A Transient Stability Simulation Package (TSSP)

User's Manual

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Chapter 1. Structure of TSSP

This user's manual is intended to be a guide in utilizing a simulation tool — the transient stability simulation package (TSSP). The package is implemented on an IBM PC in FORTRAN language. It includes a fast decoupled load flow (FDLF) program, a short circuit calculation program (STCC), the transient stability simulation main body (TSSP) and the plotting utility (WPLOT). A minimum of 410K conventional memory is required for a system of 100 buses and a CGA, EGA or VGA graphics card is needed to run the WPLOT program

The fast decoupled load flow (FDLF) algorithm is very reliable and extremely fast. It explores the loose physical interaction between real power and reactive power flow in a power system by mathematically decoupling the $P \sim \theta$ and $Q \sim V$ calculations. This program requires one data file named *pqlf.inp.*

The short circuit calculation (STCC) program, which requires one data file named *ntwk.inp,* can be used to calculate the equivalent impedances of the drive ports of the three sequence networks under both symmetrical and unsymmetrical fault. To run this program, one has to execute the FDLF program first to compute the pre-fault condition.

The transient simulation (TSSP) program includes a coordinator and many modules each of which simulates a power component or a process. The program utilizes the results from FDLF and STCC as the starting point of computation. Then the differential equations describing the dynamics of the system are integrated step by step with a properly chosen length of time step. At each time step, the computed results of these equations are iteratively interfaced with the solution of the network that is described with algebraic equations. At the time step following a disturbance, it is required to execute the FDLF program as both the voltage and the current in the network are not continuous at this operating point. A data file *mach.inp* is required to pass all machine parameters onto the coordinator and related modules.

The overall structure of the package is shown in Fig. 1. Available modules include: machine modules, automatic voltage regulator (AVR) modules, modules for speed governing and turbine systems (SGTS) and modules for power system stabilizers (PSS). User-defined modules can also be interfaced into the software.

To initialize TSSP, the fast decoupled load flow (FDLF) is run first. Then the short circuit calculation (STCC) program is executed. The results of the two runs are passed onto TSSP coordinator internally. Finally the TSSP is run. The end result of the simulation is stored in the file *simu.out*. A data sorting and plotting program (WPLOT) can then be employed to plot a maximum of five curves on one screen and up to fifteen variables can be sorted out at a time. The sorted data can be further utilized by other applications.

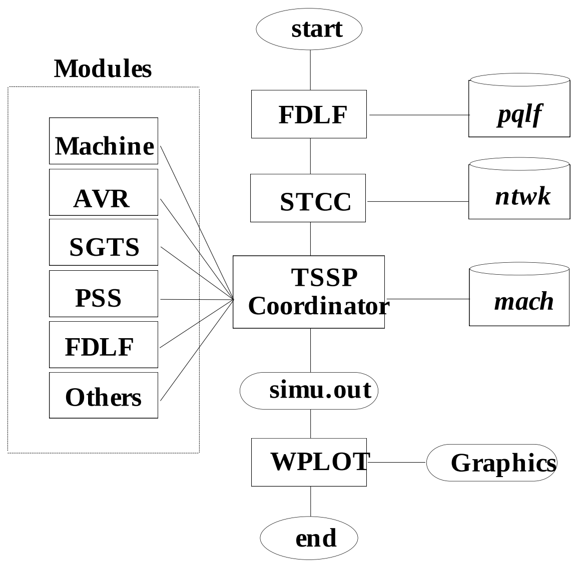


Fig. 1. Overall structure of the TSSP

Chapter 2. Fast Decoupled Load Flow (FDLF) Program

2.1 Bus Numbering

Let us assume that a power system has *n* buses in total, numbered in consecutive numbers starting from *1*, with the ground being always *zero*. There are *m* PQ buses where the injected active and reactive power P and Q are fixed, including those where the P and Q are zero. There is only one *slack* bus where the powers will be calculated after the load flow has been converged to account for power unbalance in the entire system. The rest are PV buses where the active power and the magnitude of the voltage are controlled quantities.

2.2 Preparation of Data File *pqlf.inp*

A data file named *pqlf.inp* must be prepared for performing the load flow study. This can be done by using the sample data file provided with the FDLF program named *pqlfsam.inp* and by modifying this data file according to the system to be studied.

