX
- CRANI
- CRCMGV for Both High- and Low-Pressure Turbines
- CSTCON
- CSVGN1, CSVGN3, and CSVGN4 for Appropriate Data
- CSVGN5 and CSVGN6 for Appropriate Data
- DCTC1
- DEGOV, DEGOV1
- ESAC8B
- ESDC1A, IEEET1, IEET1A, IEEEX1, IEEX2A for Appropriate Data
- ESST4B
- EX2000
- EXAC1, EXAC1A, EXAC2, EXAC3, ESAC1A, ESAC2A, ESAC3A, ESAC6A for Appropriate Values
- EXAC4, EXST1, ESAC4A, ESST1A for Appropriate Data
- EXBAS
- EXDC2, ESDC2A, ESAC5A for Appropriate Data

- EXELI
- EXPIC1
- EXST2, EXST2A, ESST2A
- EXST3, ESST3A
- EXTLD2
- GAST
- GAST2A, GASTWD
- GENROU, GENSAL, GENROE, GENSAE, GENDCO, GENCLS, GENTRA, FRECHG for Applicable Data
- GNSCN1
- GNSCN2
- HVDCAU
- HYGOV
- IEE2ST, ST2CUT
- IEESGO
- IEEEG1, WSIEG1
- IEEEG2
- IEEEG3
- IEEEST
- IEEET3, IEEEX3 for Appropriate Data
- IEEET4, IEEET5, IEET5A, IEEEX4 for Appropriate Data
- IEEEVC
- LOEXR1
- MAXEX1, MAXEX2
- MNLEX1, MNLEX2, MNLEX3
- MTDC01, MTDC03
- OLTC1, OLPS1
- PAUX1
- PAUX2

- PIDGOV
- PSS2A
- PTIST1
- PTIST3
- REXSYS and REXSY1
- RXR
- SCRX
- SEXS
- SHAF25
- SQBAUX
- STAB1
- STAB3, STAB4
- STAB2A
- STBSVC
- TGOV1
- TGOV2
- TGOV3
- TGOV4
- TGOV5
- WEHGOV
- WESGOV
- WPIDHY
- WSHYDD, WSHYGP for Appropriate Data

26.5.1.

GENROU, GENSAL, GENROE, GENSAE, GENDCO, GENCLS, GENTRA, FRECHG for Applicable Data

$1 < H < 10$	$0 < S_{1.0}$
$0 \leq D < 3$	$S_{1.0} < S_{1.2}$
$1 < T'_{do} < 10$	x''_d = IMAG(ZSORCE) for GENROU, GENSAL, GENDCO, FRECHG

$4 \times DELT < T''_{do} < 0.2$	$0.2 \leq T'_{qo} \leq 1.5$
$4 \times DELT < T''_{qo} < 0.2$	$x'_q < x_q$
$x_d < 2.5$	$x'_d < x'_q$
$x'_d < 0.5 \times x_d$	$x''_d < x'_q$
$x_q < x_d$	$0.025 \leq T_a \leq 0.1$
$x'_d < x_q$ for GENSAL, FRECHG and GENTRA only	x'_d = IMAG(ZSORCE) for GENTRA
$x''_d < x'_d$	$0 <$ Acceleration Factor ≤ 1.0
$x_1 < x''_d$	$H_1 \times MBASE_1 = H_2 \times MBASE_2$ for FRECHG

26.5.2.

COMP

$0 < | X_e | < 1$

26.5.3.

COMPCC

$X_1 > 0$ and $X_2 > 0$

26.5.4.

IEEEVC

$0 \leq | R_c | 1$	$0 <	X_c	< 1$

26.5.5.

STAB1

$4 \times DELT < T$	$4 \times DELT < T_4$
$4 \times DELT < T_3$	

26.5.6.

STAB2A

$DELT < T_2$	$DELT < T_5$
$DELT < T_3$	

26.5.7.

STAB3, STAB4

$0 = T_t$ or $4 \times DELT < T_t$	$4 \times DELT < T_{x2}$
$4 \times DELT < T_{x1}$	$4 \times DELT \leq T_C$ for STAB4

26.5.8.

IEEEST

$0 < IC \leq 6$ where IC is stabilizer input code Remote bus = 0 when IC = 2 or IC > 5 where IC is stabilizer input code	
$0 \leq T_1 \leq 10$	$4 \times DELT < T_6 < 2$
$0 \leq T_2 \leq 10$	$0 < L_{SMAX} < 0.3$
$0 \leq T_3 \leq 10$	$-0.3 < L_{SMIN} < 0$
$0 \leq T_4 \leq 10$	$0 \leq V_{CU} < 1.25$
$0 < T_5 < 10$	$0 \leq V_{CL} < 1.0$

26.5.9.

IEE2ST, ST2CUT

$0 < IC \leq 6$ where IC is either of the stabilizer inputs Remote bus = 0 when IC = 2 or IC > 5 where IC is either of the stabilizer inputs	
$0 \leq T_1 \leq 10$	$0 \leq T_8 \leq 10$
$0 \leq T_2 \leq 10$	$0 \leq T_9 < 10$
$0 < T_3 \leq 10$	$0 \leq T_{10} < 2$
$3 \times DELT < T_4 \leq 10$	$0 < L_{SMAX} < 0.3$
$0 \leq T_5 < 10$	$-0.3 < L_{SMIN} < 0$
$0 \leq T_6 < 2$	$0 \leq V_{CU} < 1.25$
$0 \leq T_7 \leq 10$	$-0.1 \leq V_{CL} < 1.0$

26.5.10.

PSS2A

$1.5 \leq T_{W1} \leq 15$	$2 \times DELT < T_9 < 2.0$
$1.5 \leq T_{W2} \leq 15$	$2 \times DELT \leq T_1 \leq 2.0$
$1.5 \leq T_{W3} \leq 15$	$2 \times DELT \leq T_3 \leq 2.0$
$1.5 \leq T_{W4} \leq 15$	$2 \times DELT \leq T_2 \leq 6.0$
$2 \times DELT < T_6$	$2 \times DELT \leq T_4 \leq 6.0$
$2 x DELT < T_7$	$0 < V_{STMAX} < 0.99$
$2 \times DELT < T_8 \leq 2$	$-0.3 \leq V_{STMIN} \leq 0$

26.5.11.

PTIST1

$T_P > 4 \times \Delta t_c$	$T_2 > 4 \times \Delta t_c$
$T_F > 4 \times \Delta t_c$	$T_4 > 4 \times \Delta t_c$

26.5.12.

PTIST3

$T_P > 4 \times \Delta t_c$	$T_4 > 4 \times \Delta t_c$
$T_F > 4 \times \Delta t_c$	$T_6 > 4 \times \Delta t_c$ or $T_6 = 0$
$T_2 > 4 \times \Delta t_c$	$B_2 > 4 \times \Delta t_c$ or $B_2 = 0$

26.5.13.

STBSVC

$\lvert K_{S1} \rvert > 0$	$0 < \lvert K_{S3} \rvert$
$2 \times DELT < T_{S9}$	$0 < \lvert K_{S2} \rvert$ if second signal is used
$0 < \lvert T_{S13} \rvert$	$2 \times DELT < T_{S12}$ if second signal is used
$2 \times DELT < T_{S14}$	

26.5.14.

SCRX

$0.05 < T_A / T_B < 0.3$	$-5 < E_{MIN} \leq 0$
$5 < T_B < 25$	$2 < E_{MAX} < 10$
$50 < K < 400$	$C_{SWITCH} = 0$ or 1
$5 \leq K \times T_A / T_B \leq 15$	$0 \leq r_c / r_{fd} \leq 10$
$0 \leq T_E < 1$	

26.5.15.

SEXS

$0.05 < T_A / T_B < 1$	$5 \leq K \times T_A / T_B \leq 15$
$5 < T_B < 20$	$E_{MIN} = 0$
$20 < K \leq 100$	$3 \leq E_{MAX} \leq 6$
$0 \leq T_E < 0.5$	

26.5.16.

ESDC1A, IEEET1, IEET1A, IEEEX1, IEEX2A for Appropriate Data

$0 \leq T_R < 0.5$	$0 < K_F < 0.3$
$10 < K_A < 500$	$4 \times DELT < T_F$ or $T_{F1} < 1.5$
$0 \leq T_A < 1$	$5 \leq T_F / K_F \leq 15$ for ESDC1A, IEEET1, IEEEX1, IEET1A, IEET1S
$0.5 < V_{RMAX} < 10$	$4 \times DELT < T_{F2} < 1.5$ for IEEET2, IEEEX2
$-10 < V_{RMIN} < 0$	$5 \leq T_{FN} / K_F \leq 15$ for IEEET2, IEEEX2

$-1 \leq K_E \leq 1$	MINIMUM(S,S2) < 0.2
$4 \times DELT < T_E < 1$	

where:

$S = \| 1 - T_{F1} / T_E \|$	$E_1 < E_2$ or EFD_{MAX}
$S_2 = \| 1 - T_{F2} / T_E \|$	$S_E(E_1) < S_E(E_2)$ or $S_E(EFD_{MAX})$
$T_{FN} = T_{F1}$ if $S_2 \leq S$	$EFD_{MIN} = 0$ and $EFD_{MIN} < EFD_{MAX}$
$T_{FN} = T_{F2}$ if $S \leq S_2$	$0 \leq T_B$
$0 \leq E_1$	$0 \leq T_C$
$0 \leq S_E(E_1) < 1$	$T_B = 0$ and $T_C \neq 0$

26.5.17.

IEEET3, IEEEX3 for Appropriate Data

$0 \leq T_R < 0.5$	$4 \times DELT < T_F < 1.5$
$10 < K_A < 200$	$5 \leq T_F / K_F \leq 15$
$0 \leq T_A < 1$	$K_p = 1.19$
$0.5 < V_{RMAX} < 1.5$	$0.9 < K_1 < 1.1$
$-1.5 < V_{RMIN} < -0.5$	$1.0 < V_{BMAX} < 4.0$
$4 \times DELT < T_E < 2$	$0 < K_E \leq 1.0$
$0 < K_F < 0.3$	

26.5.18.

IEEET4, IEEET5, IEET5A, IEEEX4 for Appropriate Data

$0.01 < K_R < 0.05$	$0 \leq E_1$
$2.0 < T_{RH} < 100$ or $T_{RH} = 0$ for IEET5A	$0 \leq S_E(E_1) < 1$
$0.02 < K_V < 0.10$	$E_1 < E_2$
$K_R < K_V$	$S_E(E_1) < S_E(E_2)$
$2.0 < V_{RMAX} < 10.0$	$0 < K_A < 25$
$0 \leq V_{RMIN} < 2.0$	$EFD_{MIN} < EFD_{MAX}$
$4 \times DELT < T_E < 1.0$	$E_2 \leq EFD_{MAX}$
$-1.0 < K_E < 0.10$	$T_R = 0$ or $4 \times DELT < T_R < 0.5$

26.5.19.

EXDC2, ESDC2A, ESAC5A for Appropriate Data

$0 \leq T_R < 0.5$	$-1.0 \leq K_E \leq 1.0$
$10 < K_A < 500$	$4 \times DELT < T_E < 2.0$ for EXDC2, ESDC2A
$0 \leq T_A < 1.0$	$4 \times DELT < T_E < 1.0$ for ESAC5A
$0 \leq T_B$	$0 < K_F < 0.3$

$0 \le T_C$	$4 \times DELT < T_{F1} < 1.5$
$T_B = 0$ and $T_C \neq 0$	$0 \le T_{F2}$
$0.5 < V_{RMAX} < 10.0$	$0 \le T_{F3}$
$-10 < V_{RMIN} < 0$	$5.0 \le T_{F1} / K_F \le 15.0$ for EXDC2, ESDC2A

For ESAC5A:

$5.0 \le T_{FN} / K_F \le 15.0$	$0 \le E_1$
MINIMUM(S,S2) < 0.2 where: $S = \| 1 - T_{F1} / T_E \|$ $S_2 = \| 1 - T_{F2} / T_E \|$ $T_{FN} = TF_1$ if $S_2 \le S$ $T_{FN} = TF_2$ if $S \le S_2$	$0 \le S_E (E_1) < 1.0$ $E_1 < E_2$ $S_E (E_1) < S_E (E_2)$

26.5.20.

EXAC1, EXAC1A, EXAC2, EXAC3, ESAC1A, ESAC2A, ESAC3A, ESAC6A for Appropriate Values

$0 \le T_R < 0.5$	$0 < V_{AMAX} \le 10$ for EXAC3, ESAC3A, EXAC2, ESAC2A, ESAC6A
$0 \le T_B < 20$	$0 < V_{AMAX} \le 15$ for ESAC1A
$0 \le T_C < 20$	$-500 \le V_{RMIN} < 0$ for EXAC2, ESAC2A, ESAC6A
$0 < K_A < 1000$	$-10 \le V_{AMIN} < 0$ for EXAC3, ESAC3A, EXAC2, ESAC2A, ESAC3A, ESAC6A
$0 \le T_A < 10.0$	$-15 \le V_{AMIN} < 0$ for ESAC1A
$0 < V_{RMAX} \le 10.0$ for EXAC3, ESAC3A, EXAC1A	$0 < K_B < 500$
$-10 \le V_{RMIN} < 0$ for EXAC3, ESAC3A, EXAC1A	$0 \le K_L \le 1.1$
$0 < V_{RMAX} < 15.0$ for EXAC1, ESAC1A	$0 \le K_H \le 1.1$
$-15.0 < V_{RMIN} < 0$ for EXAC1, ESAC1A	$5 < V_{LR} \le 10$
$0 < V_{RMAX} \le 100$ for ESAC6A only	$0 \le K_{LV} \le 1.1$
$-100 \le V_{RMIN} < 0$ for ESAC6A only	$0 \le K_{FA} \le 1.1$
$2 \times DELT < T_E < 2$	$0 \le K_R < 1.1$ for EXAC3
$2 \times DELT < T_E <$ 4.Á for ESAC3A only	$0 \le K_R < 75$ for ESAC3A
$0 \le K_F < 0.3$	$0 < K_N < 0.3$
$2 \times DELT < T_F < 1.5$	$0 < E_{FDN} \le 10$
$0 \le K_C \le 1$	$-5.0 < V_{LV} \le 5.0$
$0 \le K_D \le 1$	$-5 < V_{FEMAX} \le 20$
$0 < K_D \le 2$ for ESAC6A only	$0 \le V_{EMIN} \le 1.1$
$0 < K_E \le 1$	$0 \le K_{LI} \le 1.0$
$0 < K_E \le 2$ for ESAC6A only	$0 < T_K < 10$
$0 \le E_1$	$0 < V_{FELIM} \le 20$

$0 \le S_E(E_1) < 1$	$0 < K_H \le 100$
$E_1 < E_2$	$0 < V_{HMAX} \le 100$
$S_E(E_1) < S_E(E_2)$	$0 \le T_H \le 1$
$0 < V_{RMAX} \le 500$ for EXAC2, ESAC2A, ESAC6A	$0 \le T_J \le 1$

26.5.21.

EXAC4, EXST1, ESAC4A, ESST1A for Appropriate Data

$0 \le T_R < 0.1$	$5 \le K_A \times T_C / T_B \le 15$
$0 < V_{IMAX} \le 0.2$	$3 \le V_{AMAX} \le 8$
$-0.3 < V_{IMIN} \le 0$ for EXAC1, ESST1A	$-8 < V_{AMIN} \le -3$
$-0.2 < V_{IMIN} \le 0$ for EXAC4, ESAC4A	$3 \le V_{RMAX} \le 8$
$0 \le T_C < 10.0$	$-8 \le V_{RMIN} \le -3$
$4 \times DELT < T_B < 20$	$0 \le K_C < 0.3$
$0 \le T_{C1} < 10$	$0 < K_F \le 0.3$
$4 \times DELT < T_{B1} < 20$	$0.3 < T_F \le 1.5$
$T_B > 4 \times DELT$ or $T_A > 4 \times DELT$ for EXST1	$0 < K_{LR} \le 5.0$
$50 < K_A \le 1000$	$0 < I_{LR} \le 5.0$
$0 \le T_A < 0.5$	

26.5.22.

EXST2, EXST2A, ESST2A

$0 \le T_R < 0.5$	$0 < K_F < 0.3$
$10 < K_A < 1000$	$4 \times DELT < T_F < 1.5$
$0 \le T_A < 1$	$5 \le T_F / K_F \le 20$
$0.5 < V_{RMAX} < 1.5$	$K_p = 1.19$
$-1.5 < V_{RMIN} < 0.5$	$0 \le K_I \le 8.0$
$0 < K_E \le 1$	$0 < K_C < 2$
$4 \times DELT < T_E < 2$ and $4 \times DELT < K_E < 2$	$1 < EFDMAX < 10$

26.5.23.

EXST3, ESST3A

$0 \le T_R < 0.5$	$0 \le K_I \le 1.1$
$0 < V_{IMAX} < 1$	$1 < EFD_{MAX} < 20$
$-1 < V_{IMIN} < 0$	$0 \le K_C < 1$
$0 < K_J < 1000$	$0 < X_L < 0.5$
$0 < T_C < 20$	$0 < V_{GMAX} < 20$
$4 \times DELT < T_B < 20$	$-90 < \theta_p < 90$
$0 < K_A \le 200$	$0 \le T_M < 1.0$
$0 \le T_A < 1.0$	$0.5 < V_{MMAX} \le 1.5$

$0.5 < V_{RMAX} \leq 10$	$- 1.5 < V_{MMIN} < 0.5$
$- 10 \leq V_{RMIN} < 0.5$	$0 < K_M < 1000$
$0 \leq K_G < 1.1$	$0 < V_{BMAX} < 20$
$1 < K_p < 10$	

26.5.24.

ESST4B

$0 \leq T_R < 0.5$	$- 118.8 \leq V_{MMIN} \leq 0$
$0 \leq K_{PR} \leq 75$	$0 \leq K_G < 1.1$
$0 \leq K_{IR} \leq 75$	$1 \leq K_P < 10$
$0.8 \leq V_{RMAX} \leq 10$	$0 \leq K_I \leq 1.1$
$- 6 \leq V_{RMIN} \leq 0$	$1 < V_{BMAX} < 20$
$0 \leq T_A < 1$	$0 \leq K_C < 1$
$0 \leq K_{PM} \leq 1.2$	$0 \leq X_L < 0.5$
$0 \leq K_{IM} \leq 18$	$- 90 <$ THETAP < 90
$0.8 \leq V_{MMAX} \leq 118$	

26.5.25.

EXPIC1

$0 \leq T_R < 0.5$	$0 \leq K_C < 2$
$1 < K_A < 500$	$0 \leq K_e \leq 1$
$0 \leq T_{A1} < 10$	$1 < EFD_{MAX} < 10$ if $EFD_{MAX} < 20$
$0.5 < V_{R1} < 10.0$ if $V_{R1} < 20$	$- 6 < EFD_{MIN} \leq - 0,5$ if $EFD_{MIN} > -20$
$- 6 < V_{R2} < - 0.5$ if $V_{R2} > - 20$	$1 \leq V_{RMAX} < 15$ if $V_{RMAX} < 50$
$0 \leq T_e < 2$	$- 6 < V_{RMIN} \leq 0$ if $V_{RMIN} > - 50$
$0 \leq K_F < 0.3$	$0 \leq E_1$
$4 \times DELT < T_{F1} < 15$	$0 \leq S_E(E_1) < 1$
$5 \leq T_{F1} / K_F \leq 25$	$S_E(E_1) < S_E(E_2)$
$0 \leq K_P < 5$	$E_1 \leq E_2$
$0 \leq K_I \leq 1.1$	$0 \leq T_{F2} < 5$

26.5.26.

EXBAS

$0 \leq T_R < 0.5$	$0 \leq T_{F2}$
$0 < K_P < 5$	$T_B = 0$ and $T_C > 0$
$0 \leq K_I < 1.1$	$-1 \leq K_E \leq 1$
$10 < K_A \leq 4000$	$4*DELT < T_E < 10$
$0 \leq T_A \leq 10$	$5 \leq T_F/K_F \leq 15$ or $5\ T_{F2}/K_F \leq 15$
$0 \leq T_B < 20$	$K_C \leq 1$

$0 \le T_C < 20$	$K_D \le 2$
$0.5 < V_{RMAX} < 20$	$0 \le E_1$
$-20 < V_{RMIN} < 0$	$0 \le S_E (E_1) < 1.0$
$4*DELT < T_F < 1.5$	$E_1 < E_2$
$0 \le T_{F1}$	$S_E(E_1) < S_E (E_2)$

26.5.27.

ESAC8B

$0 \le T_R < 0.5$	$-1 < V_{RMIN} < 1.5$
$10 < K_P < 500$	$0 < T_E$
$10 < KI < 500$	$-1 \le K_E \le 1$
$10 < K_D < 500$	$0 \le E_1$
$0 \le T_D < 0.5$	$0 \le S_E (E_1) < 1.0$
$0 < K_A \le 1$	$E_1 < E_2$
$0 \le T_A \le 1$	$S_E (E_1) < S_E (E_2)$
$0 < V_{RMAX} \le 10$	

26.5.28.

EXELI

T_{fv} ^{3} 0	X_e ^{3} 0
T_{fi} ^{3} 0	T_w ^{3} 0
$T_{nv} > 0$	T_{s1} ^{3} 0
V_{pnf} ^{3} 0	T_{s2} ^{3} 0
D_{pnf} ^{3} 0	$S_{max} > 0$
EFD_{max} ^{3} EFD_{min}	

26.5.29.

BBSEX1

$0 \le T_F < 0.5$	$0 < T_4$
$10 < K < 500$	$T_4 = 0$ and $T_3 \ne 0$
$2 \times DELT < T_1 < 10$	$0.5 < V_{RMAX} < 10$
$2 \times DELT < T_2 < 10$	$-10 < V_{RMIN} < 0$
$0 < T_3$	$0.5 \le K \times T_2 / T_1 \le 25$

26.5.30.

EX2000

$0 \le KPR < 50$	$0 \le KRCC < 0.2$
$0.5 \le KIR < 15$	$0 \le TR < 0.1$

0.5 ≤ VRMAX < 3	2.7 ≤ IFDREF1 < 4
- 3 < VRMIN < - 0.5	2 ≤ IFDREF2 < 3
0 ≤ KPA < 50	1.8 ≤ IFDREF3 < 2.7
0.5 < KIA ≤ 20	2.5 ≤ IFDREF4 < 4
0.7 ≤ VAMAX ≤ 1.5	2 ≤ I1 < 3
- 1.5 ≤ VAMIN ≤ - 0.7	30 ≤ T1 < 90
0 ≤ KP ≤ 50	2 ≤ I2 < 4
5 ≤ KL ≤ 50	20 ≤ T2 < 40
Delta / 2 < TE < 7 where Delta is the time step	3.5 ≤ I3 < 5
	10 ≤ T3 < 20
4 ≤ VFEMAX < 6	4 ≤ I4 < 6
0 ≤ KE ≤ 1.5	5 ≤ T4 < 9
90 ≤ KC ≤ 0.5	0 ≤ TLEAD < 3
0 < KD ≤ 0.5	0 ≤ TLAG < 0.5
0 ≤ KF1 < 1	0 ≤ KPIFD < 5
0 ≤ KF2 < 1	0.5 ≤ KIIFD < 10
2.5 ≤ E1 < 4	0.5 ≤ IFDLIMP < 1.5
0 ≤ S (E1) < 0.4	- 1.5 ≤ IFDLIMN < - 0.5
3 ≤ E2 < 5	0 ≤ IFDADVLIM < 1.5
0 ≤ S (E2) < 0.7	-10 ≤ VEMIN < 0.1
1.05 ≤ KVHZ < 1.2	0.9 ≤ REFLIMP ≤ 1.3

26.5.31.

REXSYS and REXSY1

$0 \leq T_R < 0.5$	$0 \leq K_{II} < 0.5$
$0 \leq K_{VP} < 200$	$K_{IP} = 0$ and $K_{II} = 0$
$0 \leq K_{VI} < 200$	$0 \leq T_P$
$K_{VI} = 0$ and $K_{VP} = 0$	$0.5 < V_{FMAX} < 100$
$0 < V_{IMAX} \leq 20$	$-100 < V_{FMIN} < 0$
$0 \leq T_A \leq 10$	$-10 \leq K_H \leq 10$
$0 \leq T_{B1} < 20$	$-10 \leq K_E \leq 10$
$0 \leq T_{C1} < 20$	$DEL2 < T_E < 10$
$0 \leq T_{B2} < 20$	$K_C \leq 1$
$0 \leq T_{C2} < 20$	$K_D \leq 2$
$0.5 < V_{RMAX} < 20$	$0 \leq E_1$
$-20 < V_{RMIN} < 0$	$0 \leq S_E (E_1) < 1$
$0 < K_F < 0.3$	$E_1 < E_2$
$DEL2 < T_F < 1.5$	$S_E (E_1) < S_E (E_2)$
$0 \leq T_{F1}$	$0 \leq F_{LIMF} \leq 1$
$0 \leq T_{F2}$	$0 < X_C < 6$
$0 \leq F_{BF} \leq 2$	$0 \leq V_{CMAX} \leq 10$

$0 \le K_{IP} < 0.5$	

26.5.32.

MNLEX1, MNLEX2, MNLEX3

$0 < K_{F2} < 0.3$	$0 < K < 10$ for MNLEX1
$4 \times DELT < T_{F2} < 1.5$	$0.5 < Q_o < 1$ for MNLEX2
$5 \le T_{F2} / K_{F2} \le 15$	$1 < R < 2$ for MNLEX2
$0 \le K_M < 5$	$-0.5 < Q_o < 0$ for MNLEX3
$0 \le T_M \le 4$	$0 \le B < 0.5$ for MNLEX3
$0 \le MELMAX < 0.2$	

26.5.33.

TGOV1

$0 < R < 0.1$	$0 < T_2$
$4 \times DELT < T_1 < 0.5$	$4 \times DELT < T_3 < 10.0$
$0.5 < V_{MAX} < 1.2$	$T_2 < T_3 / 2.0$
$V_{MIN} < V_{MAX}$	$0 \le D_t < 0.5$
$0 \le V_{MIN} < 1.0$	

26.5.34.

TGOV2

$0 < R < 0.1$	$1.0 < T_3 < 10.0$
$4 \times DELT < T_1 < 0.5$	$0 \le D_t < 0.5$
$0.5 < V_{MAX} < 1.2$	$4 \times DELT < T_t < 0.5$
$V_{MIN} < V_{MAX}$	$4 \times DELT < T_A < 0.25$
$0 \le V_{MIN} < 1.0$	$T_A + 0.1 < T_B < 50.0$
$0.1 < K < 0.5$	$T_B + 1.0 < T_C < 50.0$

26.5.35.

TGOV3

$5.0 \le K \le 30$	$0 < T_4 \le 1$
$0 \le T_1 < 5$	$-2.0 \le K_1 \le 1$
$0 \le T_2 < 10$	$4 \times DELT < T_5 < 10$
$4 \times DELT < T_3 \le 1.0$	$0 \le K_2 < 0.5$
$0.01 \le U_o \le 0.3$	$0 \le T_6 < 10$
$-0.3 \le U_c < 0$	$0 \le K_3 < 0.35$
$0.5 \le P_{MAX} \le 1.0$	$4 \times DELT < T_A < 0.25$
$0 \le P_{MIN} < 0.5$	$T_A + 0.1 < T_B < 50.0$

$P_{MIN} < P_{MAX}$	$T_B + 1.0 < T_C < 50.0$

26.5.36.

GAST

$0 < R < 0.1$	$0 < K_t < 5.0$
$4 \times DELT < T_1 < 0.5$	$0.5 < V_{MAX} < 1.2$
$4 \times DELT < T_2 < 0.5$	$0 \le V_{MIN} < 1.0$
$4 \times DELT < T_3 < 5.0$	$V_{MIN} < V_{MAX}$
$0 <$ Ambient Load Limit ≤ 1.0	$0 \le D_{turb} < 0.5$

26.5.37.

HYGOV

$0 < R < 0.1$	$0 < G_{MAX} \le 1.0$
$0 < r < 2.0$	$0 \le G_{MIN} < 1.0$
$R < r$	$G_{MIN} < G_{MAX}$
$4 \times DELT < T_r < 30$	$0.5 < T_w < 3.0$
$4 \times DELT < T_f < 0.1$	$0.8 < A_t < 1.5$
$4 \times DELT < T_g < 1.0$	$0 \le D_{turb} < 0.5$
$0 < V_{ELM} < 0.3$	$0 < q_{n1} < 0.15$

26.5.38.

DEGOV, DEGOV1

$0 \le T_1 < 25.0$	$0 \le T_D < 0.125$
$0 \le T_2 < 0.5$	$0 \le T_{MAX} < 1.5$
$0 \le T_3 < 10$	$-0.05 \le T_{MIN} < 0.5$
$15 \le K < 25.0$	$0 \le DROOP < 0.1$
$0 \le T_4 < 25.0$	$0 \le T_E < 1.0$
$0 \le T_5 < 10$	If $T_1 = 0$, then $T_3 = 0$
$0 \le T_6 < 0.5$	

26.5.39.

IEESGO

$0 \le T_1 < 100$	$5 \le K_1 \le 30$
$0 \le T_2 < 10$	$0 \le K_2 \le 3.0$
$4 \times DELT < T_3 \le 1.0$	$-1.0 \le K_3 \le 1.0$
$0 \le T_4 \le 1.0$	$0.5 \le P_{MAX} \le 1.5$
$0 \le T_5 \le 50$	$0 \le P_{MIN} \le 0.5$
$0 \le T_6 \le 1.0$	$P_{MIN} < P_{MAX}$

26.5.40.

CRCMGV for Both High- and Low-Pressure Turbines

$0.5 < P_{MAX} < 1.2$	$4 \times DELT < T_4$
$0 < R < 0.1$	$4 \times DELT < T_5$
$4 \times DELT < T_1$	$D_H = 0$
$4 \times DELT < T_3$	

26.5.41.

IEEEG1, WSIEG1

$5.0 \le K \le 30$	$0 \le K_3 < 0.5$
$0 \le T_1 < 5.0$	$0 \le K_4 < 0.5$
$0 \le T_2 < 10.0$	$0 \le T_6 < 10.0$
$4 \times DELT < T_3 \le 1.0$	$0 \le K_5 < 0.35$
$0.01 \le U_o \le 0.3$	$0 \le K_6 < 0.55$
$-0.3 \le U_c < 0$	$0 \le T_7 < 10.0$
$0.5 \le P_{MAX} \le 2.0$	$0 \le K_7 < 0.3$
$0 \le P_{MIN} < 0.5$	$0 \le K_8 < 0.3$
$P_{MIN} < P_{MAX}$	$0 \le DB1 \le 0.02$
$0 < T_4 \le 1.0$	$0 \le ERR \le 0.02$
$-2.0 \le K_1 \le 1$	$0 \le DB2 \le 0.02$
$K_2 = 0$	$GV_1 \le GV_2 \le GV_3 \le GV_4 \le GV_5$
$0 \le T_5 < 10.0$	

26.5.42.

IEEEG2

$5.0 \le K \le 30$	$0.5 \le P_{MAX} \le 1.5$
$0 \le T_1 < 100$	$0 \le P_{MIN} \le 0.5$
$0 \le T_2 < 10$	$P_{MIN} < P_{MAX}$
$4 \times DELT < T_3 \le 1$	$4 \times DELT \le T_4 \le 5.0$

26.5.43.

IEEEG3

$4 \times DELT \le T_G \le 1.0$	$0 < \gamma \le 1.2$
$4 \times DELT \le T_p < 0.1$	$1.0 \le T_R < 50$
$0 \le U_o < 0.3$	$4 \times DELT < T_w < 10$
$-0.3 < U_c \le 0$	$0 < a_1 < 1.5$
$0.5 \le P_{MAX} \le 1.0$	$0 < a_{13} < 1.5$
$0 \le P_{MIN} \le 0.5$	$0 < a_{21} \le 1.5$

$0 < \sigma \leq 0.1$	$0 < a_{23} < 1.5$

26.5.44.

SHAF25

$H_i < 5$ where i is any mass	$0 \leq D_i \leq 1.0$ where i is any mass
$\Sigma H_i < 10$	$0 \leq K_{shaft\ i\text{-}j} \leq 200$ where i and j are masses
$0 \leq$ Power Fraction$_i < 1.0$ where i is any mass	$0.4 \leq X_d - X'_d \leq 2.5$
Σ Power Fraction = 1.0	$2 \leq T'_{do} \leq 10$
Exciter and generator mass numbers are valid.	

26.5.45.

TGOV4

$5 \leq K \leq 30$	$0 \leq$ CV#3 ≤ 0.5
$0 \leq T_1 \leq 5$	CV#2 $\leq$ CV#3
$0 \leq T_2 \leq 10$	$0 \leq$ CV#4 ≤ 0.75
$0 < T_2$ and $T_1 = 0$	CV#3 $\leq$ CV#4
$4 \times$ DELT $< T_3 \leq 1$	IV = 0.8 or $0.2 \leq$ IV ≤ 0.7
$0.01 \leq U_o \leq 0.3$	$0 \leq$ IV#2 ≤ 0.5
$-0.3 \leq U_c \leq -0.01$	CV CHAR = 0.8 or $0.2 \leq$ CV CHAR ≤ 0.7
$0.05 \leq K_{CAL} \leq 1.5$	IV CHAR = 0.8 or $0.2 \leq$ IV CHAR ≤ 0.7
$0 \leq T_4 \leq 1$	$0 \leq$ CV START ≤ 0.1
$0.1 \leq K_1 \leq 0.5$	$1 \leq$ CV CLOSE ≤ 10
$4 \times$ DELT $< T_5 \leq 10$	$0 \leq$ TIME CV1 CLOSED ≤ 5
$0 \leq K_2 \leq 0.5$	$0 \leq$ TIME CV2 CLOSED ≤ 5
$0 \leq T_6 \leq 2.0$	$0 \leq$ TIME CV3 CLOSED ≤ 5
$1.1 \leq P_{RMAX} \leq 1.5$	$0 \leq$ TIME CV4 CLOSED ≤ 5
$0.2 \leq K_P \leq 1$	$0 \leq$ IV START ≤ 0.1
$0.01 \leq K_I \leq 0.1$	$1 \leq$ IV CLOSE ≤ 10
$0 \leq T_{FUEL} \leq 30$	$0 \leq$ TIME IV1 CLOSED ≤ 5
$0 \leq T_{FD1} \leq 30$	$0 \leq$ TIME IV2 CLOSED ≤ 5
$0 \leq T_{FD2} \leq 30$	$4 \times$ DELT $< T_{RPLU} \leq 0.1$
$0.1 \leq K_b \leq 0.3$	$0 \leq$ PLU RATE ≤ 1
$150 \leq C_b \leq 300$	$0 \leq$ TIMER ≤ 0.1
$4 \times$ DELT $< T_{IV} \leq 1$	$0 \leq$ PLU UNBALANCE LEVEL ≤ 1
$0.01 \leq U_{OIV} \leq 0.3$	$4 \times$ DELT $\leq T_{REVA} \leq 0.1$
$-0.3 \leq U_{CIV} \leq -0.01$	$0 \leq$ EVA RATE LEVEL ≤ 1
$0.01 \leq R \leq 0.05$	$0 \leq$ EVA UNBALANCE LEVEL ≤ 1
$0 \leq$ Offset ≤ 0.60	$0 \leq$ Load Ref ≤ 0.5
CV = 0.8 or $0.2 \leq$ CV ≤ 0.7	$0 \leq$ Ramp Rate ≤ 0.1
$0 \leq$ CV#2 ≤ 0.25	

26.5.46.

BBGOV1

$0 \le f_{cut} < 0.01$	$0 \le T_4 \le 1$
$5 \le K_S < 30$	$0 < K_2 < 1.0$
$0.05 < K_{LS} \le 0.3$	$0 \le T_5 \le 50$
$0.1 \le K_P \le 2.0$	$0 \le K_3 \le 1.0$
$1.0 \le T_N \le 10.0$	$0 \le T_6 \le 1.0$
$0.1 \le K_D \le 2$	$4 \times DELT < T_1 \le 5$
$4 \times DELT < T_D \le 2$	$0.5 \le P_{MAX} \le 0.5$

26.5.47.

GAST2A, GASTWD

$0 < W < 30$ for GAST2A	$0.5 < K_4 < 1$
$0 \le X$ for GAST2A	T_C ³ T_R
$4 \times DELT < Y < 0.5$ for GAST2A	$0.8 \times MBASE \le T_{RATE} \le 1.05 \times MBASE$
$Z = 0$ and $Z \ne 1$ for GAST2A	$0 \le T \le 0.05$
$0 \le K_{DROOP} \le 0.1$ for GASTWD	$0 \le C_{f2} \le 1$
$0 \le K_P \le 20$ for GASTWD	$10 < T_3 < 25$
$0 \le K_I \le 10$ for GASTWD	$1 < T_4 < 5$
$0 \le K_D \le 20$ for GASTWD	$100 < \tau_t < 600$
Max > Min	$1 < T_5 < 5$
$0.5 < Max < 1.8$	$500 < a_{f1} < 1000$
$-0.2 < Min < 0.1$	$300 < b_{f1} < 700$
$0.5 < K_3 < 1$	$-1 < a_{f2} < 1$
$0.5 < a < 50$	$0.9 < b_{f2} < 1.5$
$4 \times DELT < b < 2$	$700 < T_R < 1050$
$0 \le c \le 1.01$	$0.1 < K_6 < 0.5$
$0.05 < \tau_f < 0.8$	$0 \le \varepsilon_{TD} < 0.5$
$0 \le K_f \le 1.0$	$0 \le \varepsilon_{CR} < 0.5$
$0.05 < K_5 < 0.5$	$0 \le T_{CD} < 0.5$

26.5.48.