The sample data file contains simple guidelines for how to input system parameters for the program to conduct the computation. To use this file, simply copy it onto another data file named *pqlf.inp*

Three blocks of data are defined in the data file *pqlf.inp* as described below. Proceeding each block, there are comments and definitions specifying what data are to be entered and how. Any length of comments can be added into the files as long as a (!) precedes each comment line.

2.2.1 System size, convergence criteria and controlling switches

no. of buses	=	the total number of buses in the system, excluding the grounded bus that is always numbered as zero
max. no. of iterations	=	computation stop criteria
max. P, Q mismatch	=	convergence criteria (0.001 ~ 0.00001pu)
ntwk switch	=	ignored if not conducting stability studies 0, if only FDLF to be executed 1, if STCC and/or TSSP to be executed
per unit switch	=	0, if the generation and load are in per unit based on 100 MVA; 1, if nominal unit MVA is used

2.2.2 Network data

A branch in a power system will fall into one of the following three categories. For each branch one record of data will be required to be input in the data file in the following free format in per unit based on 100MVA. Note that the following parameter notations apply to all branches:

r(+), x(+) = positive sequence resistance and reactance
r(-), x(-) = negative sequence resistance and reactance

A). Transmission line shown in Fig. 1 as its equivalent circuit

i, j, r(+), r(-), x(+), x(-), b_{io}

where

i, j = bus numbers of the two ends of the branch
b_{io} = total line charging susceptance

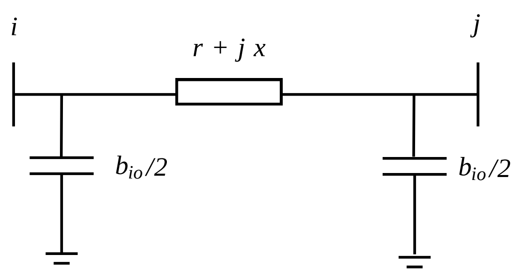


Fig. 1 Equivalent circuit for transmission line.

B). Two winding transformer shown in Fig. 2 as its equivalent circuit

i, - j, r(+), r(-), x(+), x(-), ratio

where

\- = this negative sign indicating that the ratio is on side j, ratio on side i is not allowed
i, j = bus numbers of the two windings of the transformer
ratio = the actual transformer ratio in per unit on j side

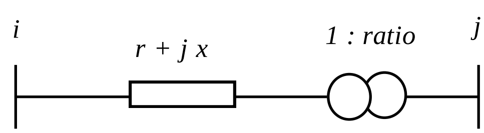


Fig. 2 Equivalent circuit for a two winding transformer.

C). Three winding transformer or auto transformer shown in Fig. 3 as its equivalent circuit

i,	o,	$r_1(+)$,	$r_1(-)$,	$x_1(+)$,	$x_1(-)$,	0.0
o,	- j,	$r_2(+)$,	$r_2(-)$,	$x_2(+)$,	$x_2(-)$,	ratio
o,	- k,	$r_3(+)$,	$r_3(-)$,	$x_3(+)$,	$x_3(-)$,	ratio

where

-	=	this negative sign indicating that the ratio is on side j or k, ratio on side i is not allowed
i, j, k	=	bus numbers of the three windings of the transformer
o	=	neutral point of the transformer
1, 2, 3	=	indicating the three windings
ratio	=	the actual transformer ratio in per unit on j side

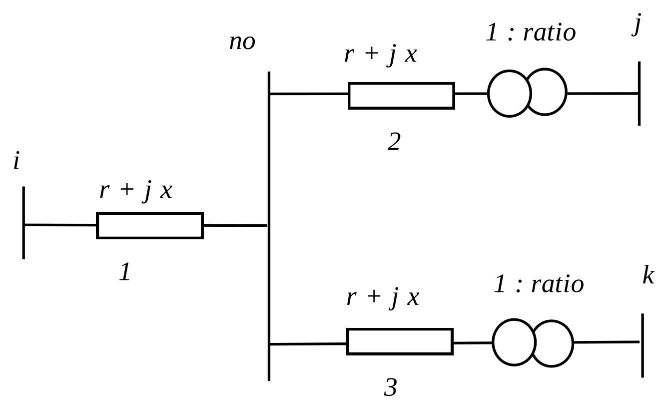


Fig. 3 Equivalent circuit for a three windings or auto transformer.

D). Grounded line shown in Fig. 4 as its equivalent circuit:

i,	0,	r(+),	r(-),	x(+),	x(-),	1.0

or

i,	0,	g(+),	g(-),	b(+),	b(-),	- 1.0

where

i	=	bus number of the grounded branch
g(+), b(+)	=	positive sequence conductance and susceptance of the branch
g(-), b(-)	=	negative sequence conductance and susceptance of the branch
1.0, - 1.0	=	indicating impedance and admittance, respectively

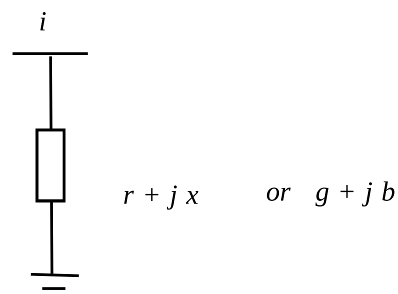


Fig. 4 Equivalent circuit for a grounded line.

If only the fast decoupled load flow (FDLF) program is to be executed, the negative sequence parameters can be entered as any real numbers. Otherwise the actual values should be entered.

To end branch data input, use 0/ as a record of data in a new line.

2.2.3 Bus data

For a bus belonging to one or more categories of the following four, one record of data must be entered. No data are required to be entered for buses which do not belong to the defined categories. The four categories are :

a) the voltage magnitude of the bus is regulated
b) one or more generators are present
c) a load is present
d) a SVC is present

The data to be entered for each bus are of the following format:

i, bus_type, P_G, Q_G, P_L, Q_L, V_0

where

i = bus number
bus_type = 1, if it is a PQ bus
2, if it is a PV bus
3, if it is the slack bus
P_G, Q_G = active and reactive generation in p.u. or MVA, respectively
P_L, Q_L = active and reactive load in p.u. or MVA, respectively
V_o = given voltage in p.u., if the bus_type is 2 or 3
1.0, if bus_type is 1

To end bus data input, use 0/ as a record of data in a new line.

Chapter 3. Short Circuit Calculation (STCC) Program

3.1 Symmetrical and Asymmetrical Faults

Power system faults can be categorized into two classes, symmetrical and asymmetrical. Symmetrical faults can be easily modeled in both short circuit calculations and stability study, because the three phases of the network are still symmetrical after the disturbance. In case of asymmetrical faults, the network has to be decomposed into three symmetrical ones to obtain accurate modeling. They are positive, negative and zero sequence networks, respectively. Accurate modeling can be accomplished for short circuit analysis based on these sequence networks, while for stability studies it could be cumbersome and very difficult to do three phase time domain simulation for even a medium size power system.

Assume that only a single asymmetrical fault happens at a time. I has been understood that the average braking torque produced by the reaction of the two magnetic fields, one produced by the negative sequence current and the other by the rotor winding current, is approximately zero, and that zero sequence currents yield a zero compound torque as the three-phase zero sequence currents are electrically in phase and have 120 degree displacement in space. Hence only the positive sequence quantities are needed to be computed during a transient process. However, the negative and zero sequence networks have to be incorporated into the positive sequence network. at the faulted point through an *additional impedance* Z_{eq} can be calculated that is a certain combination of the negative and zero sequence impedances (Z_{-} , Zo), fault impedance Z_f and grounding impedance Z_g.

3.2 Data Preparation

A data file named *ntwk.inp* is required to perform a short circuit analysis. This can be done by using the sample data file provided with the STCC program named *ntwksam.inp* and modify this data file according to the system and fault type under study.

This sample data file contains simple guidelines for inputting fault information and system parameters. To use this file, simply copy it to another data file named *ntwk.inp*.

3.2.1 Fault information

no of buses	=	the total number of buses in the system, excluding the grounded one that is always numbered as zero
no of fault	=	1, only one fault at a time
no of events	=	no of events of the fault
$\pm$ i, $\pm$ j	=	fault at nearby the bus with a minus (–) sign i, j denote the bus numbers of the two ends of the line on which the fault occurs
double/single circuit	=	2, indicating the faulted line is a double circuit 1, indicating the faulted line is a single circuit 0, indicating no fault during this event (prefault)
start time	=	starting time of a event (≥ 0.0)
end time	=	ending time of a event (> starting time)
Z_{gnd}	=	grounding impedance in p.u., it is a complex number
Z_{fault}	=	fault impedance in p.u., it is a complex number
fault type indicator	=	3-phase-to-ground 1-phase-to-ground 2-phases-to-ground phase-to-phase 1-phase-open 2-phases-open

3.2.2 Positive, negative sequence network data

This block of data is similar to that described in FDLF, see 2.4 for details. The only difference is that the sequence impedance for each generator must be entered here. The negative sequence parameters must be entered as the actual data obtained from either nameplates or tests.