WPIDHY

$0.05 \le T_{REG} < 5.0$	$0.3 \le GATMX \le 1$
$0 < R_{EG} < 0.1$	$0 \le GATMN \le 0.5$
$0 \le K_P < 10$	$0.5 \le T_W \le 3.0$
$0 \le K_I \le 5$	$0.5 \le PMAX \le 1.1$
$0 \le K_D \le 5$	$0 \le PMIN \le 0.5$

$4 \times DELT < T_A \leq 2$	$0 < D < 0.5$
$4 \times DELT < T_B \leq 2$	$G_0 \leq G_1 \leq G_2$
$0 \leq VELMX \leq 1$	$P_1 \leq P_2 \leq P_3$
$-1 \leq VELMN \leq 0$	

26.5.49.

TGOV5

$5 \leq K \leq 30$	$0 \leq R_{MAX} \leq 0.5$
$0 \leq T_1 < 5$	$-0.5 \leq R_{MIN} \leq 0$
$0 \leq T_2 < 10$	$0 \leq L_{MAX} \leq 2.2$
$4 \times DELT < T_3 \leq 1$	$0 \leq L_{MIN} \leq 1.1$
$0.01 \leq U_o \leq 0.3$	$L_{MAX} > L_{MIN}$
$-0.3 \leq U_c < 0$	$0.1 \leq C_1 \leq 1$
$0.5 \leq V_{MAX} \leq 2$	$-1 \leq C_2 \leq 20$
$0 \leq V_{MIN} < 0.5$	$0 \leq C_3 \leq 1$
$V_{MAX} > V_{MIN}$	$0 \leq B \leq 30$
$0 < T_4 \leq 1$	$50 \leq C_B \leq 300$
$0 \leq K_1 \leq 1$	$0 \leq K_1 \leq 0.5$
$K_2 = 0$	$20 \leq T_1 \leq 300$
$0 \leq T_5 < 10$	$0 \leq T_R \leq 100$
$0 \leq K_3 < 0.5$	$0 \leq T_{R1} \leq 10$
$0 \leq K_4 < 0.5$	$0 \leq C_{MAX} \leq 2.4$
$0 \leq T_6 < 10$	$0 \leq C_{MIN} \leq 0.5$
$0 \leq K_5 < 0.35$	$C_{MAX} > C_{MIN}$
$0 \leq K_6 < 0.55$	$T_D = 0$ or $0.5 \leq T_D \leq 100$
$0 \leq T_7 < 10$	$0 \leq T_F \leq 30$
$0 \leq K_7 < 0.3$	$0 \leq T_W \leq 15$
$0 \leq K_8 < 0.3$	$0 < P_{SP} \leq 2$
$0 \leq K_9 < 1$	$0 \leq T_{MW}$
$0 \leq K_{10} \leq 1$	$K_L = 0$ or $K_L = 1$
$0 \leq K_{11} \leq 1$	$K_{MW} = 0$ or $K_{MW} = 1$
$0 \leq K_{12} \leq 10$	$K_L = 0$ and $K_{MW} = 0$
$0 \leq K_{13} \leq 1$	$0 \leq \Delta P_E \leq 0.2$
$0 \leq K_{14} \leq 5$	

26.5.50.

WSHYDD, WSHYGP for Appropriate Data

$0 \leq DB1 \leq 0.02$	$0 \leq T_t \leq 0.5$
$0 \leq ERR \leq 0.02$	$0 \leq K_G \leq 5.0$
$0 \leq T_d < 10.0$	$0 \leq T_P \leq 0.5$

$0 < K_1 \le 1.0$	$0 \le VEL_{OPEN} \le 0.01$
$0 \le T_f \le 1.0$	$0 \le VEL_{CLOSE} \le 0.01$
$0 \le K_2 \le 1.0$	$0 \le P_{MAX} \le 1.05$
$0 \le K_D \le 1$	$0 \le P_{MIN} \le 0.5$
$0 \le K_P \le 200$	$P_{MIN} < P_{MAX}$
$0 \le K_I \le 200$	$0 \le DB2 \le 0.02$
$0 \le R \le 0.5$	$GV_1 \le GV_2 \le GV_3 \le GV_4 \le GV_5$

26.5.51.

WESGOV

$0 < \Delta TP \le 0.25$	$0 \le T_1 < 0.2$
$0 < \Delta TC \le 0.25$	$0.2 \le T_2 \le 0.6$
$0 < DROOP < 0.10$	$0.15 \le A_{LIM} < 0.4$
$10 \le K_P < 25$	$0 \le T_{pe} < 0.2$
$1.0 \le T_I < 10$	

26.5.52.

WEHGOV

0 < R-PERM-GATE < 0	$0 \le D_{TURB} < 0.5$
0 < R-PERM-PE < 0.1	$0.5 < T_W < 3$
$4 \times DELT < T_{pe} < 0.5$	$0 < D_{BAND} < 0.005$
$1 < K_P < 10$	$0 \le D_{IPV} < 0.1$
$1 < K_I < 20$	$0 \le D_{ICM} < 0.1$
$0 < K_D < 20$	GATE1 → GATE5 ascending value order
$4 \times DELT < T_D < 0.1$	0.8 < GATE5 < 1.3
$4 \times DELT < T_P < 0.2$	FLOWG1 → FLOWG5 ascending value order
$4 \times DELT < T_{DV} < 0.2$	0.8 < FLOWG5 < 1.3
$4 \times DELT < T_G < 1$	FLOWP1 → FLOWP10 ascending value order
0 < GTMXOP < 0.3	0.8 < FLOWP10 < 1.3
-0.3 < GTMXCL < 0	PMECH1 → PMECH10 ascending value order
$0 \le G_{MAX} < 1$	0.8 < PMECH10 < 1.3
$-0.1 < G_{MIN} < 0.3$	

26.5.53.

PIDGOV

$2 \times DELT < T_a < 1$	$P_1 \rightarrow P_3$ ascending value order
$2 \times DELT < T_b < 1$	$0.01 \le Vel_{max} \le 0.3$
$2 \times DELT < T_W < 1$	$-0.3 \le Vel_{min} < 0$
$G_0 \rightarrow G_2$ ascending value order	

26.5.54.

PAUX1

$4 \times DELT < T_r$	$K_c \neq 0$
$0 \leq T_D \leq 10.5 \times DELT$	MIN < MAX

26.5.55.

PAUX2

$4 \times DELT < T_R$	$0 < T_2$
$0 \leq T_D \leq 9.5 \times DELT$	$4 \times DELT < T_3$
$K_c \neq 0$	$4 \times DELT < T_4$
$0 < T_1$	MIN < MAX

26.5.56.

SQBAUX

$4 \times DELT < T_2$	$0 \leq T_D \leq 10.5 \times DELT$
$0 < B_2$	$0 \leq T_L < 0.25$
$I_{MIN} < I_{MAX}$	

26.5.57.

CPAAUX

$C_m \neq 0$	$P_{MIN} < P_{MAX}$
$4 \times DELT < T_B < 1$	$0 < P_{MAX} < 50$
$4 \times DELT < T_A < 1$	$-50 < P_{MIN} < 0$

26.5.58.

GNSCN1

50 < Angle < 200

26.5.59.

GNSCN2

1.0 < Power Threshold < 1.2

26.5.60.

RXR

$0 < R_1$	$R_{10} \leq R_9 < R_8$

$X_1 < X_2$	$R_{10} \le R_6$
$R_3 < R_2$	$X_6 < X_{10}$
$0 < X_3$	$X_{10} < X_9$
$X_1 < X_4$	$X_{11} < X_{12}$
$R_5 < R_4$	$R_{13} < R_{12}$
$0 < X_5$	$R_{14} < R_{11}$
$R_6 < R_7$	$X_{14} < X_{13}$
$X_7 < X_8$	

26.5.61.

LOEXR1

$0 \le T_{Z1} < 6$	$0 < REACH_2 < 0.6$
$0 < REACH_1 < 0.4$	$80 < ANGLE_2 \le 100$
$80 < ANGLE_1 \le 100$	$-0.4 \le CDIST_2 < 0$
$-0.2 \le CDIST_1 < 0$	$0.5 \le VPICKUP$
$3 \le T_{Z2} < 20$	

26.5.62.

CDC1

$T_1 = 0$ or $4 \times DELT < T_1 < 0.2$	$I_1 < I_2 < I_3$
$T_2 = 0$ or $4 \times DELT < T_2 < 0.2$	$V_2 < V_3$
$0 < I_{MIN} < 300$	$0.05 < DELTI < 0.2$

26.5.63.

CDC4 and CDC6 for Appropriate Data

ALFDY $\le$ ALFMX from power flow	$C_1 \le C_2 \le C_3$
GAMDY $\le$ GAMMX from power flow	$V_1 \le V_2 \le V_3$
$TVDC = 0$ or $4 \times DELT < TVDC < 0.2$	$0 \le TCMODE < 0.2$
$TIDC = 0$ or $4 \times DELT < TIDC < 0.2$	$TVRDC = 0$ or $4 \times DELT < TVRDC < 0.2$
$0 < C\phi \le 300$	

26.5.64.

CLOAD

$0 \le$ % LARGE MOTOR ≤ 100	$0 \le$ % CONSTANT POWER ≤ 100
$0 \le$ % SMALL MOTOR ≤ 100	$0 < K_P < 5$
$0 \le$ % TRANSFORMER EXC CUR ≤ 5	$0 \le R < 0.5$
$0 \le$ % DISCHARGE LIGHTING ≤ 100	$0 < x < 1.0$

26.5.65.

CSVGN1, CSVGN3, and CSVGN4 for Appropriate Data

$50 \leq K < 1000$	$V_{MIN} < V_{MAX}$
$4 \times DELT < T_3$	$0 \leq C_{BASE} < 500$
$0 \leq R_{MIN} < MBASE$	$0.1 \leq VOV \leq 0.5$
$1.0 \leq V_{MAX} \leq 2.0$	$0.4 \leq V_L \leq 0.8$
$-0.5 \leq V_{MIN}$	$1.05 \leq V_H \leq 2.0$

26.5.66.

CSVGN5 and CSVGN6 for Appropriate Data

$T_{S1} < 0.4$ sec	$-2B_{MAX} < B_{MIN}$
$V_{E\,MAX} < 0.3$ per unit	$2 \times DELT < T_{S6} \leq 0.2$
$T_{S2} < 2$ sec	$0 \leq D_V < 0.5$
$0 < T_{S3} < 5$ sec	$V_{E\,MIN} < 0.3$
$T_{S4} < 2$ sec	$V_{MAX} < 0.3$
$T_{S5} < 5$ sec	$V_{MIN} < 0.3$
$50 \leq K_{SVS} < 1000$	$BIAS < 1.0$
$0 < K_{SD} < 1000$	$DV2 < 0.3$
$0 < B_{MAX} < 10$	$\mid BSHUNT \mid < 2.0$
$B'_{MAX} < B_{MAX}$	$T_{DELAY} < 0.1$
$B_{MIN} < B'_{MIN}$	

26.5.67.

CIMTR1, CIMTR2, CIMTR3 and CIMTR4 for Appropriate Data

$0.2 < T' < 10$	$x_1 < x''$
$T'' = 0$ or $4 \times DELT < T'' < 0.2$	$0 \leq E_1$
$0.5 < H < 10.0$	$E_1 < E_2$
$0 < x < 5.0$	$S(E_1) < S(E_2)$
$x' < 0.5 \times x$	$0.2 < D < 5$ for motor
$T'' \neq 0$	$Z_{SORCE} = x''$
$x'' < x'$	

26.5.68.

MTDC01, MTDC03

$DY_i \leq ANGMAX_i$	$0 < c\,\phi - i \leq 300$
$TVAC_i = 0$ or $4 \times DELT \leq TVAC_i < 0.2$	c1-i ≤ c2-i ≤ c3-i
$TVDC_i = 0$ or $4 \times DELT \leq TVDC_i < 0.2$	v1-i ≤ v2-i ≤ v3-i

$TIDC_i = 0$ or $4 \times DELT \leq TIDC_i < 0.2$	$0 \leq TCMODE \leq 0.2$

26.5.69.

HVDCAU

$0 < IC \leq 5$ where IC is input code	$T_4 \neq 0$ if $T_5 > 0$
$MININ < MAXIN$	$B = 0$ or $B = 1$
$A = 0$ or $A = 1$	$MINOUT < MAXOUT$
$T_3 \neq 0$ if $T_2 > 0$	$4 \times DELT \leq T_1 < 0.2$

26.5.70.

CRANI

$0 \leq T_1 < 5$	$0 < T_W < 2$
$0 \leq T_2 < 5$	$X_{MIN} < X_{MAX}$
$1 < T_3 < 20$	

26.5.71.

EXTLD2

$0 < K_P \leq 0.1$	$0 < K_Q \leq 0.1$
$1.0 \leq P_{MLTMX} \leq 1.2$	$1.0 \leq Q_{MLTMX} \leq 1.2$
$0.8 \leq P_{MLTMN} \leq 1.0$	$0.8 \leq Q_{MLTMN} \leq 1.2$

26.5.72.

DCTC1

$5 < T_{DR}$	$5 < T_{DI}$
$T_{SDR} < T_{DR}$	$T_{DI} < T_{CI}$
$T_{CR} < T_{SDR}$	$T_{SDI} < T_{DI}$

26.5.73.

OLTC1, OLPS1

$5 < T_D$	$T_C < T_{SD}$
$T_{SD} < T_D$	

26.5.74.

MAXEX1, MAXEX2

$1.0 < EFD_{RATED} < 4.0$	$40 \leq TIME_1 < 120$

$1.0 < EFD_1 < 2.0$	$40 \leq TIME_2 < 120$
$1.0 < EFD_2 < 2.0$	$40 \leq TIME_3 < 120$
$1.0 < EFD_3 < 2.0$	

26.5.75.

CSTCON

$T_3 > 0$	$X_t > 0$
$T_4 > 0$	$V_{MAX} > V_{MIN}$

26.6. Other Data Assumptions Made By Models

In certain models, not only the time constant itself but its effective time constant may cause numerical instability in the modified Euler used in RUN. In these models, an inner loop has been added in which ten time steps have been simulated rather than one. For these models, the time constants are still set to zero if they are less than or equal to 0.5 * DELT. Table 26.2, "Time Constants Assumed Zero if Less Than or Equal to 1/2 Times DELT" lists these models and the time constants.

Table 26.2. Time Constants Assumed Zero if Less Than or Equal to 1/2 Times DELT

Model	Time Constant
EXAC1	T_R, T_A
IEET1S	T_R
EXAC2	T_R, T_A
EXST1	T_R, T_B, T_A
IEEX2A	T_R, T_A
CSVGN5	T_{S1}, T_{S5}

The only area where PSS®E models make data assumptions is with small time constants. In Fault Analysis, numerical integration stability was discussed and it was stated that ΔT should be kept smaller than 20 to 25% of the shortest time constant in the process being simulated. This guideline is not always practical, especially because data often comes from a central bureau and small filter time constants are often entered. To avoid numerical instability in the modified Euler used in RUN, PSS®E will assume a time constant to be zero if it is less than or equal to twice ΔT in certain models. Table 26.3, "Time Constants Assumed Zero if Less Than or Equal to Two Times DELT" lists the models and time constants where this assumption is made.

Table 26.3. Time Constants Assumed Zero if Less Than or Equal to Two Times DELT

Model	Time Constant
STAB3	T_T
STAB4	T_T, T_d, T_e
IEE2ST	T_1, T_2
ST2CUT	T_1, T_2
STBSVC	T_{S7}, T_{S10}
IEEET1	T_R, T_A
IEEET3	T_R, T_A
IEET1A	T_A
IEEEX1	T_R, T_A
IEEEX3	T_R, T_A
IEEEX4	T_R
EXDC2	T_R, T_A
EXAC1A	T_R, T_A
EXAC3	T_R, T_A
EXAC4	T_R, T_A, T_B
EXST2, EXST2A	T_R, T_A
EXST3	T_R, T_B, T_A

Model	Time Constant
SCRX	T_E
SEXS	T_E
EXPIC1	T_R, T_{A4}, T_{F2}
EXBAS	T_R, T_A
ESAC8B	T_R, T_A, T_D
EXELI	T_{fv}, T_{fi}, T_w, T_{s1}, T_{s2}
BBSEX1	T_F, T_2
MNLEX1, MNLEX2, MNLEX3	T_R, T_M, T_{A2}, T_{A1}
TGOV3	T_1, T_4, T_6
TGOV4	T_1, T_4, T_6, T_{FUEL}, T_{FD1}, T_{FD2}
TGOV5	T_{MW}, T_F, T_W, T_1, T_4, T_5, T_6, T_7
IEESGO	T_1, T_4, T_6
IEEEG1	T_1, T_4, T_5, T_6, T_7
IEEEG2	T_1
DEGOV	T_5, T_6
BBGOV1	T_4, T_5, T_6, T_1
GAST2A, GASTWD	b, τ_f, T_{CD}
WEHGOV	T_{pe}, T_P, T_{DV}
WESGOV	T_{pe}, T_1, T_2
WPIDHY	T_{REG}
CSVGN5	T_{S1}, T_{S5}
CSVGN1, CSVGN3, CSVGN4	T_5
CDC1	T_1, T2
CDC4	T_{VDC}, T_{IDC}
CDC6	T_{VDC}, T_{IDC}, T_{VRDC}
MTDC01, MTDC03	$TVAC_i$, $TVDC_i$, $TIDC_i$
PAUX2	T_R
SQBAUX	T_L
HVDCAU	T_1
CRANI	T_1

Chapter 27
Linear Analysis

27.1. Overview

The linear system functions that are described in this chapter are designed for studies on small disturbance (dynamic) stability of power systems. The activities handle the state space matrix determination, eigenvalue, and eigenvector calculations and frequency response predictions.

The functions are not designed to solve any specific problem but rather comprise an arsenal of computational tools that can be directed by the user in the solution of a wide class of problems associated with the dynamic response of power systems.

The basic premise in the design of these functions is that the intimate control over the application of analytical tools be retained by the user. So as throughout PSS®E, the results of each stage of the computation are available to the user for interpretation in order to decide whether to proceed to the next step.

The capacity of these functions has been set at 20 input and 50 output variables.

LSYSAN auxiliary program, binary matrix file incompatibility with older versions of PSS®E. Because PSS®E-30 allows longer bus names, up to 18 characters verses 12 characters maximum in older versions, the binary matrix file that is produced by activity ASTR will not be compatible with earlier versions of PSS®E. Likewise, ASTR binary files produced by older versions of PSS®E cannot be read in by the BCAS activity of LSYSAN in PSS®E-30.

27.1.1. State Space Formulation of a Linear System

Execution of activity ASTR in the dynamics section of PSS®E is usually the first step a user would perform. This converts the system modeled by the user's CONEC and CONET and data contained in the working files into the following linear equations

$$\dot{x} = Ax + Bu \quad (27.1)$$

$$v = Hx + Fu \quad (27.2)$$

where:

A, B, H, F

= Constant matrices.

x

= Real state vector.

u

= Real input vector.

v

= Vector of real system outputs.

This is the state space formulation, and equations Equation 27.1 and Equation 27.2 are called state equations.

Assume the following:

The number of states = n.

The number of inputs = m.

The number of outputs = k.

Then,

x is an nxl vector.

u is an mxl vector.

v is a kxl vector.

A is an nxn matrix.

B is an nxm matrix.

H is a kxn matrix.

F is a kxm matrix.

27.1.2. Eigenvalues

The solution of the state equations Equation 27.1 and Equation 27.2 can be obtained by taking the Laplace Transforms. Thus:

$$x(s) = (SI - A)^{-1}[x(0) + Bu(s)] = \frac{[x(0) + Bu(s)][Adj(SI - A)]}{Det(SI - A)} \tag{27.3}$$

and

$$Y(s) = H(SI - A)^{-1}[x(0) + Bu(s)] + Fu(s) \tag{27.4}$$

where:

I

= Is the identity matrix of the same dimension as matrix A.

Det (SI - A)

= Denotes the determinant of matrix (SI - A).

Adj (SI - A)

= Denotes the adjoint of matrix (SI - A).

X(0)

= Is the state at time t = 0.

The poles of X(s) are the roots of:

$$Det(SI - A) = 0 \tag{27.5}$$

or equivalently the roots of:

$$Det(A - SI) = 0 \tag{27.6}$$

The values of S that satisfy equation Equation 27.6 are called eigenvalues. The eigenvalues, typically denoted by λ , are functions of the state matrix A. The number of eigenvalues is equal to the number of states. For a stable system, all the eigenvalues have negative real parts.

27.1.3. Eigenvectors

For each eigenvalue (λ_i), there exists a vector t_i that satisfies an equation of the form

$$At_i = \lambda_i t_i \tag{27.7}$$

The vector t_i is called the eigenvector of A associated with eigenvalue λ_i. The dimensionality of vector t_i is equal to the number of states.

27.1.4. Linear Independence of Eigenvectors

Let t_1, ..., t_n be the eigenvectors corresponding to eigenvalues λ_1, ..., λ_n. If C_1, ..., C_n are scalars (real or complex numbers), then the sum

$$C_1 t_1 + \ldots + C_n t_n$$

is called a linear combination of the eigenvectors.

The vectors t_1, ..., t_n are said to be linearly independent if no one of them is a linear combination of the others.

27.1.5. Modal Formulation of a Linear System

It is common in linear system analysis to transform the original set of system differential equations into the modal form

$$\dot{y} = \Lambda y + \theta u \tag{27.8}$$

$$x = Ty \tag{27.9}$$

where:

Λ

= Diagonal matrix of eigenvalues.

y

= Complex system state vector in modal domain.

T

= Complex matrix for which the columns are eigenvectors of A.

$\theta = T^{-1}B$

= Complex input matrix.

Each element (y_i) of vector y is termed a mode of the system.

Activities EIGN and DIAG of program LSYSAN obtain the L, θ , and T matrices given A, B, H, and F. The L, θ , and T matrices themselves convey a great deal of information on inherent system dynamics characteristics. The alternative to the modal or time-domain information provided by Equation 27.8 and Equation 27.9 is to produce plots of the frequency response of key outputs of the system when selected inputs are subjected to sinusoidal perturbations.

The frequency response activity FRRS, obtains the complex output vector, v', corresponding to a unit input signal by using the equations

$$y = -(\Lambda - j\omega I)^{-1}\theta u' \tag{27.10}$$

$$s = Ty \tag{27.11}$$

$$v' = Hs + Fu' \tag{27.12}$$

where:

u'

= u vector with one unity element and all others equal to zero.

s

= Complex state vector in frequency domain.

v'

= Complex output vector in frequency domain.

27.1.6. Participation Factors

In practice, it is helpful to determine the magnitude of the influence of a particular state, and hence device, on a given mode of oscillation. A controller should be located at a device that strongly influences the mode to be controlled.

Before introducing the notion of a participation factor, it is necessary to define the right and left participation matrices.

The matrix T, which appears in equation Equation 27.11, is referred to as the right eigenmatrix.

Let:

$$Z = T^{-1}$$

The matrix Z is referred to as the left eigenmatrix.

A participation factor is defined as

$$P_{ik} = \left| t_{ik} z_{ki} \right| \tag{27.13}$$

where:

t_{ik}

= The i^{th} element of the k^{th} column of matrix T.

z_{ki}

= The i^{th} element of the k^{th} row of matrix Z.

The participation factor P_{ik} is the measure of the influence of state i on mode k.

The description that follows presents one logical sequence a user may use in solving a problem. Figure 27.1, "Tree Structure Showing Flow of Functions" is a tree graph that shows prerequisites for each activity. If the user runs an inappropriate activity a message is printed.

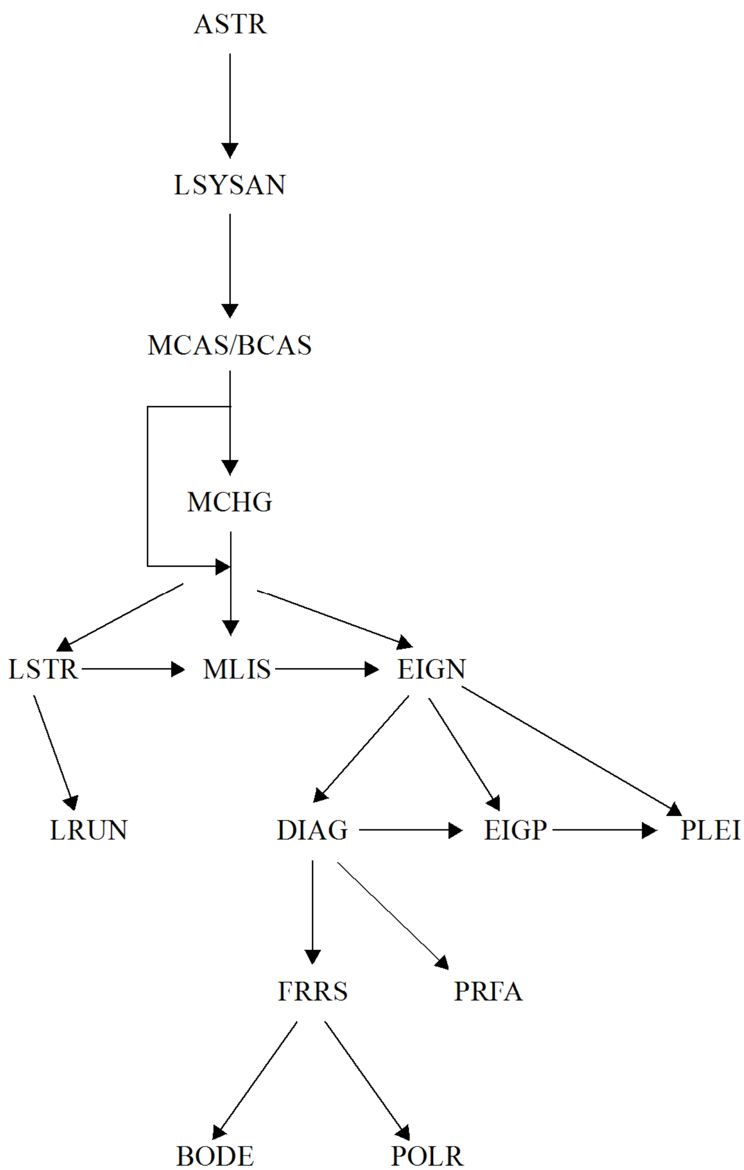


Figure 27.1. Tree Structure Showing Flow of Functions

27.2. PSS®E Interface - Inferring Linear System Matrices

The basic function of ASTR is to sequentially perturb the differential and algebraic equations representing the power system and subsequently infer the state space equations describing the power system dynamic performance.

Executing activity ASTR allows the user to obtain the A, B, H, and F matrices describing the small perturbation behavior of a system that has already been set up. Linear analysis is illustrated by a small system. The power flow raw data file of the system is shown in Figure 27.2, "Small Example System for Linear Analysis Examples". Figure 27.3, "Dynamics Raw Data File for Setup of Simulation Model of Small Example System" shows the dynamics raw data file.

Consider a system described by the ordinary differential equations:

$$x = f(x, u, v) \tag{27.14}$$

and the algebraic equations:

$$v = g(x, u, v)$$

that constitute a dynamics set-up.

Let x^o be an x vector giving a valid equilibrium condition, that is, dx/dt is zero when evaluated at $x = x^o$. Now, let x^j be a vector in which all elements except the j^{th} one are identical to those of x^o, and in which the j^{th} element differs from the corresponding value by Δx^j. Then, if Δx^j is sufficiently small, the j^{th} columns of A and H may be estimated from

$$\left(\frac{dx}{dt}\right)^j - \left(\frac{dx}{dt}\right)^o = A_j \Delta x^j$$

$$v^j - v^o = H_j \Delta x^j$$

where $(dx/dt)^o$ and $(dx/dt)^j$ are evaluated from Equation 27.14 using x^o and x^j; v^j and v^o are system outputs evaluated on the basis of x^o and x^j; and A_j and H_j are the j^{th} columns of A and H. The columns of B and F are estimated similarly by evaluating (dx/dt) and v with individual elements perturbed in the input vector u.

ASTR, using the user's set-up first does a standard initialization to set up the equilibrium condition (see *PSS®E Program Operation Manual*, Building a State Variable Matrix for Linear Dynamic Analysis (LSYSAN)). During this initialization all equipment values are calculated for each model's boundary conditions.

Activity ASTR then instructs the user to ENTER THE LARGEST DERIVATIVE CHANGE ALLOWED. If no value is entered, the derivative defaults to 0.01. ASTR then checks the values of all state variable derivatives, DSTATE, against a user entered limit. All elements of the DSTATE array should ideally be zero, but small deviations may exist in practice due to a small error in the initial estimate in the power flow or in the x, v, and u vectors. ASTR is different from the standard STRT in that the actual DSTATE is checked against the perturbation specified by the user rather than a default value. A new specified perturbation is required because it is felt that the method used should ideally be in equilibrium for utmost accuracy and engineering judgment is required to decide if it is close enough. If any DSTATE is above the derivative change allowed, it is printed and the activity is aborted.

```
0    100.00          / TUE, OCT 27 1998  11:33
TWO MACHINE EXAMPLE WITH INFINITE BUS

    1 'INF BUS '    0.0000 3      0.000      0.000   1   1 1.00000    0.0000   1
    2 'GEN 1   '    0.0000 2      0.000      0.000   1   1 1.00000   16.3116   1
    3 '        '    0.0000 1      0.000      0.000   1   1 1.01351   13.0876   1
    4 'GEN 2   '    0.0000 2      0.000      0.000   1   1 1.00000   22.7724   1
 0
    3 1  1   1   1    400.000   -100.000      0.000      0.000      0.000      0.000   1
 0
    1 1    -150.000      1.877   9999.000  -9999.000 1.00000     0   100.000    0.00000    0.10000    0.00000    0.00000 1.00000 1    100.0
9999.000  -9999.000   1 1.0000
    2 1      50.000    -15.443   9999.000  -9999.000 1.00000     0   200.000    0.00000    0.25000    0.00000    0.00000 1.00000 1    100.0
9999.000  -9999.000   1 1.0000
    4 1     500.000     -7.259   9999.000  -9999.000 1.00000     0   600.000    0.00000    0.30000    0.00000    0.00000 1.00000 1    100.0
9999.000  -9999.000   1 1.0000
 0
    1      3 1     0.00000    0.15300    0.13000     0.00     0.00     0.00,,,   0.00000   0.00000   0.00000   0.00000 1     0.0    1 1.0000
    2      3 1     0.00000    0.11400    0.10000     0.00     0.00     0.00,,,   0.00000   0.00000   0.00000   0.00000 1     0.0    1 1.0000
    3     -4 1     0.00000    0.03410    0.20000     0.00     0.00     0.00,,,   0.00000   0.00000   0.00000   0.00000 1     0.0    1 1.0000
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
 0
```

Figure 27.2. Small Example System for Linear Analysis Examples

```
1 'GENCLS' 1 0. 0./
2 'GENROU' 1 6. .035 1. .07 4. 0. 2.2 2.0 .4 .47 .25 .1 .12 .3667/
4 'GENROU' 1 4.8 .035 1.5 .07 3.2 0. 1.8 1.75 .37 .47 .3 .15 .12 .3667/
2 'SCRX' 1 .1 10. 150. .05 -3.2 4.0 1.0 0/
4 'SCRX' 1 .1 10. 150. .05 -3.2 4.0 1.0 0/
```

Figure 27.3. Dynamics Raw Data File for Setup of Simulation Model of Small Example System

The activity then instructs the user to enter an output filename. It then instructs the user to enter single or range of state variables to be used and whether or nor the user would like to perturb them. The overall flow chart of the process is shown in Figure 27.4, “Flow Chart of Activity ASTR”.

The elements of the output vector, v, are defined as the first fifty (or less) output channels the user selects.

Before determining the A,H or B,F matrices, ASTR allows the user to designate up to 20 system variables as inputs for the B matrix. It does this by instructing the user:

```
ENTER INPUT QUANTITY CATEGORY AND
      AMOUNT OF PERTURBATION:
0=EXIT      1=EFD         2=PMECH
3=VOTHSG    4=VREF        5=VAR
```

Each input is specified in response to questions by ASTR by typing in

1. Input quantity and amount of perturbation, 0.01 per unit is default for each input. This perturbation default value is reset for each quantity.

2. Bus number and machine ID for machine quantities or VAR number. If a bus entered is not found or a machine is not available, an appropriate message is printed and the user is asked to specify the bus and machine again. No checks are made on VAR inputs.

Note that specifying EFD for a machine with an exciter or PMECH for a machine with a governor as inputs is invalid. The activity however does not print any messages indicating the invalid requests because the information is not known by the program.

The user response is the output file for storing the matrices for use by the linear analysis program. A carriage return exits the activity without storing the matrices.

The activity now instructs the user to

```
ENTER SINGLE STATE OR STARTING AND ENDING STATES
TO BE
INCLUDED IN MATRICES
```

because the user may not always want all the states represented. If the user specifies the last state greater than the number used, the question is repeated. After the user input, the activity writes the matrices or parts of the matrix to the appropriate file.

If state space matrices corresponding to different system conditions are required, the system may now be updated (i.e., new power flow case, different system parameters via ALTR, etc.) and ASTR can be rerun.

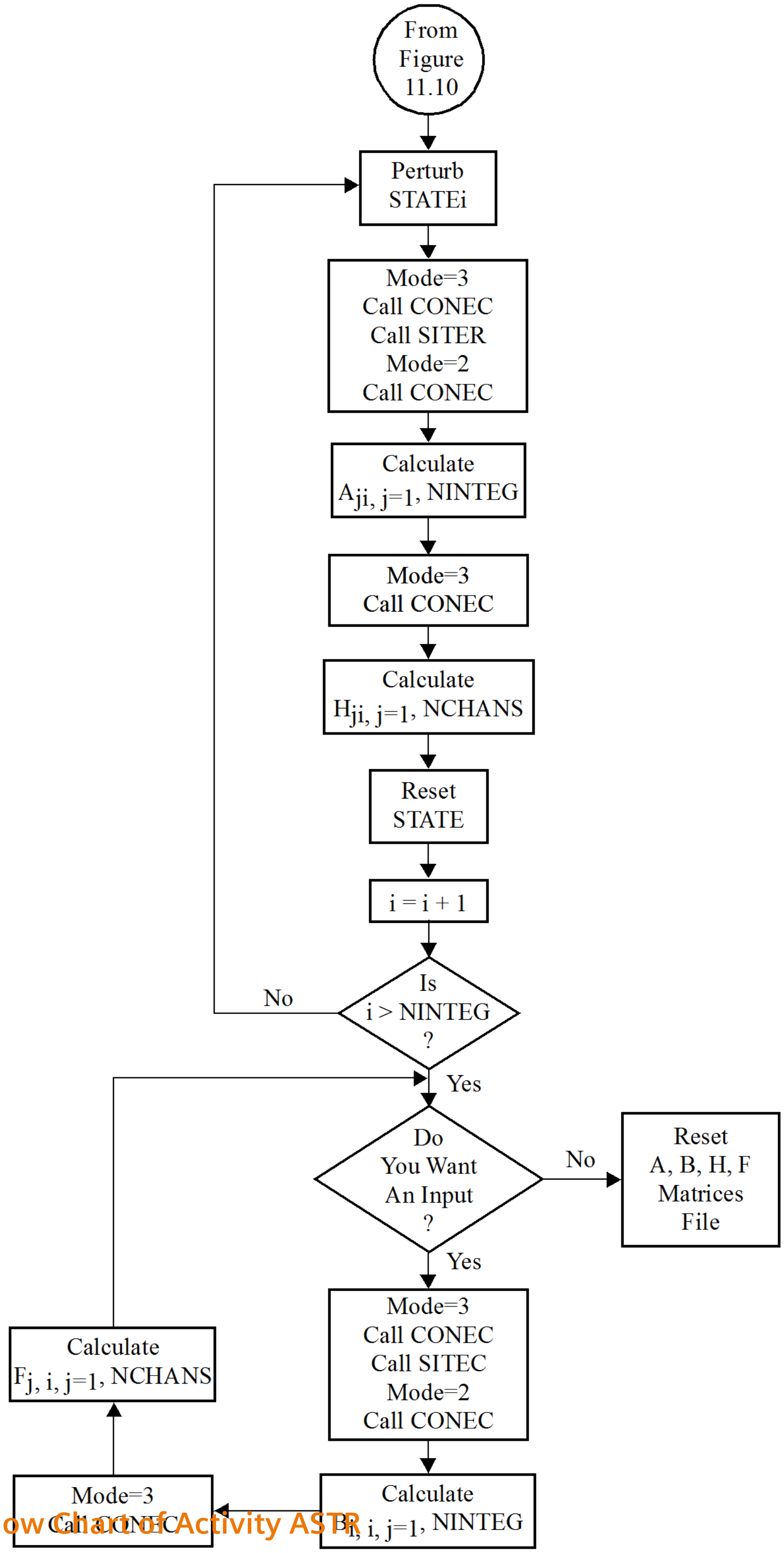


Figure 27.4. Flow Chart of Activity ASTR

```
$ PSSDS4

               POWER TECHNOLOGIES INCORPORATED

        12000 BUS POWER SYSTEM SIMULATOR--PSS®E-20.1

INITIATED AT DYNAMICS ENTRY POINT ON THU, OCT 15 1992  16:40

ACTIVITY? RSTR SNAP2
```