3.2.3 Zero sequence network data

The zero sequence network configuration and its parameters are dependent on the connections of the various power components and the location of the fault.

1) Transmission lines

All the transmission lines in the system will be present in the data file, no matter whether they are in service or not during the fault. The raison for this is that in this way different faults at different locations can be modeled without changing the zero sequence parameters of the various power components in the system.

Generally the zero sequence impedance of a transmission line is 2 ~ 5 times the positive sequence impedance. For each such line, one record of data of the following free format is entered:

i, j, r(0), x(0), b(0)

where

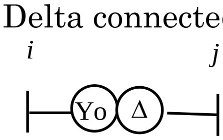
i, j	=	bus numbers of the two ends of a line
(0)	=	indicating zero sequence parameters

2) Transformers

The zero sequence reactance of a transformer is dependent on the structure of the transformer and network configuration connected to it. The following list serves as examples of how the zero sequence reactances of the transformers are recognized and prepared in the data file. The following notations apply whenever appropriate.

x_n	=	grounding reactance of a transformer
x_{mo}	=	zero sequence magnetizing reactance
i, j, k	=	bus numbers of the three windings
x_1, x_2, x_3	=	leakage reactances of the three windings numbered 1, 2, 3 that are connected to bus i, j, k, respectively
no	=	neutral point of a multiwinding transformer
o	=	grounding indication except otherwise stated
//	=	indicating parallel connection of two reactances

A) Wye-grounded Delta connected two-winding transformers



One record of data of free format is entered .

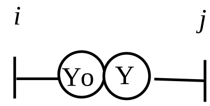
i, 0, r(0), x(0), 1.0

where

x(0) = $3\,x_n + x_1 + x_2 \,//\, x_{mo}$

= $3\,x_n + x(+)$, if x_{mo} is very large or infinitive

B) Wye-grounded Wye connected two-winding transformers



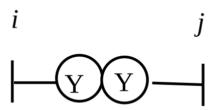
One record of data of free format is entered .

i, 0, r(0), x(0), 1.0

where

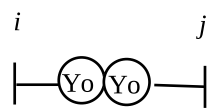
$x(0) = 3\,x_n + x_1 + x_{mo}$

C) Wye Wye connected two-winding transformers



No date are entered.

D) Wye- Wye-grounded two-winding transformers



Three records of data of free format are entered .

i, j, r(0), $x_{ij}(0)$, 0.0

i, 0, r(0), $x_{io}(0)$, 1.0

j, 0, r(0), $x_{jo}(0)$, 1.0

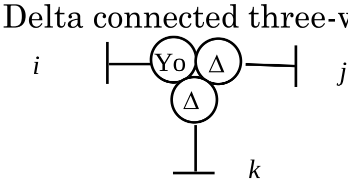
where

$x_{ij}(0) = (x_1 * x_2 + x_2 * x_{mo} + x_{mo} * x_1) / x_{mo}$

$x_{io}(0) = (x_1 * x_2 + x_2 * x_{mo} + x_{mo} * x_1) / x_2$

$x_{jo}(0) = (x_1 * x_2 + x_2 * x_{mo} + x_{mo} * x_1) / x_1$

E) Wye-grounded Delt Delta connected three-winding transformers



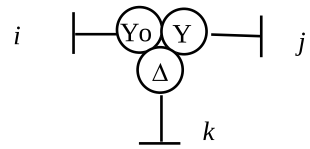
One record of data of free format is entered .

i, 0, r(0), x(0), 1.0

where

$x(0) = x_1 + x_2 \,//\, x_3$

F) Wye-grounded Wye Delta connected three-winding transformers



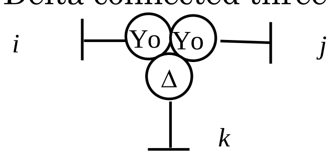
One record of data of free format is entered .

i, 0, r(0), x(0), 1.0

where

$x(0) = x_1 + x_2$

G) Wye- Wye-grounded Delta connected three-winding transformers



Three records of data of free format are entered .