Pick up Snapshot

```
TWO MACHINE EXAMPLE WITH INFINITE BUS

SNAPSHOT SNAP2.SNP WAS SAVED ON TUE, OCT 13 1992  09:22

NUMBER OF ELEMENTS RESTORED:
  CONS STATES   VARS  ICONS CHANNELS
    46     18      0      0      5

ACTIVITY? LOFL
```

Pick up power flow

```
ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY?
CASE CVLF2
TWO MACHINE EXAMPLE WITH INFINITE BUS

CASE CVLF2.SAV WAS SAVED ON TUE, OCT 13 1992  09:22

ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? FACT

    4 DIAGONAL AND     3 OFF-DIAGONAL ELEMENTS

ACTIVITY RTRN TO RETURN TO DYNAMICS--ACTIVITY? RTRN

ACTIVITY? STRT
```

Do a standard STRT to make sure all is okay

```
INITIAL CONDITION LOAD FLOW USED  1 ITERATIONS

--------------------------MACHINE INITIAL CONDITIONS---------------------------
X------ BUS -----X ID  ETERM   EFD    POWER    VARS   P.F.   ANGLE   ID     IQ
    1 INF BUS       1 1.0000 0.9968 -150.00  -14.51-0.9954  -8.65 0.0823-1.5048
    2 GEN 1         1 1.0000 1.0839   50.00  -15.47 0.9553  38.38 0.0507 0.2567
    4 GEN 2         1 1.0000 1.9046  500.00   -7.33 0.9999  69.60 0.6592 0.5100

INITIAL CONDITIONS CHECK O.K.

ENTER CHANNEL OUTPUT FILENAME:

ENTER SNAPSHOT FILENAME:

ACTIVITY? DOCU,ALL
```

Do a DOCU to note state variables

```
ENTER OUTPUT DEVICE CODE:
 0 FOR NO OUTPUT         1 FOR CRT TERMINAL
 2 FOR A FILE            3 FOR KMW_UP
 4 FOR QMS_LG            5 FOR HARD COPY TERMINAL
 6 FOR ALTERNATE SPOOL DEVICE: 1

ENTER 0 FOR REPORTING MODE, 1 FOR DATA CHECKING MODE: 0
```

Figure 27.5. Creating the Linear Analysis Matrices (Sheet 1 of 4)

```
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU, OCT 15 1992  16:40
TWO MACHINE EXAMPLE WITH INFINITE BUS


REPORT FOR ALL MODELS AT ALL BUSES         BUS     1 [INF BUS     ] PLANT MODELS

        ** GENCLS **  BUS    NAME  BSKV MACH    C O N ' S     STATE'S
                        1 INF BUS        1       1-    2      1-     2    We will want to delete
                                                                          these state variables
    MBASE      Z S O R C E          X T R A N        GENTAP       H      DAMP
    100.0  0.00000+J 0.10000  0.00000+J 0.00000  1.00000      0.00    0.000

ENTER 0 TO END LIST, 1 FOR NEXT PAGE: 1

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU, OCT 15 1992  16:40
TWO MACHINE EXAMPLE WITH INFINITE BUS


REPORT FOR ALL MODELS AT ALL BUSES         BUS     2 [GEN 1       ] PLANT MODELS

        ** GENROU **  BUS    NAME  BSKV MACH    C O N ' S     STATE'S
                        2 GEN 1          1       3-   16      3-     8

            MBASE      Z S O R C E          X T R A N        GENTAP
            200.0  0.00000+J 0.25000  0.00000+J 0.00000  1.00000

 T'DO T''DO  T'QO T''QO     H   DAMP   XD     XQ     X'D    X'Q   X''D    XL
 6.00 0.035  1.00 0.070   4.00  0.00 2.2000 2.0000 0.4000 0.4700 0.2500 0.1000

                              S(1.0)  S(1.2)
                              0.1200  0.3667


     ** SCRX **  BUS    NAME  BSKV MACH    C O N ' S     STATE'S   SOLID
                   2 GEN 1          1      31-   38     15-    16    FED

       TA/TB     TB       K       TE      EMIN    EMAX  SWITCH  RC/RFD
       0.100  10.000   150.0   0.050    -3.20    4.00    1.0     0.00

REPORT FOR ALL MODELS AT ALL BUSES         BUS     4 [GEN 2       ] PLANT MODELS

        ** GENROU **  BUS    NAME  BSKV MACH    C O N ' S     STATE'S
                        4 GEN 2          1      17-   30      9-    14

            MBASE      Z S O R C E          X T R A N        GENTAP
            600.0  0.00000+J 0.30000  0.00000+J 0.00000  1.00000

 T'DO T''DO  T'QO T''QO     H   DAMP   XD     XQ     X'D    X'Q   X''D    XL
 4.80 0.035  1.50 0.070   3.20  0.00 1.8000 1.7500 0.3700 0.4700 0.3000 0.1500

                              S(1.0)  S(1.2)                   We will also want to drop
                              0.1200  0.3667                   these state variables

     ** SCRX **  BUS    NAME  BSKV MACH    C O N ' S     STATE'S   SOLID
                   4 GEN 2          1      39-   46     17-    18    FED

       TA/TB     TB       K       TE      EMIN    EMAX  SWITCH  RC/RFD
       0.100  10.000   150.0   0.050    -3.20    4.00    1.0     0.00

ACTIVITY? DLST                                                 List output channels
```

Figure 27.6. Creating the Linear Analysis Matrices (Sheet 2 of 4)

```
ENTER OUTPUT DEVICE CODE:
 0 FOR NO OUTPUT           1 FOR CRT TERMINAL
 2 FOR A FILE              3 FOR KMW_UP
 4 FOR QMS_LG              5 FOR HARD COPY TERMINAL
 6 FOR ALTERNATE SPOOL DEVICE: 1

ENTER CON RANGE: 0

ENTER VAR RANGE: 0

ENTER STATE RANGE: 0

ENTER ICON RANGE: 0

ENTER OUTPUT CHANNEL RANGE: 1,5


     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU, OCT 15 1992  16:40
TWO MACHINE EXAMPLE WITH INFINITE BUS



OUTPUT CHANNELS:

#:ADDR     1:  4002        2:  4003       3: 24002       4: 24003       5: 16002
       P ELECTRICAL   P ELECTRICAL   SPD DEVIAT'N   SPD DEVIAT'N   FIELD VLTAGE
      BUS     2 MC 1  BUS     4 MC 1  BUS     2 MC 1  BUS     4 MC 1  BUS     2 MC 1
IDENT   P 1GEN 1       P 1GEN 2       SPD1GEN 1      SPD1GEN 2      EFD1GEN 1
VALUE   0.50000         5.0000         0.00000E+00    0.00000E+00     1.0839

ACTIVITY? ASTR <------------------------------------ Now create linear analysis matrices

    PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      THU, OCT 15 1992  16:40
TWO MACHINE EXAMPLE WITH INFINITE BUS


INITIAL CONDITION LOAD FLOW USED  1 ITERATIONS

--------------------------MACHINE INITIAL CONDITIONS--------------------------
X------ BUS -----X ID  ETERM   EFD    POWER    VARS    P.F.   ANGLE   ID      IQ
    1 INF BUS        1 1.0000 0.9968 -150.00  -14.51-0.9954  -8.65 0.0823-1.5048
    2 GEN 1          1 1.0000 1.0839   50.00  -15.47 0.9553  38.38 0.0507 0.2567
    4 GEN 2          1 1.0000 1.9046  500.00   -7.33 0.9999  69.60 0.6592 0.5100

ENTER LARGEST DERIVATIVE CHANGE ALLOWED (DEFAULT IS 0.01):


ENTER MATRIX OUTPUT FILE NAME (0 TO EXIT): MATOUT

   18 STATES IN USE.  ENTER SINGLE STATES OR STARTING AND
ENDING STATES TO BE INCLUDED IN MATRICES (CR FOR FIRST  18)


ENTER STARTING AND ENDING STATES: 3 16


ENTER STARTING AND ENDING STATES: 0


ENTER AMOUNT TO PERTURB SELECTED STATES (DEFAULT IS 0.01):


   5 OUTPUT CHANNELS IN USE.  ENTER SINGLE CHANNELS OR STARTING AND
ENDING CHANNELS TO BE INCLUDED AS LINEAR SYSTEM OUTPUTS (CR FOR FIRST  5)
```

Figure 27.7. Creating the Linear Analysis Matrices (Sheet 3 of 4)

```
ENTER STARTING AND ENDING OUTPUT CHANNELS: 1 5

ENTER STARTING AND ENDING OUTPUT CHANNELS:

ENTER INPUT QUANTITY CATEGORY AND AMOUNT OF PERTURBATION:
0 = EXIT      1 = EFD       2 = PMECH

3 = VOTHSG    4 = VREF      5 = VAR: 2

ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 2

ENTER INPUT QUANTITY CATEGORY AND AMOUNT OF PERTURBATION:
0 = EXIT      1 = EFD       2 = PMECH

3 = VOTHSG    4 = VREF      5 = VAR: 2

ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 4

ENTER INPUT QUANTITY CATEGORY AND AMOUNT OF PERTURBATION:
0 = EXIT      1 = EFD       2 = PMECH

3 = VOTHSG    4 = VREF      5 = VAR: 4

ENTER BUS NUMBER, MACHINE ID, 'IDENTIFIER': 2

ENTER INPUT QUANTITY CATEGORY AND AMOUNT OF PERTURBATION:
0 = EXIT      1 = EFD       2 = PMECH

3 = VOTHSG    4 = VREF      5 = VAR: 0
```

Two of the inputs are mechanical powers

The third input is reference voltage

Figure 27.8. Creating the Linear Analysis Matrices (Sheet 4 of 4)

Figure 27.5, "Creating the Linear Analysis Matrices (Sheet 1 of 4)" shows the dialog to create the matrices of the small example system. In this problem the user had full representation of the generators and excitation systems. For the linear analysis calculations it was not useful to keep the excitation states of the machine on bus 4 or those of the classical generator. The interactive dialog reflects this decision for the starting and last state variables.

All the linear system activities keep the state variable in the order they are assigned in CONEC. When the user enters a starting integrator greater than one, the order is kept but the index will be reduced so that the first retained state is numbered one.

Note that activity ASTR does not calculate bus frequency because the perturbation technique used to build the matrices is a t-minus, t-plus calculation in which frequency will not change. Approximations obtained by using bus angle change tend to produce meaningless results. Therefore, any model such as a stabilizer where the input is bus frequency will not contribute to the eigenvalues (it will be as if the device is not there).

27.3. Accessing Linear System Activities or Picking Up the Matrices

Before any of the linear system activities can be run, it is necessary for the user to leave PSS®E and enter the linear system activities program, LSYSAN. If a frequency response calculation has been run and the output stored, the user can then run a BODE or POLAR plot. Most likely, however, the linearized matrices describing the problem will be read into memory. This is accomplished by either activities MCAS or BCAS. Activity MCAS reads data in ASCII form while BCAS reads binary data.

The program activity selector will print the following:

```
ACTIVITY?
```

Activity MCAS asks the user to

```
ENTER MATRIX INPUT FILE NAME:
```

This file was either created by activity ASTR or by the user via the CRT or another program. User input files are allowed so that all the linear system analysis activities are made available to the user for other type studies. The file should contain the following:

IHA IHB NINTEG, NOUTS, NINPUT A matrix B matrix H matrix F matrix IDENT NINDEN

where:

IHA and IHB

= Records describing the case. Each line may contain up to 60 characters that are entered in columns one through 60.

NINTEG

= Number of integrators.

NOUTS

= Number of outputs.

NINPUT

= Number of inputs.

IDENT

= The 12 character identifiers of the outputs.

NINDEN

= The 12 character identifiers of the inputs.

These values are entered in free format except for IDENT and NINDEN for which the format is 5(1X,A). Matrices should be input by rows. Activity BCAS should be used if the matrix data is in binary form. Note that the activities of LSYSAN use frequency response techniques that require that no row of the A matrix is comprised of only zero elements. If the user reads in an A matrix that has rows that are composed of only zero elements, LSYSAN will eliminate the zero rows and the user will be informed.

27.4. Listing the A, B, H, and F Matrices

Often the user will want to list these matrices to check their reasonableness. This is performed via activity MLIS. The activity allows all the standard PSS®E output destinations. Figure 27.9, "Linking to Linear Analysis Activities Picking-Up and Listing Matrices" shows the dialog to start program LSYSAN, to pick up and to list the matrices for the simple system created in Figure 27.5, "Creating the Linear Analysis Matrices (Sheet 1 of 4)". Figure 27.10, "Sample System Matrix" lists the matrices for our sample system.

27.5. Calculating Eigenvalues and Eigenvectors

Activity EIGN uses EISPACK [1] subroutines to determine the eigenvalues and eigenvectors. The eigenvalues are saved in order of decreasing magnitude of their imaginary part, followed by eigenvalues with zero imaginary part in order of decreasing magnitude of real part. The eigenvectors are saved in order corresponding to the original state variable order with the corresponding eigenvalues. The eigenvectors are normalized so that the largest element of each is unity.

The activity will print messages if the algorithms cannot find the eigenvalues or eigenvectors. The messages indicate that the results of EIGN cannot be trusted as input to activities using the eigensystem of A. If such messages appear, the user should check the validity of the A matrix, and should check for a very wide range of magnitudes of elements of A, or other evidence of ill-conditioning.

[1] Matrix Eigensystem Routines - EISPACK Guide, Springer-Verlag, 1974.

27.6. Documenting the Eigensystem

Activity EIGP automatically lists the eigenvalues of the system. The activity allows all the standard PSS®E output destinations. As an option, the user can list eigenvectors also. Eigenvalues and eigenvectors listings can be limited to those associated with synchronous machine angles. These are often the ones in which the user is most concerned about. When listing eigenvalues, the damping factor is also printed. This is done so that the users attention can focus on the lightly damped modes.

Activity PLEI will give a planar plot of all the eigenvalues. Activity PLEI also allows the user to plot individual elements of each eigenvector. This is often very valuable when trying to analyze the modes of oscillation of the system.

Figure 27.11, "Obtaining and Listing Eigenvalues and Eigenvectors (Sheet 1 of 2)" shows the dialog used to create, list, and plot the eigenvalues and eigenvectors as well as their values for our sample system. Figure 27.13, "Plot of Eigenvalues" shows a planar plot for our sample system while Figure 27.14, "Plot of an Eigenvector" shows a plot of three elements of the second eigenvector.

```
LSYSAN


                   POWER TECHNOLOGIES INCORPORATED

 LINEAR SYSTEM ANALYSIS PROGRAM INITIATED ON FRI OCT 16, 1992  09:49

 ACTIVITY? BCAS
 ENTER MATRIX INPUT FILE NAME (0 TO EXIT): MATOUT

 ACTIVITY? MLIS

 ENTER OUTPUT DEVICE CODE:
  0 FOR NO OUTPUT          1 FOR CRT TERMINAL
  2 FOR A FILE             3 FOR PRINTER-1
  4 FOR PRINTER-2          5 FOR HARD COPY TERMINAL
  6 FOR ALTERNATE SPOOL DEVICE: 1

      PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI OCT 16, 1992  09:50
 TWO MACHINE EXAMPLE WITH INFINITE BUS


 ROW   BUS  X-- NAME --X MC  MODEL   STATE
   1     2  GEN 1         1  GENROU  K
   2     2  GEN 1         1  GENROU  K+1
   3     2  GEN 1         1  GENROU  K+2
   4     2  GEN 1         1  GENROU  K+3
   5     2  GEN 1         1  GENROU  K+4
   6     2  GEN 1         1  GENROU  K+5
   7     4  GEN 2         1  GENROU  K        Identification of the system state
   8     4  GEN 2         1  GENROU  K+1
   9     4  GEN 2         1  GENROU  K+2
  10     4  GEN 2         1  GENROU  K+3
  11     4  GEN 2         1  GENROU  K+4
  12     4  GEN 2         1  GENROU  K+5
  13     2  GEN 1         1  SCRX    K
  14     2  GEN 1         1  SCRX    K+1
```

Figure 27.9. Linking to Linear Analysis Activities Picking-Up and Listing Matrices

```
    PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI OCT 16,
1992  09:50
 TWO MACHINE EXAMPLE WITH INFINITE BUS


 A MATRIX COLUMNS STARTING AT   1
   1 -0.8637     -0.2818E-01  0.3030     -0.4142E-01  0.0000     -0.1314     0.1156
0.2954E-01  0.5392E-01  0.3347E-01
   2 -0.1323      -3.975     -0.1323      1.701      0.0000      0.9114     -0.1776     0.3285    -
0.8289E-01  0.3723
   3   21.42     -0.2763      -35.73     -0.4064      0.0000     -7.511      6.603      1.688
3.081      1.912
   4  0.2106       10.71      0.2108      -19.53      0.0000      7.766      -1.514      2.799    -
0.7064      3.172
   5 -0.6338E-01  0.7128E-01 -0.6338E-01  0.1045    -0.3094E-01 -0.2089     0.7151E-01
-0.4899E-01  0.3337E-01 -0.5551E-01
   6  0.0000      0.0000      0.0000      0.0000      377.0      0.0000      0.0000      0.0000
0.0000      0.0000
   7  0.3031E-01 -0.2214E-01  0.3031E-01 -0.3250E-01  0.0000     0.7358E-01 -0.8736
-0.7249E-01  0.3219     -0.8225E-01
   8  0.5382E-01  0.4841E-01  0.5381E-01  0.7099E-01  0.0000    -0.6282E-01 -0.1777
-2.421     -0.8241E-01   1.034
   9  0.9380     -0.6853      0.9379     -1.006      0.0000      2.277      24.89     -0.6309    -
30.29     -0.7151
  10  0.6151      0.5534      0.6151      0.8114      0.0000     -0.7178      0.6677      12.45
0.3117     -16.37
  11 -0.1697E-02 -0.2611E-01 -0.1695E-02 -0.3830E-01  0.0000     0.5619E-01 -0.1318
-0.8287E-02 -0.6149E-01 -0.9412E-02
  12  0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000
0.0000      0.0000
  13 -0.2351E-01 -0.9470E-02 -0.2351E-01 -0.1389E-01  0.0000     0.1592E-02 -
0.1220E-01 -0.9561E-02 -0.5691E-02 -0.1084E-01
  14  -78.35      -31.57      -78.36      -46.31      0.0000      5.307      -40.67      -31.87    -
18.97      -36.12

 A MATRIX COLUMNS STARTING AT  11
   1  0.0000      0.5827E-01  0.0000      0.1667
   2  0.0000     -0.7292      0.0000      0.0000
   3  0.0000       3.330      0.0000      0.0000
   4  0.0000      -6.214      0.0000      0.0000
   5  0.0000      0.1511      0.0000      0.0000
   6  0.0000      0.0000      0.0000      0.0000
```

a. A Matrix

b. B Matrix

c. H Matrix

d. F Matrix

Figure 27.10. Sample System Matrix

```
ACTIVITY? eign                         The A matrix is in memory; run EIGN
                                       List eigenvalues and eigenvectors
ACTIVITY? eigp

ENTER DESIRED OUTPUT OF EIGEN ANALYSIS RESULTS:
  0 TO EXIT         1 FOR EIGENVALUES
  2 FOR EIGENVECTORS   3 FOR EIGENVALUES AND EIGEN-
VECTORS
  4 FOR EIGENVALUES AND EIGENVECTORS OF SYNCHRO-
NOUS MACHINE ANGLES: 3

ENTER OUTPUT DEVICE CODE:
 0 FOR NO OUTPUT      1 FOR CRT TERMINAL
 2 FOR A FILE         3 FOR QMS PS2000
 4 FOR QMS_PS800      5 FOR HARD COPY TERMINAL
 6 FOR ALTERNATE SPOOL DEVICE: 1

    PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E
FRI DEC 03, 1993  10:30
 TWO MACHINE EXAMPLE WITH INFINITE BUS


 EIGENVALUES:

 NO.   REAL       IMAG       DAMP       FREQ   List the elements of eigenvector #5
  1  -1.2322     8.8473    0.13794     1.4081
  2  -1.2322    -8.8473    0.13794     1.4081

  3 -0.22455     4.2638    0.52591E-01  0.67860
  4 -0.22455    -4.2638    0.52591E-01  0.67860

  5 -0.63916     0.59114   0.73415     0.94082E-01
  6 -0.63916    -0.59114   0.73415     0.94082E-01

 ENTER 0 TO EXIT, 1 FOR NEXT PAGE: 1

    PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E
```