i, no, $r_1(0)$, $x_1(0)$, 1.0

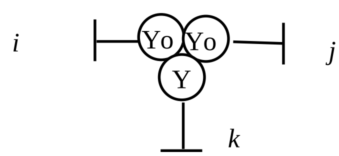
no, j, $r_2(0)$, $x_2(0)$, 1.0

no, 0, $r_3(0)$, $x_3(0)$, 1.0

where

$x_{30} = x_3(0) // x_{mo}$

H) Wye- Wye-grounded Wye connected three-winding transformers



Three records of data of free format are entered .

i, no, $r_1(0)$, $x_1(0)$, 1.0

no, j, $r_2(0)$, $x_2(0)$, 1.0

no, 0, 0.0, x_{mo} , 1.0

3) Synchronous machines

The passage of a zero sequence current from the network to the ground through a generator will be dependent on the structure of the generator and its connection to the network. If no passage exists, no zero sequence impedance for the generator is required to be entered. Otherwise the actual zero sequence impedance and the grounding impedance if any should be entered for that generator.

To end data input for zero sequence branches, use 0/ as a record of data in a new line.

4) Bus classification

All the buses in the zero sequence network under a fault can be classified into two groups. One is that of which the buses are **in** the zero sequence network, while the other is that of which they are **not in** the zero sequence network.

There are two ways to input this information which will be used to form the zero sequence network admittance. If the bus numbers which are ***not in*** the zero sequence network are chosen to be input, a ' ***- 1*** ' is entered as the first record in this block of data. If the bus numbers which are ***in*** the zero sequence network are chosen to be input, a ' ***+ 1*** ' is entered as the first record. These two sets of buses are complementary to each other. Usually the smaller set is chosen. A slash (/) is added only to the end of the bus number list to end it. The list can have as many lines as needed. A coma(,) is also necessary between bus numbers.

Chapter 4. Transient Stability Simulation Program (TSSP)

4.1 Sample data file: *machsam.inp*

A sample data file named *machsam.inp* is provided with the program. Simple guidelines are also included in the file. To use this file, simply copy it to a file named *mach.inp*.

4.2 Modify your data file: *mach.inp*

There are five blocks of data in this data file, corresponding to the following categories: computing control variables, synchronous machines, excitation systems, speed governing and turbine systems, and power system stabilizers, respectively.

4.2.1 Computing control variables

time step length = this is the step length used through out the TSSP in integrating differential equations (0.05 ~ 0.0005 sec)

printing interval = this is the sample frequency to output simulated state variables (0.01 ~.50 sec)

no of generators = this number is entered here again

4.2.2 Synchronous machines

Five synchronous machine models, including the one for infinite-busbar modeling, have been incorporated in TSSP. Their input data formats are given below, respectively.

A) Two-axis model with subtransient

This is a subtransient machine model designated as model #4. It has a field winding (f), one damper winding (D) on d-axis and one damper winding (Q) on q-axis.

$$Generator\#,4$$

$$M_{base}, H, r_a, x_\ell$$

$$x_d, x_d^{'}, x_d^{''}, x_q, x_q^{''}$$

$$\tau_{do}^{'}, \tau_{do}^{''}, \tau_{qo}^{''}$$

$$D, A_G, B_G \text{ or } D, S_{1.0}, S_{1.2}, -1$$

B) Two-axis model with transient only

This is a transient model for round-rotor machines. It has a field winding (f) on d-axis, one damper winding (Q) on q-axis. It is similar to model #4, but its subtransient is ignored. It is designated as model #3.

$$Generator\#,3$$

$$M_{base}, H, r_a, x_\ell$$

$$x_d, x_d^{'}, x_q, x_q^{'}$$

$$\tau_{do}^{'}, \tau_{qo}^{'}$$

$$D, A_G, B_G \text{ or } D, S_{1.0}, S_{1.2}, -1$$

C) One-axis model with transient

This is also a transient model. It has only one rotor winding, i.e., the field winding (f). It is designated as model #2.

$$Generator\#,2$$

$$M_{base}, H, r_a, x_\ell$$

$$x_d, x_d^{'}, x_q$$

$$\tau_{do}^{'}$$

$$D, A_G, B_G \text{ or } D, S_{1.0}, S_{1.2}, -1$$

D) Classic model

This is a representation of the synchronous machine where its transient effects have been totally ignored. It is designated as model #1.

$Generator\#,1$

M_{base}, H, r_a, x_ℓ

$x_d, x_d^{'}$

$D, A_G, B_G \text{ or } D, S_{1.0}, S_{1.2}, -1$

E) Infinite bus

The infinite bus is treated as a machine with large inertia constant and only the input of an assumed machine capacity(MVA), usually 100.0, is required.