Figure 27.11. Obtaining and Listing Eigenvalues and Eigenvectors (Sheet 1 of 2)

```
ACTIVITY? plei

SUPPORTED PLOTTING DEVICES ARE:
  0 = NONE                      2 = HP 7221A
  3 = TEKTRONIX 4010            4 = TEKTRONIX 4014
  5 = TEKTRONIX 4014 W/EGM      6 = TEKTRONIX 4662
  7 = TEKTRONIX 4663           11 = GRPG FILE
 17 = TEKTRONIX 4105/04/06     18 = TEKTRONIX 4107/09
 20 = TEKTRONIX 4112           21 = TEKTRONIX 4113
 22 = TEKTRONIX 4114           23 = TEKTRONIX 4115/4125
 25 = X Window (B&W)           27 = HP 7470A
 28 = HP 7475A                 31 = QMS LASERGRAFIX      Do a planar plot first
 33 = TEKTRONIX 4111           37 = TEKTRONIX 41XX FILE
 38 = HP-GL FILE               39 = X Window
 40 = TEKTRONIX 4010/4014 FILE 41 = POSTSCRIPT
 99 = INDE. PLOT FILE
SELECT PLOTTING DEVICE [,PARM FILE]: 41
ENTER FIRST OPTIONAL 60 CHARACTER TITLE:
planar plot
ENTER SECOND OPTIONAL 60 CHARACTER TITLE:
                                                         Plot eigenvector #2
ENTER 1 FOR PLANAR PLOT OF EIGENVALUES
      2 TO PLOT SELECTED EIGENVECTORS
      3 TO PLOT SELECTED EIGENVECTORS OF SYNCHRO-
NOUS MACHINE ANGLES: 1
ENTER MINIMUM, MAXIMUM FOR ABSCISSA: -40 5
ENTER MINIMUM, MAXIMUM FOR ORDINATE: -10 10
ENTER 25 CHARACTER LABEL:
eigenvalues

ENTER:
  0 = RETURN                                             Choose these elements
  1 = SELECT NEW PLOTTING DEVICE
  2 = NEW PLOT ON THE POSTSCRIPT
  3 = REPEAT PLOT ON NEW DEVICE: 2
ENTER FIRST OPTIONAL 60 CHARACTER TITLE:
plot an eigenvector
ENTER SECOND OPTIONAL 60 CHARACTER TITLE:
                                                         No other plots
ENTER 1 FOR PLANAR PLOT OF EIGENVALUES
```

Figure 27.12. Obtaining and Listing Eigenvalues and Eigenvectors (Sheet 2 of 2)

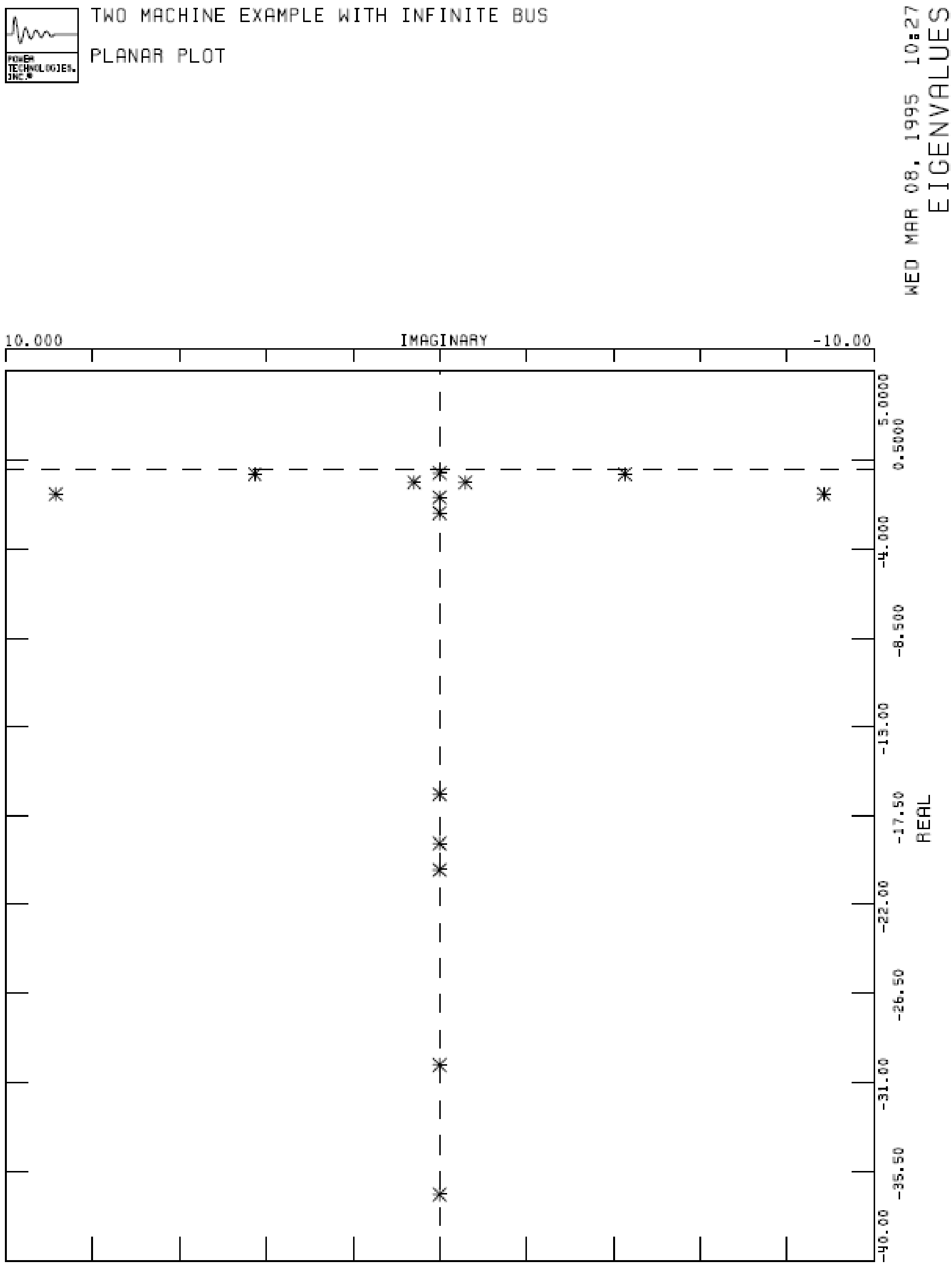


Figure 27.13. Plot of Eigenvalues

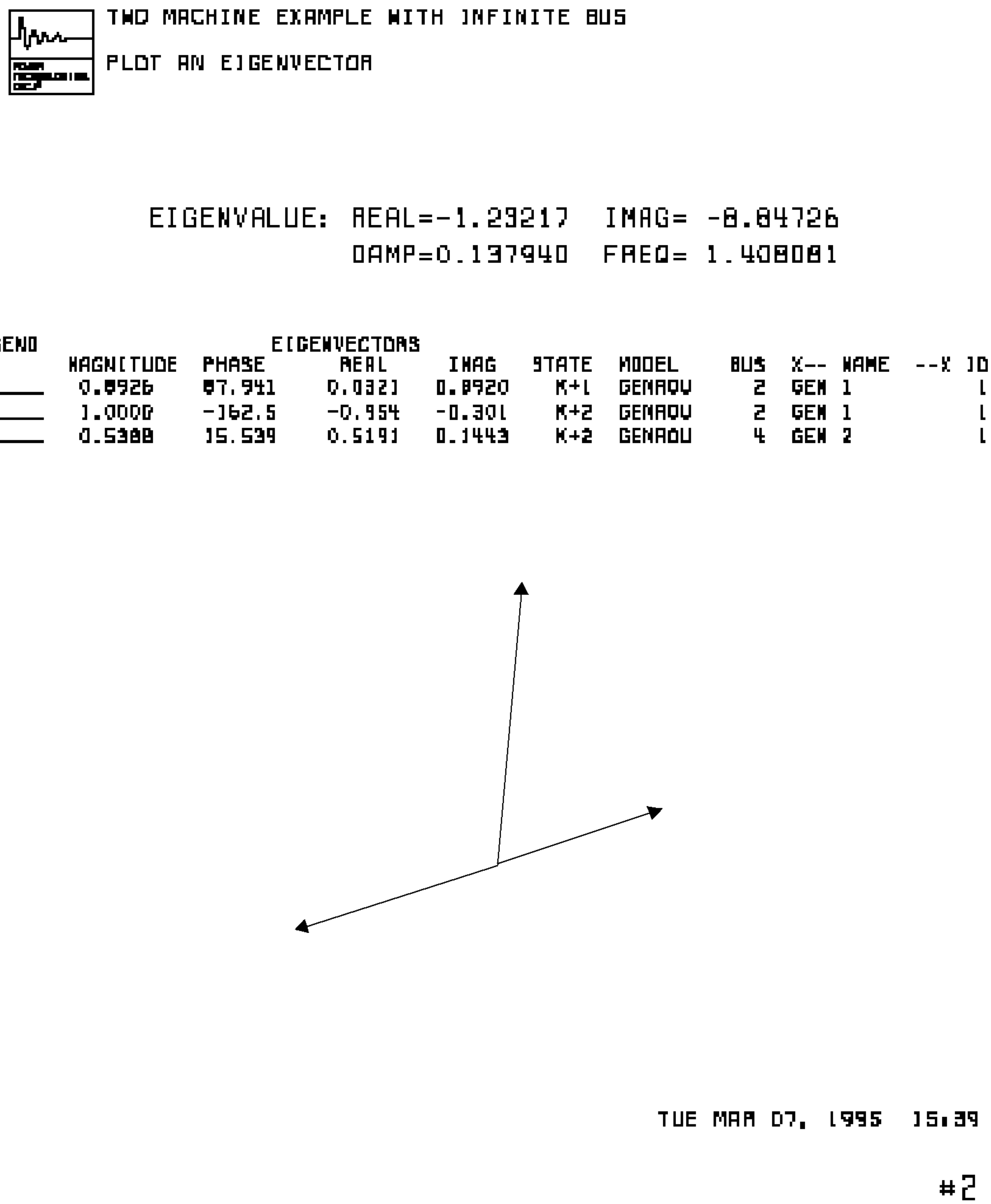


Figure 27.14. Plot of an Eigenvector

27.7. Modal Form Transformation of Activity DIAG

This activity calculates the matrix θ of equation Equation 27.8 corresponding to the basic linear system equation Equation 27.1. While the EIGN activity constructs the Λ and T matrices, activity DIAG completes the transformation of Equation 27.1 and Equation 27.2 into the modal form Equation 27.8 and Equation 27.9.

The Λ matrix is given by:

$$\theta = T^{-1} \times B$$

DIAG checks for isolated natural modes that may cause the frequency response calculation to be inaccurate and prints an appropriate message. If the error message is received, the user should carefully check the model and data and be cautious of results of activity FRRS. Note the eigenvalues and eigenvectors previously calculated are correct.

DIAG also checks the accuracy of the transformation by computing the residual terms of (B - T θ). These are printed if they exceed a tolerance of 0.001.

This activity can only be run after EIGN had been completed with no error messages.

The activity requires that the eigenvectors are linearly independent (see Section 27.1.4, "Linear Independence of Eigenvectors" for the definition of linear independence). If two eigenvalues have very nearly equal values, the eigenvectors produced by EIGN may be linearly dependent. This produces a singular T matrix.

If this occurs, the user will see the message

```
CANNOT DIAGONALIZE THE MATRIX---ABORT ACTIVITY
```

As an option the user can list at all the standard PSS®E output destinations both Λ and θ . Both Λ and θ are saved even if the user specifies that no output is desired.

Figure 27.15, "Obtaining Modal Equivalents for Sample System" lists Λ and θ for our sample system.

27.8. Calculating and Listing Participation Factors

Activity PRFA calculates the participation factors associated with the user-specified modes. The activity selectively lists the participation factors according to magnitude. PRFA allows all the standard PSS®E output destinations.

As a prerequisite activity PRFA requires that the matrix eigenvalues and eigenvectors have been calculated (activity EIGN has been run) and the matrices have been diagonalized (activity DIAG has been run). If they have not, an appropriate message will be printed.

Figure 27.16, "Obtaining and Listing Participation Factors" shows the dialog used to calculate and list the participation factors for mode 4.

Note that the largest participation factors are for STATE(K+4) and STATE(K+5) of the GENROU model at bus 4. These are the speed and angle states for this model. Placing a device, such as a stabilizer, at this machine would have the greatest effect on mode 4.

```
ACTIVITY? DIAG

ENTER OUTPUT DEVICE CODE:
 0 FOR NO OUTPUT         1 FOR CRT TERMINAL
 2 FOR A FILE            3 FOR QMS PS2000
 4 FOR QMS_PS800         5 FOR HARD COPY TERMINAL
 6 FOR ALTERNATE SPOOL DEVICE: 1

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI OCT 16, 1992  16:04
TWO MACHINE EXAMPLE WITH INFINITE BUS


NABLA                      THETA

-0.123E+01 J 0.885E+01  -0.378E+00 J-0.198E+01   0.534E+00 J 0.251E+01
                         0.307E+00 J-0.314E+00
-0.123E+01 J-0.885E+01  -0.378E+00 J 0.198E+01   0.534E+00 J-0.251E+01
                         0.307E+00 J 0.314E+00
-0.224E+00 J 0.426E+01  -0.674E+00 J-0.216E+01  -0.251E+01 J-0.736E+01
                         0.119E+01 J-0.677E+00
-0.224E+00 J-0.426E+01  -0.674E+00 J 0.216E+01  -0.251E+01 J 0.736E+01
                         0.119E+01 J 0.677E+00
-0.639E+00 J 0.591E+00   0.232E+00 J-0.118E+01   0.138E+01 J 0.423E+00
                        -0.841E+00 J 0.580E+01
-0.639E+00 J-0.591E+00   0.232E+00 J 0.118E+01   0.138E+01 J-0.423E+00
                        -0.841E+00 J-0.580E+01
-0.367E+02 J 0.000E+00  -0.102E+01 J 0.278E-06   0.856E+00 J-0.351E-06
                         0.651E+01 J-0.131E-04
-0.301E+02 J 0.000E+00   0.372E+00 J-0.273E-07  -0.144E+01 J 0.727E-06
                         0.241E+01 J 0.122E-04
-0.202E+02 J 0.000E+00   0.117E+02 J-0.256E-06  -0.116E+02 J-0.115E-06
                        -0.320E+02 J 0.295E-04
-0.189E+02 J 0.000E+00  -0.840E+01 J-0.355E-06   0.136E+02 J-0.134E-05
                         0.280E+03 J-0.322E-04
-0.164E+02 J 0.000E+00  -0.111E+01 J 0.158E-06   0.238E+01 J 0.317E-07
                         0.471E+02 J-0.447E-05
-0.219E+01 J 0.000E+00  -0.246E+01 J-0.158E-07   0.345E+00 J 0.290E-06
                        -0.475E+01 J-0.441E-05
-0.139E+01 J 0.000E+00  -0.656E+00 J-0.371E-07   0.145E+00 J 0.102E-06
                        -0.380E+00 J-0.589E-06
-0.157E+00 J 0.000E+00   0.289E-01 J 0.266E-07   0.999E+00 J-0.117E-06
                        -0.419E+00 J-0.617E-06
```

Note that the eigenvalues have not changed

Figure 27.15. Obtaining Modal Equivalents for Sample System

```
ACTIVITY? prfa

ENTER OUTPUT DEVICE CODE:
 0 FOR NO OUTPUT         1 FOR CRT TERMINAL
 2 FOR A FILE            3 FOR QMS PS2000
 4 FOR QMS_PS800         5 FOR HARD COPY TERMINAL
 6 FOR ALTERNATE SPOOL DEVICE: 1
ENTER MODE NUMBER (0 TO EXIT): 4 <---------------------- Select mode #4

ENTER OUTPUT CODE FOR PARTICIPATION FACTORS FOR MODE    4
  0 = NO OUTPUT
  1 = ALL FACTORS IN DESCENDING ORDER OF MAGNITUDE
  2 = ONLY LARGEST FACTORS: 1

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI DEC 03, 1993  11:30
TWO MACHINE EXAMPLE WITH INFINITE BUS


NORMALIZED PARTICIPATION FACTORS FOR MODE   4: -0.22455      -4.2638

 FACTOR    ROW  STATE  MODEL     BUS  X-- NAME --X  ID
1.00000    11    K+4   GENROU      4  GEN 2          1
0.99887    12    K+5   GENROU      4  GEN 2          1
0.38487     5    K+4   GENROU      2  GEN 1          1
0.38473     6    K+5   GENROU      2  GEN 1          1
0.10884     7    K     GENROU      4  GEN 2          1
0.02742     1    K     GENROU      2  GEN 1          1
0.01883     9    K+2   GENROU      4  GEN 2          1
0.01233    14    K+1   SCRX        2  GEN 1          1
0.01214    13    K     SCRX        2  GEN 1          1
0.01075     3    K+2   GENROU      2  GEN 1          1
0.00704     2    K+1   GENROU      2  GEN 1          1
0.00437     8    K+1   GENROU      4  GEN 2          1
0.00302     4    K+3   GENROU      2  GEN 1          1
0.00161    10    K+3   GENROU      4  GEN 2          1
ENTER MODE NUMBER (0 TO EXIT): 0
```

Figure 27.16. Obtaining and Listing Participation Factors

27.9. Frequency Response Calculations

Activity FRRS calculates the frequency response of selected system outputs to unit sinusoidal perturbations of the selected system inputs. The outputs and inputs were defined during the execution of either activity BCAS or MCAS and both are reflected in the H and B matrices. They may be changed only by completely rebuilding the A, B, H, and F matrices via activity ASTR or by editing the matrix input file.