$Generator\#,0$

M_{base}

4.2.3 Excitation systems

Fur groups of excitation systems can be simulated in the TSSP. They are DC, AC, ST and modified types.

1) Type DC systems

They are exciters with rotating direct current commentator. They are designated as model #11 ~ model #14.

A) Field controlled DC commutator exciters with continuously acting voltage regulators

$Exciter\#, 11$

K_A, K_E, K_F

T_C, T_B, T_A, T_E, T_F

$V_{RMIN,} V_{RMAX}$

$A_E, B_E \text{ 0r } E_I, S_I, E_2, S_{2,} -1$

B) Field controlled DC commutator exciters with continuously acting voltage regulators, having supplies obtained from the generator or auxiliaries bus voltage

$Exciter\ \#, 12$

K_A, K_E, K_F

T_C, T_B, T_A, T_E, T_F

$V_{RMIN,} V_{RMAX}$

$A_E, B_E\ 0r\ E_I, S_I, E_2, S_{2,}\ -1$

C) Field controlled DC commutator exciters with non-continuously acting voltage regulators

$Exciter\ \#, 13$

K_E, K_V

T_{RH}, T_E

$V_{RMIN,} V_{RMAX}$

$A_E, B_E\ 0r\ E_I, S_I, E_2, S_{2,}\ -1$

D) Modified DC type 2 excitation system with its block diagram shown in Fig. 5

$Exciter\ \#, 14$

K_A, K_E, K_F

T_C, T_B, T_A, T_E, T_F

$V_{RMIN,} V_{RMAX}$

$A_E, B_E\ 0r\ E_I, S_I, E_2, S_{2,}\ -1$

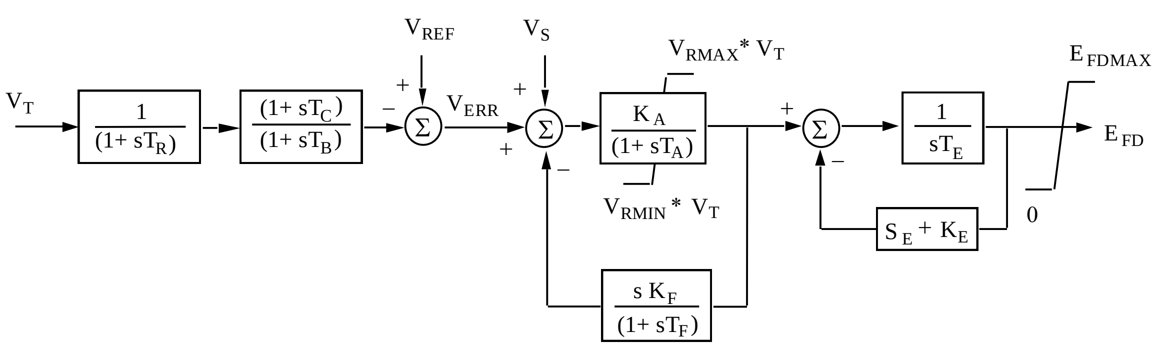


Fig. 5 Modified IEEE DC type 2 exciter.

2) Type AC systems

They are alternator supplied rectifier excitation systems designated as model # 21 ~ model #24.

A) Field controlled alternator rectifier excitation systems

$Exciter\ \#, 21$
K_A, K_C, K_D, K_E, K_F
T_C, T_B, T_A, T_E, T_F
V_{RMIN}, V_{RMAX}
A, B

B) High initial response field controlled alternator rectifier excitation systems

$Exciter\ \#, 22$
$K_A, K_C, K_D, K_E, K_F, K_H, K_L$
T_C, T_B, T_A, T_E, T_F
$V_{AMIN}, V_{AMAX}, V_{RMIN}, V_{RMAX}$
A, B, V_{LR}

C) Field controlled alternator rectifier excitation systems

$Exciter\ \#, 23$
$K_A, K_C, K_D, K_E, K_F, K_N, K_R, K_{LV}$
T_C, T_B, T_A, T_E, T_F
V_{AMIN}, V_{AMAX}
A, B, V_{LR}

D) Alternator supplied controlled rectifier excitation systems

$Exciter\ \#, 24$
K_A, K_C
T_C, T_B, T_A
$V_{AMIN}, V_{AMAX}, V_{RMIN}, V_{RMAX}$

3) Type ST systems

They are static excitation systems and designated as model #31 ~ model #33.

A) Type ST1 potential source controlled rectifier excitation system supplied through a transformer from either the bus terminal or the auxiliary bus of the unit and regulated by a controlled rectifier

Exciter #, 31

K_A, K_C, K_F

T_C, T_B, T_A, T_E

$V_{AMIN}, V_{AMAX}, V_{RMIN}, V_{RMAX}$

B) Type ST2 compound source controlled rectifier excitation system supplied by a phaser combination of terminal voltage V_T and terminal current I_T

Exciter #, 32

$K_A, K_C, K_E, K_F, K_I, K_P$

T_A, T_E, T_F

$V_{RMIN}, V_{RMAX}, E_{FDMAX}$

C) Type ST3 compound source controlled rectifier excitation system similar to model # 32, with internal quantities of the unit being used to form the source of the excitation power

Exciter #, 33

$K_A, K_C, K_G, K_I, \{K_{PR}, K_{PI}\}$

T_C, T_B, T_I

$V_{IMIN}, V_{IMAX}, V_{RMIN}, V_{RMAX}, E_{FDMAX}, V_{GMAX}$

4) Modified type excitation systems

They are SCRX type exciters and designated as model #41 ~ model #42.

A) Solid state exciter SCRX is supplied either from the ac bus voltage (busfed = 1) or from a fixed independent source (busfed = 0). If the exciter can accept negative current, then set the Neglogic = 1, otherwise 0. The block diagram of the exciter is shown in Fig. 6.

$Exciter\ \#, 41$

$K_E, Neg\,log\,ic, Busfed$

T_1, T_B, T_A, T_E

E_{MIN}, E_{RMAX}

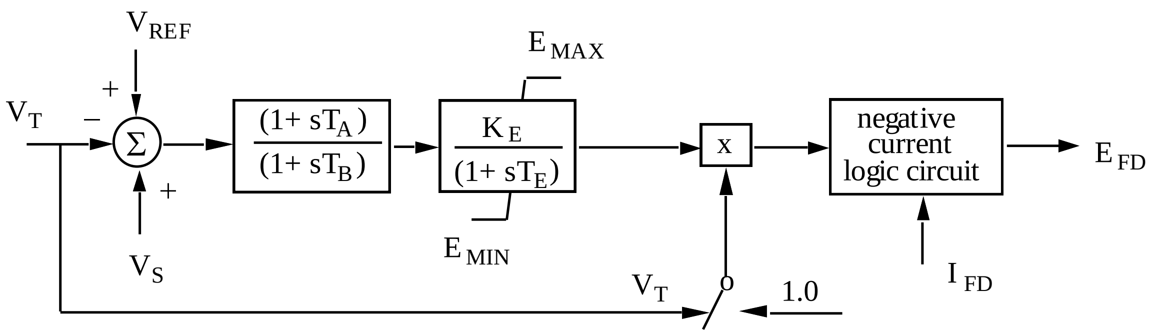


Fig. 6 SCRX excitation system fed either by bus or by solid.

B) SCRXIL model with maximum field current limit (Ifdmax)

$Exciter\ \#, 42$

$K_E, Neg\,log\,ic, Busfed$

T_1, T_B, T_A, T_E

$E_{MIN}, E_{RMAX}, I_{FDMAX}$

4.2.4 Speed Governing and Turbine Systems

Two categories of speed governing and turbine systems: speed governing and steam turbine system, and speed governing and hydro turbine systems.

1) Speed governing and steam turbine systems

They are designated as model #211~#216.

A) Non-reheat steam system

$Governor\#,211$
T_{CH}
$\dot{G}_{MIN},\dot{G}_{MAX},G_{MIN},G_{MAX}$
T_3,T_2,T_1

B) Tandem - Compound, Single - Reheat steam systems

$Governor\#,212$
T_{CH},T_{RH},T_{CO}
F_{HP},F_{IP},F_{LP},K
$\dot{G}_{MIN},\dot{G}_{MAX},G_{MIN},G_{MAX}$
T_3,T_2,T_1

C) Tandem - Compound, Double - Reheat steam systems

$Governor\#,213$
$T_{CH},T_{RH1},T_{RH2},T_{CO}$
$F_{VHP},F_{HP},F_{IP},F_{LP},K$
$\dot{G}_{MIN},\dot{G}_{MAX},G_{MIN},G_{MAX}$
T_3,T_2,T_1