To illustrate frequency response calculations, the linear system was modified to include only the two states (15 and 16) of the exciter for the machine at bus #2. The inputs and outputs were not changed.

The matrices that comprise the new linear system are shown in Figure 27.17, "The Matrices of the Linear System Used in the Frequency Calculations". The eigenvalues and eigenvectors of the linear system are shown in Figure 27.18, "The Eigenvalues and Eigenvectors of the Linear System".

FRRS computes the complex vector $v'(j\omega)$ resulting from a sinusoidal perturbation of each individual element of u' at a frequency of ω radians per second. In our sample system, the outputs are:

v'_1

= Electric power of the machine at bus #2.

v'_2

= Electric power of the machine at bus #4.

v'_3

= Speed deviation of the machine at bus #2.

v'_4

= Speed deviation of the machine at bus #4.

v'_5

= Field voltage of the exciter for the machine at bus #2.

The system input variables for our sample system are:

u'_1

= Mechanical power of the machine at bus #2.

u'_2

= Mechanical power of the machine at bus #4.

u'_3

= Reference voltage of the exciter for the machine at bus #2.

FRRS deposits the output-input quantities directly into the plotting file so that the frequency response ratios, $\partial vi(j\omega)/\partial \pi uj(j\omega)$ may be displayed in Polar or Bode plots.

Frequency inputs are specified by the user by entering a lower frequency, upper frequency, and an increment ratio x. The value of x must be greater than unity. The value of frequency is then scanned logarithmically, that is

$$\omega_{new} = \omega_{old} \times x$$

FRRS compares the new value of each output for each new frequency value with the corresponding previous output. If any has changed in magnitude ratio by more than .3 or phase by more than 10 degrees, the frequency change is halved and the frequency response is recalculated. For cases where a smooth plot is not obtained because of sharp resonances, the user will have to run to a specific frequency, reduce the increment, and then run to just past the resonance where the increment could again be increased.

```
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      MON OCT 19, 1992  14:43
TWO MACHINE EXAMPLE WITH INFINITE BUS

ROW   BUS  X-- NAME --X MC  MODEL   STATE
  1     2  GEN 1         1  SCRX    K
  2     2  GEN 1         1  SCRX    K+1
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      MON OCT 19, 1992  14:43
TWO MACHINE EXAMPLE WITH INFINITE BUS

A MATRIX COLUMNS STARTING AT   1
  1 -0.1000      0.0000
  2   3000.      -20.00
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      MON OCT 19, 1992  14:43
TWO MACHINE EXAMPLE WITH INFINITE BUS

B MATRIX COLUMNS STARTING AT   1
  1  0.0000      0.0000      0.9000E-01
  2  0.0000      0.0000       300.0
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      MON OCT 19, 1992  14:43
TWO MACHINE EXAMPLE WITH INFINITE BUS

H MATRIX COLUMNS STARTING AT   1
  1  0.0000      0.0000
  2  0.0000      0.0000
  3  0.0000      0.0000
  4  0.0000      0.0000
  5  0.0000       1.000
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      MON OCT 19, 1992  14:43
TWO MACHINE EXAMPLE WITH INFINITE BUS

F MATRIX COLUMNS STARTING AT   1
  1  0.0000      0.0000      0.0000
  2  0.0000      0.0000      0.0000
  3  0.0000      0.0000      0.0000
  4  0.0000      0.0000      0.0000
  5  0.0000      0.0000      0.0000
```

The linear system incorporates only the two states of the exciter for the machine at bus 2

Figure 27.17. The Matrices of the Linear System Used in the Frequency Calculations

```
     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI DEC 03, 1993  16:18
TWO MACHINE EXAMPLE WITH INFINITE BUS


EIGENVALUES:

NO.     REAL      TIME CONSTANT
  1  -20.000       0.50000E-01      Both eigenvalues have negative real parts
  2 -0.10000        10.000
ENTER EIGENVECTOR NUMBER (0 FOR ALL, -1 TO EXIT): 1

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI DEC 03, 1993  16:18
TWO MACHINE EXAMPLE WITH INFINITE BUS


EIGENVALUE   1: REAL=   -20.000
       TIME CONSTANT=   0.50000E-01

ROW  X---------------- VECTOR  ELEMENT ----------------X  STATE  MODEL     BUS  X-- NAME --X
ID
      MAGNITUDE      PHASE        REAL        IMAGINARY
  1   0.00000       0.00000      0.00000      0.00000        K    SCRX         2  GEN 1
1
  2    1.0000       0.00000       1.0000      0.00000        K+1  SCRX         2  GEN 1
1
ENTER EIGENVECTOR NUMBER (0 FOR ALL, -1 TO EXIT): 2

     PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS®E      FRI DEC 03, 1993  16:18
TWO MACHINE EXAMPLE WITH INFINITE BUS


EIGENVALUE   2: REAL=  -0.10000
       TIME CONSTANT=    10.000

ROW  X---------------- VECTOR  ELEMENT ----------------X  STATE  MODEL     BUS  X-- NAME --X
ID
      MAGNITUDE      PHASE        REAL        IMAGINARY
  1   0.66333E-02   0.00000      0.66333E-02  0.00000        K    SCRX         2  GEN 1
1
  2    1.0000       0.00000       1.0000      0.00000        K+1  SCRX         2  GEN 1
1
```

Figure 27.18. The Eigenvalues and Eigenvectors of the Linear System

Used in the Frequency Response Calculations

While calculating the frequency response, FRRS allows the user to see one input/output pair. For the pair the real part, imaginary part, magnitude and angle are printed.

As a prerequisite activity FRRS requires that the matrix eigenvalues and eigenvectors have been calculated (activity EIGN has been run) and the matrices have been diagonalized (activity DIAG has been run). If they have not, an appropriate message will be printed. When invoked, activity FRRS instructs the user to specify the output device for the desired input/output pair to scan. The activity then instructs the user to

`ENTER OUTPUT FILE NAME:`

The user responds with the name of the output file to store all input/output pair information from the subsequent frequency response calculations. If no filename is specified, the activity is aborted.

The activity then instructs the user to

`ENTER OUTPUT NO., INPUT NO. FOR PRINTING (-1 TO EXIT)`

The user must then enter valid input and output numbers, zeroes, or -1 to exit the activity. The default values for the input and output are zero (no printing). The activity then instructs the user to

`ENTER MIN OMEGA, MAX OMEGA, INC FACTOR (-1 TO EXIT)`

After the user has entered the values, the activity then applies its calculations until the maximum frequency input has been reached. At that point the activity instructs the user to

```
ENTER NEW MAX OMEGA, INCREMENT FACTOR
```

If no new increment factor is specified, the previous one input is assumed. The new frequency specified must be greater than the current value of frequency. A carriage return should be entered to exit the activity. Activity FRRS only responds to the interrupt control code AB. It forces a pause by setting the maximum frequency to the current value of frequency, overriding the value entered. In addition, if the activity was invoked in the response file mode (via IDEV, response file) the response file is closed and subsequent user commands are taken from the user's terminal. Figure 27.19, "Frequency Response Calculation" shows the dialog for our sample system.

27.10. Plotting Results

Activities BODE and POLR (Polar) create plots of the frequency response predictions obtained using FRRS. The dialog is straightforward and similar to that of auxiliary program PSSPLT. Figure 27.20, "Dialog to Create Bode Plot" shows the dialog to obtain a Bode plot for the exciter output, field voltage (EFD), at bus #2 when the reference voltage, V_{ref}, is the input. Figure 27.21, "Bode Plot of Output 5 Varying with Input 3" is the resulting plot. Note that this linear system incorporates only the states of the SCRX model for the machine at bus #2. The data for this model, given in Figure 27.3, "Dynamics Raw Data File for Setup of Simulation Model of Small Example System", should result in breaks at the following frequencies:

ω

= 0.1, which corresponds to $1/T_B$

ω

= 1.0, which corresponds to $1/T_A$

ω

= 2.0, which corresponds to $1/T_e$

This is consistent with the Bode magnitude plot in Figure 27.21, "Bode Plot of Output 5 Varying with Input 3".

```
ACTIVITY? FRRS

ENTER OUTPUT DEVICE CODE:
 0 FOR NO OUTPUT          1 FOR CRT TERMINAL
 2 FOR A FILE             3 FOR KMW_UP
 4 FOR QMS_LG             5 FOR HARD COPY TERMINAL
 6 FOR ALTERNATE SPOOL DEVICE:
1

ENTER OUTPUT FILE NAME:
EXAMFROUT
ENTER OUTPUT NO., INPUT NO. FOR PRINTING (-1 TO EXIT):
5 3
ENTER MIN OMEGA, MAX OMEGA, INC FACTOR (-1 TO EXIT):
.001, 10000,  1.1

OUTPUT    5 EFD1GEN 1
INPUT    3  VRF1GEN 1
           OMEGA         REAL         IMAG           MAGNITUDE     ANGLE
    1      0.0010      0.1126E+01   0.3271E-01     0.1126E+01   0.1664E+01
    2      0.0011      0.1126E+01   0.3598E-01     0.1126E+01   0.1831E+01
    3      0.0012      0.1126E+01   0.3958E-01     0.1126E+01   0.2014E+01
    4      0.0013      0.1126E+01   0.4354E-01     0.1127E+01   0.2215E+01
    5      0.0015      0.1126E+01   0.4790E-01     0.1127E+01   0.2437E+01
    6      0.0016      0.1126E+01   0.5269E-01     0.1127E+01   0.2680E+01
    7      0.0018      0.1126E+01   0.5796E-01     0.1127E+01   0.2947E+01
    8      0.0019      0.1126E+01   0.6376E-01     0.1128E+01   0.3241E+01
    9      0.0021      0.1126E+01   0.7014E-01     0.1128E+01   0.3564E+01
   10      0.0024      0.1126E+01   0.7715E-01     0.1129E+01   0.3919E+01
   11      0.0026      0.1126E+01   0.8487E-01     0.1129E+01   0.4309E+01
   12      0.0029      0.1126E+01   0.9336E-01     0.1130E+01   0.4738E+01
   13      0.0031      0.1127E+01   0.1027E+00     0.1131E+01   0.5208E+01
   14      0.0035      0.1127E+01   0.1130E+00     0.1133E+01   0.5724E+01
   15      0.0038      0.1127E+01   0.1242E+00     0.1134E+01   0.6290E+01
   16      0.0042      0.1128E+01   0.1367E+00     0.1136E+01   0.6911E+01
   17      0.0046      0.1128E+01   0.1503E+00     0.1138E+01   0.7591E+01
   18      0.0051      0.1129E+01   0.1653E+00     0.1141E+01   0.8335E+01
   19      0.0056      0.1129E+01   0.1819E+00     0.1144E+01   0.9149E+01
   20      0.0061      0.1130E+01   0.2000E+00     0.1148E+01   0.1004E+02

    .        .             .            .               .             .
    .        .             .            .               .             .
    .        .             .            .               .             .
    .        .             .            .               .             .

  290   6637.7700      0.1300E-03  -0.4520E-01     0.4520E-01  -0.8984E+02
  291   7301.5474      0.1075E-03  -0.4109E-01     0.4109E-01  -0.8985E+02
  292   8031.7021      0.8882E-04  -0.3735E-01     0.3735E-01  -0.8986E+02
  293   8834.8721      0.7340E-04  -0.3396E-01     0.3396E-01  -0.8988E+02
  294   8945.3086      0.7160E-04  -0.3354E-01     0.3354E-01  -0.8988E+02
  295   9839.8398      0.5917E-04  -0.3049E-01     0.3049E-01  -0.8989E+02
  296  10331.8320      0.5367E-04  -0.2904E-01     0.2904E-01  -0.8989E+02
ENTER NEW MAX OMEGA,INCREMENT FACTOR:
```

Ask for output 5, input 3

No higher frequencies

Figure 27.19. Frequency Response Calculation

```
ACTIVITY? BODE

SUPPORTED PLOTTING DEVICES ARE:
  0 = NONE                        1 = VERSATEC
  2 = HP 7221A                    3 = TEKTRONIX 4010
  4 = TEKTRONIX 4014              5 = TEKTRONIX 4014 W/EGM
  6 = TEKTRONIX 4662              7 = TEKTRONIX 4663
 10 = CALCOMP                    12 = KMW V.P.
 17 = TEKTRONIX 4105/04/06       18 = TEKTRONIX 4107/09
 20 = TEKTRONIX 4112             21 = TEKTRONIX 4113
 22 = TEKTRONIX 4114             23 = TEKTRONIX 4115/4125
 25 = Invalid X Window DISPLAY   27 = HP 7470A
 28 = HP 7475A                   31 = QMS LASERGRAFIX
 33 = TEKTRONIX 4111             36 = REGIS
 37 = TEKTRONIX 41XX FILE        38 = HP-GL FILE
 39 = Invalid X Window DISPLAY   40 = TEKTRONIX 4010/4014 FILE
 41 = POSTSCRIPT                 99 = INDE. PLOT FILE
ENTER DESIRED PLOTTING DEVICE:
31
ENTER OUTPUT FILE NAME:
EXAMFROUT
ENTER FIRST OPTIONAL 60 CHARACTER TITLE:
BODE PLOT
ENTER SECOND OPTIONAL 60 CHARACTER TITLE:
Field voltage versus reference voltage at bus 2
ENTER MINIMUM, MAXIMUM FREQUENCY:
.001 10000.

ENTER LINE TYPE
  0 = SYMBOLS, 1 = PATTERNED LINES, 2 = BOTH:
2
ENTER OUTPUT, INPUT NUMBERS (-1 TO EXIT):
5 3
EFD1GEN 1   /VRF1GEN 1
ENTER 1 FOR LOG MAGNITUDE
      2 FOR NATURAL MAGNITUDE
      3 FOR ANGLE              :
1
ENTER MINIMUM, MAXIMUM PLOTTING RANGE:
.01 1000.
ENTER OUTPUT, INPUT NUMBERS (-1 TO EXIT):
5 3
EFD1GEN 1   /VRF1GEN 1
ENTER 1 FOR LOG MAGNITUDE
      2 FOR NATURAL MAGNITUDE
      3 FOR ANGLE              :
3
ENTER MINIMUM, MAXIMUM PLOTTING RANGE:
-180, 180
ENTER OUTPUT, INPUT NUMBERS (-1 TO EXIT):
-1
ENTER 25 CHARACTER LABEL:
5/3

ENTER:
  0 = RETURN
  1 = SELECT NEW PLOTTING DEVICE
  2 = NEW PLOT ON THE QMS LASERGRAFIX
  3 = REPEAT PLOT ON NEW DEVICE:
0

ENTER NUMBER OF COPIES (0 TO 5), DEVICE NAME FOR QMS LASERGRAFIX:
1
 Job 00290 entered on queue QMS_1200.
```

Figure 27.20. Dialog to Create Bode Plot

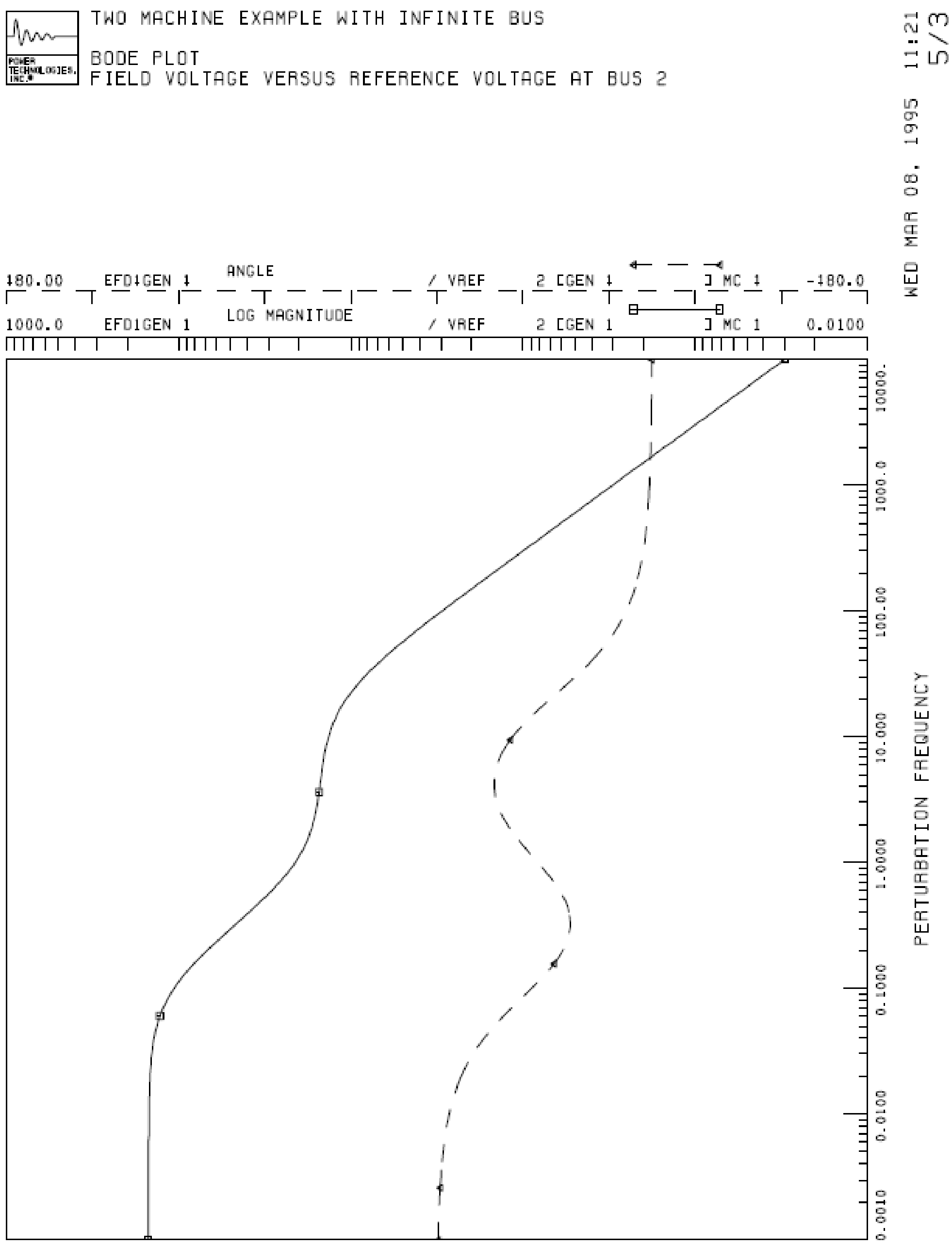


Figure 27.21. Bode Plot of Output 5 Varying with Input 3

Figure 27.22, "Natural Scale Polar Plot of Output 5 Varying with Input 3" and Figure 27.23, "Logarithmic Scale Polar Plot of Output 5 Varying with Input 3" present the frequency response results in polar plots. Note that when entering the maximum and minimum plotting range and using a logarithmic scale, the user should enter positive values that are integral powers of 10. For example, .001 or 10^{-3} is valid while .002 or 10-2.6989 is not valid.

27.11. Small Perturbation Simulations

Execution of activities LSTR and LRUN allow the user to run a simulation using the matrices. If the matrices were initially obtained from a standard PSS®E setup, use of these activities would give the user a quicker simulation as compared to simulating the entire system with network to check if the system is dynamically stable. These activities can also be used to confirm the results obtained from calculating the eigenvalues and frequency response of the system.

The initialization activity LSTR requires the matrices first to be read into memory via MCAS. The activity, when invoked, first initializes all state variables to zero. Activity LSTR then instructs the user:

```
DELT=0.01 SECONDS, ENTER NEW DELT:
```

A response of carriage return will leave the value unchanged. The activity then sets the value of simulation TIME to minus two time steps. This provides for a period of simulation under steady-state conditions prior to initiating a disturbance. Activity LSTR then instructs the user to:

```
ENTER INPUT #, PERTURBATION (P.U.):
```

The user should then enter the desired input to perturb (default is zero) and a perturbation amount (no default value is placed). The program will repeat the question until a carriage return, zero, or negative value has been entered or all inputs have been perturbed. These disturbances are automatically applied at time equals zero during activity LRUN. Activity LSTR then instructs the user to:

```
ENTER CHANNEL OUTPUT FILENAME:
```

The user responds with the name of the Simulation Channel Output File to be used in the subsequent dynamic simulation run. If no filename is specified in response to the above instruction, the writing of the output channel variable values to a file is suppressed during the simulation run.

The time simulation activity LRUN, sequences through time solving the system's differential equations at each time step. Upon selecting activity LRUN, the user is instructed:

```
AT TIME=0.000 ENTER TPAUSE, NPRT, NPLT
```

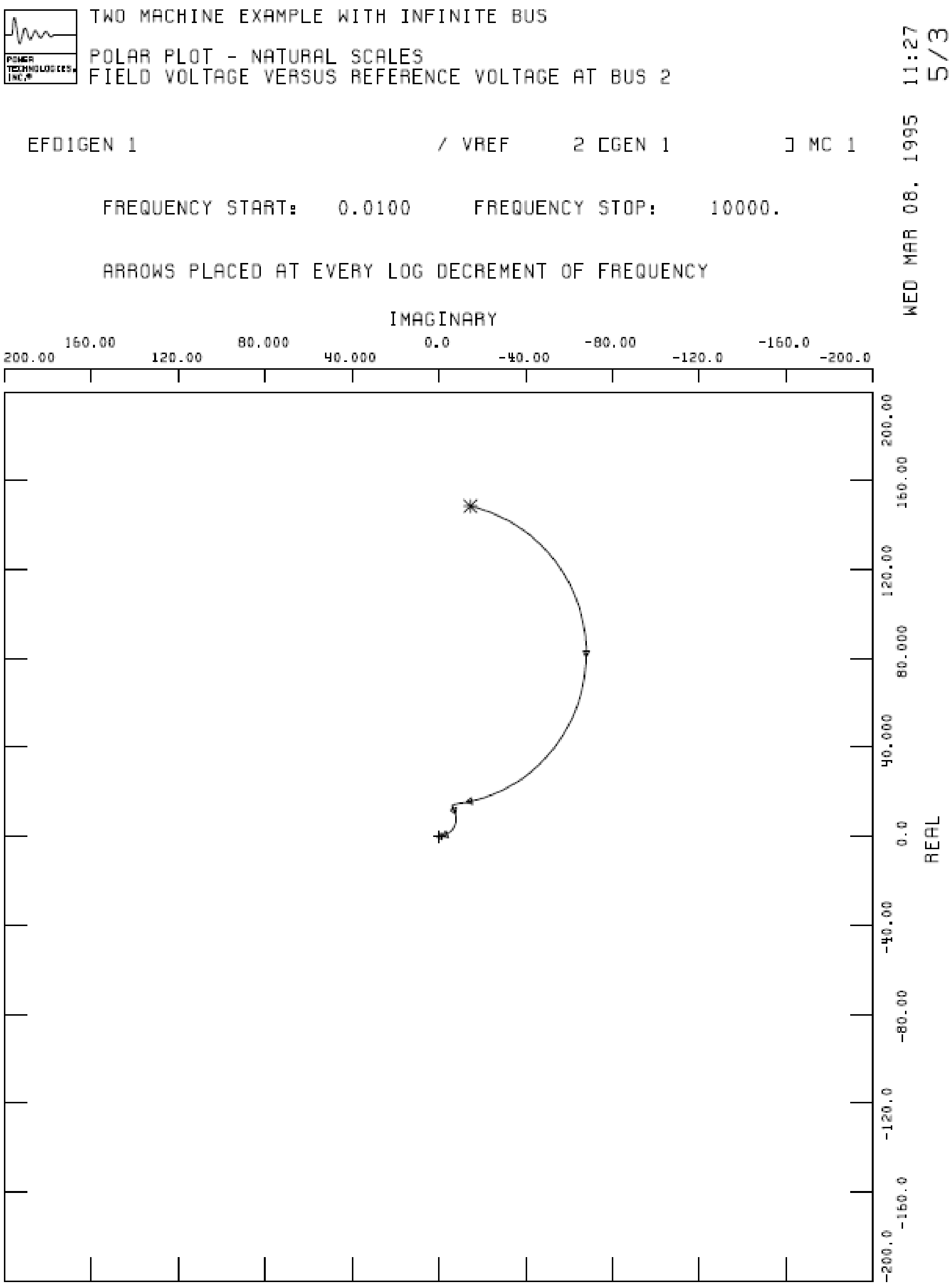


Figure 27.22. Natural Scale Polar Plot of Output 5 Varying with Input 3

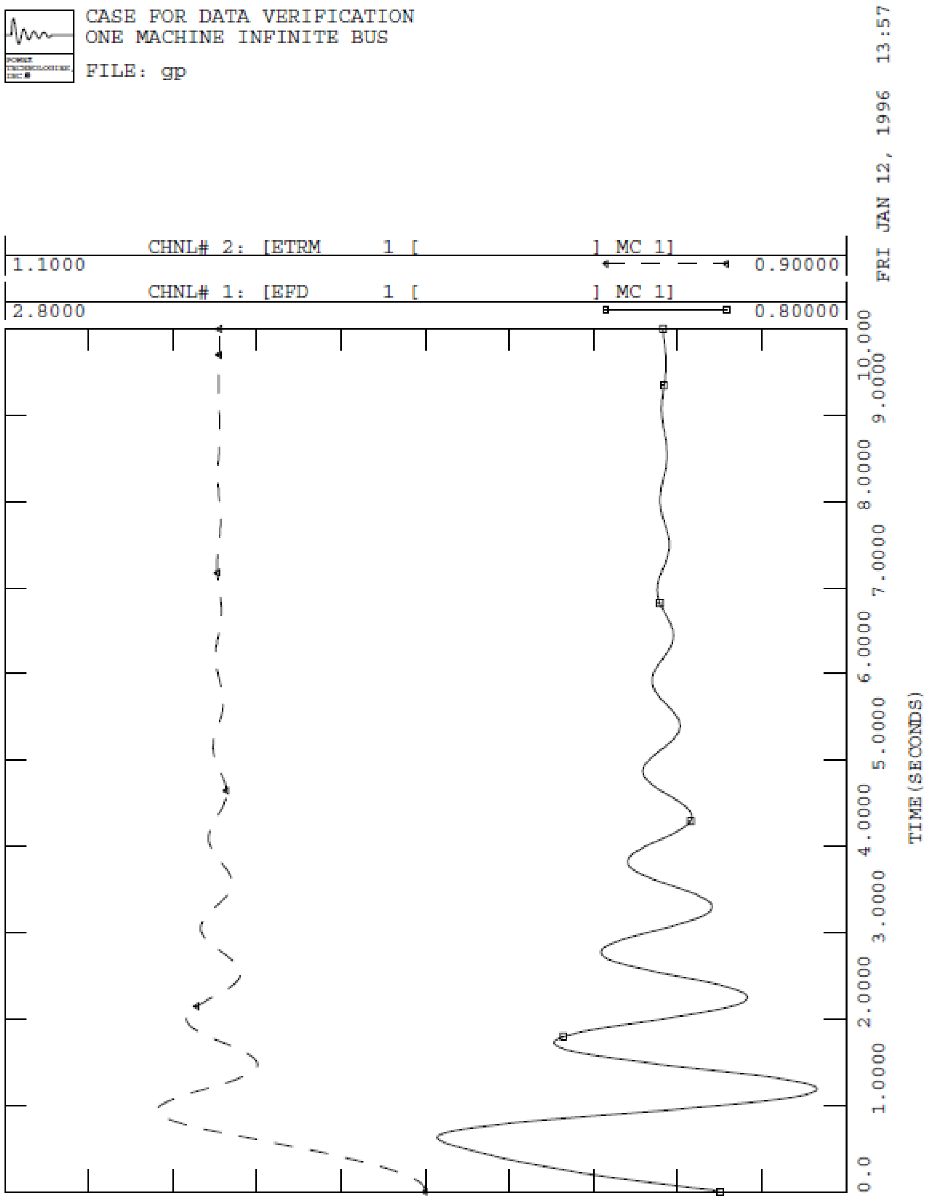


Figure 27.23. Logarithmic Scale Polar Plot of Output 5 Varying with Input 3

The user responds with three data items having the following significance.

TPAUSE	Activity LRUN steps through time simulating the system, starting at the present value of simulation TIME, until TIME > TPAUSE.
NPRT	The values of the output channel variables are written to the output device every NPRT time steps. They are printed for the present value of TIME, every NPRT time steps thereafter, and for TIME = TPAUSE. If NPRT

	is entered as zero, the tabulation of output channel values is bypassed.
NPLT	The values of the output channel variables are written to the Simulation Channel Output File every NPLT time steps. They are written to the file for the present value of TIME, every NPLT time steps thereafter, and for TIME = TPAUSE. If NPLT is entered as zero (or one), channel values are written to the output file at the completion of each time step. NPLT has significance only if a channel output file has been specified either in activity LSTR.

Following the specification of the above parameters, if the value specified for TPAUSE is less than the current value of simulation TIME, activity LRUN is terminated. Otherwise, if a Simulation Channel Output File has been opened, the message is printed at the dialog output device:

```
CHANNEL OUTPUT FILE IS aaaaaa
```

The simulation, starting at the present value of simulation TIME, then commences.

Activity LRUN responds to the following interrupt control codes:

AB	Force a pause by setting TPAUSE to the current value of simulation TIME. This overrides the value of TPAUSE, which was specified at the time activity LRUN was invoked. In addition, if LSYSAN is operating in its response file mode (i.e., activity IDEV,file had previously been selected), the response file is closed and subsequent user commands are taken from the user's terminal.
CH	Print the output channel values at each time step. The value of NPRT that was entered at the time activity LRUN was invoked is overridden while this option is in effect. When this option is cleared, the original value of NPRT is restored and the next printing of channels occurs NPRT time steps from the TIME of the clearing of the option.
TI	Print the value of simulation TIME at the user's terminal.

Activity LSTR sets the output control variables NPRT and NPLT to one. On the first subsequent execution of activity LRUN, these values are the defaults for these variables. On following executions of activity LRUN, these variables default to the values specified on the previous execution of activity RUN.

Whenever the value of simulation TIME reaches the time specified for TPAUSE, the time derivative calculations are applied with a flag set to inform the simulation that this is a t- calculation. For any of the channel output options that are active, the appropriate output is generated regardless of whether the present time step is a print or plot time step as determined by the variables NPRT and NPLT. When activity LRUN is re-entered, the time step is repeated as a t+ calculation. Appropriate channel output is run at the completion of the time step as determined by the new specification of the output control variables. This applies both for the case in which activity LRUN has advanced TIME to the value specified for TPAUSE and when the user forces a pause with the AB interrupt control code.

When using the AB interrupt control code to force a pause in the simulation, care must be taken when LSYSAN is being executed from a command file with LSYSAN commands and responses taken from a response file. As described above, activity LRUN closes the PSS®E response file.

The PSS®E auxiliary plotting program PSSPLT can be used to plot the results placed in the output file.

27.12. Stopping the Program

The LSYSAN termination activity STOP, is the normal exit from the program. When selected, all files opened are closed and the user is returned to the operating system level.

27.13. Timing Statistics

The timing statistics activity TIME allows the user to obtain execution time statistics during a work session. When invoked with the suffix INIT, or on the first selection of activity TIME following entry into LSYSAN, the timers are initialized and the following message is printed:

```
TIMER INITIALIZED
```

On subsequent executions of activity TIME when no suffix is specified, activity TIME prints a summary of elapsed, CPU, and disc channel times, in seconds, since the previous execution of activity TIME, and cumulative times from the point at which the timers were last initialized. This tabulation is of the form:

```
                      ELAPSE      CPU       DISK
SINCE LAST "TIME"     XX.XXX     X.XXX     X.XXX
CUMULATIVE            XX.XXX     X.XXX     X.XXX
```

Activity TIME is not sensitive to any interrupt control code options.

27.14. The Null Activity

The null activity TEXT doesn't really do anything. However, it does provide a mechanism by which the user may insert descriptive comments in a Response File at any point at which the next activity to be run is specified.

In response to the question `ACTIVITY?`, the user may enter the activity name TEXT followed by any descriptive text that is suitable; for example:

```
TEXT *** HAVE YOUR MESSAGE PRINTED HERE!
```

Activity TEXT is not sensitive to any interrupt control code options.

27.15. Report Output Devices

The report output device selection activity OPEN allows the user to preselect the destination for output reports generated by the LSYSAN output reporting activities.

The report output device closing activity CLOS terminates output to the previously OPENed selection and returns to the operating mode in which each reporting activity requests the user to select the destination for its report.

When initiated, activity ECHO first CLOSes the previously OPENed output device if any, and then instructs the user to:

```
ENTER OUTPUT DEVICE CODE:
 0 FOR NO OUTPUT  1 FOR CRT TERMINAL
 2 FOR A FILE     3 FOR VERSATEC
 4 FOR PRINTER    5 FOR HARD COPY TERMINAL
 6 FOR ALTERNATE SPOOL DEVICE:
```

The user then selects the device to be used for output reports. If a file is selected, activity OPEN asks the user to:

```
ENTER OUTPUT FILE NAME:
```

If the Versatec or line printer is selected, the user is able to have up to six copies printed:

```
ENTER NUMBER OF COPIES:
```

If an alternate spool device is selected, the user is instructed to:

```
ENTER SPOOL DEVICE NAME:
```

and

```
ENTER NUMBER OF COPIES:
```

After the report output device is selected and activity OPEN is terminated, the above `ENTER OUTPUT DEVICE` instruction from subsequently selected PSS®E reporting activities is suppressed, and the output is automatically sent to the device selected in activity OPEN. When the selection is a file or high speed printing device, output reports are stacked in the order in which they are generated.

When a hard copy device is selected in activity OPEN, the output is not printed until activity OPEN, CLOS or STOP is selected.

The device specified in activity OPEN applies to all reporting activities.

Activity OPEN is not sensitive to any interrupt control code options.

Activity CLOS is not sensitive to any interrupt control code options.

27.16. Activity ECHO

The dialog echoing activity ECHO enables the writing of all subsequent user dialog input to a designated echo file.

When activity ECHO is initiated, if an echo file had previously been opened with an earlier execution of activity ECHO, it is closed and the message:

```
CLOSING ECHO FILE old-echo-filename
```

is printed. If activity ECHO was selected with no suffix specified, it is terminated and the echoing of subsequent user responses is disabled.

When invoked with the activity command ECHO,filename, the designated file is opened as an echo file and activity ECHO prints the message:

```
OPENED ECHO FILE filename
```

All subsequent dialog input is then written to the file filename>. If some file system related error occurs in opening the echo file, an appropriate error message is printed and activity ECHO is terminated with the echoing of subsequent user responses disabled.

Activity ECHO is not sensitive to any interrupt control code options.

The file built by activity ECHO is in the form of a LSYSAN Response File, which may be specified to activity IDEV to exactly reproduce a sequence of PSS®E activity commands and responses to instructions. Files written by activity ECHO are source files that may be modified with the text editor to tailor the original set of user responses to the application at hand.

27.17. Activity HELP

The help activity HELP prints a summary of the activity names and a brief description of their function.

27.18. Directory Listing

The directory listing activity CATA tabulates an alphabetical listing of the names of files contained in the current directory.

If no suffix is specified in invoking activity CATA, a listing of the names of all files in the directory is printed.

Otherwise, the suffix is treated as a partial filename specification, and the names of all files in the directory that appropriately contain this character string as a part of their name are listed. The activity suffix may contain imbedded asterisks (*) that are treated as wild characters matching zero, one or more characters. For example, selecting activity CATA with the activity command CATA,AB will produce a tabulation of all filenames beginning with AB; the activity command CATA,*AB results in a tabulation of all files that contain the consecutive characters AB anywhere in the filename.

The actual implementation of activity CATA differs among the various host computers of PSS®E. There may be certain host computers on which it is not implemented.

Activity CATA is not sensitive to any interrupt control code options.

27.19. Dialog Input Selection

The dialog input device selection activity IDEV is used to change the source from which LSYSAN accepts the user's portion of its conversational dialog to either the user's terminal or a Response File in the user's directory.

If run with no suffix specified, activity IDEV sets the dialog input device to be the user's terminal.

When invoked with the activity command IDEV,filename, subsequent dialog input will be taken from the specified file. If the file filename> does not exist or some other file system related error occurs, an appropriate message is printed and terminal input is assumed. Otherwise, the message:

```
DIALOG INPUT FROM FILE filename
```

is printed, activity IDEV is terminated, and LSYSAN looks to the specified file for the next activity command.

The Response File must contain an exact image of the user responses that would normally be typed by the user in terminal input mode. Therefore, the manual creation of a Response File, which is done with the text editor, requires an intimate familiarity with the LSYSAN dialog.

The recommended method of setting up a Response File, therefore, is to first run the sequence of activities to be implemented in terminal input mode with an ECHO file enabled (see Section 27.16, “Activity ECHO ”).

The final activity command in a Response File should be either STOP (if the Response File completely defines the sequence of activities to be run) or IDEV (to return control back to the user's terminal). It is also possible for the last command in the Response File to be the activity command IDEV,file2; that is, Response Files may be chained. However, it is not possible to nest Response Files; if the command IDEV,file2 occurs in the middle of the Response File <file1>, it is not possible to get back to <file1> at its next command upon the completion of the sequence of activities contained in <file2>.

27.20. Changing Elements of the Matrices

Any element of any of the four matrices A, B, H or F can be changed with activity MCHG. The user may wish to change elements in order to investigate the effects of opening a feedback loop or changing a time constant. After any element is changed, the program assumes that it is just as though the matrices have just been read.