D) Cross - Compound , Single - Reheat steam systems

$Governor\#,214$
T_{CH},T_{RH},T_{CO}
$F_{HP},F_{IP},F_{LP/2},F_{LP/2},K$
$\dot{G}_{MIN},\dot{G}_{MAX},G_{MIN},G_{MAX}$
T_3,T_2,T_1

E) Cross - Compound, Single - Reheat steam systems

Governor#,215

T_{CH}, T_{RH}, T_{CO}

$F_{HP}, F_{IP}, F_{LP}, K$

$\dot{G}_{MIN}, \dot{G}_{MAX}, G_{MIN}, G_{MAX}$

T_3, T_2, T_1

F) Cross - Compound, Double - Reheat steam systems

Governor#,216

$T_{CH}, T_{RH1}, T_{RH2}, T_{CO}$

$F_{VHP}, F_{HP}, F_{IP/2}, F_{IP/2}, F_{LP/2}, F_{LP/2}, K$

$\dot{G}_{MIN}, \dot{G}_{MAX}, G_{MIN}, G_{MAX}$

T_3, T_2, T_1

2) Speed governing and hydro turbine systems

They are designated as model #221~#222.

A) Accurate speed governing and turbine system for hydro generators

Governor#,221

T_W, T_P, T_G, T_R

σ, δ

$\dot{G}_{MIN}, \dot{G}_{MAX}, G_{MIN}, G_{MAX}$

T_3, T_2, T_1

B) Approximate speed governing and turbine system for hydro generators

Governor#,222

T_W, T_1, T_2, T_3

K

P_{MIN}, P_{MAX}

4.2.5 Power system stabilizers

Three power system stabilizer models are incorporated in TSSP. Different signals can be employed as input. These input signals are identified by the following input type indicators:

1 = deviation of rotor speed in per unit
2 = net accelerating power in per unit
3 = electrical power in per unit
4 = deviation of terminal voltage in per unit
5 = deviation of terminal frequency

A) Power system stabilizer with Fig. 7 as its block diagram, identified as IEEEST PSS in TSSP

Stabilizer #,311

Input type indicator

A_1

$T_1, T_2, T_3, T_4, T_5, T_6$

K_S, V_{MIN}, V_{MAX}

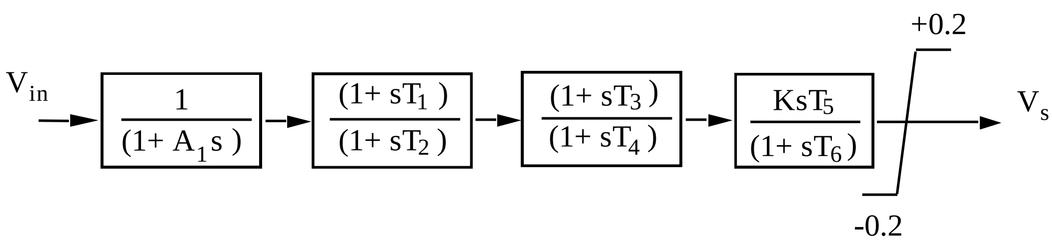


Fig. 7 Model IEEEST power system stabilizer

B) Power system stabilizer with Fig. 8 as its block diagram, identified as IEEESN PSS in TSSP

Stabilizer #,312

Input type indicator

A_1

$T_1, T_2, T_3, T_4, T_5, T_6$

K_S, V_{MIN}, V_{MAX}

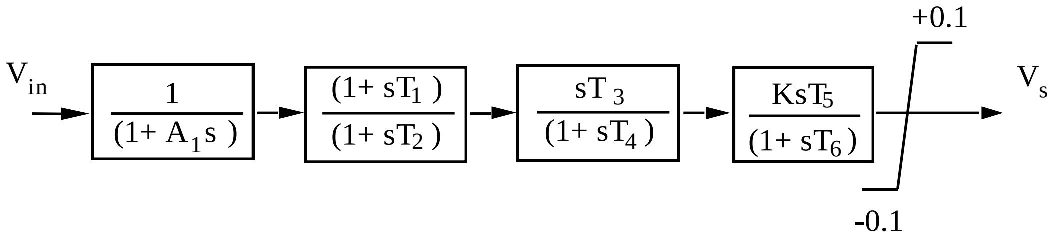


Fig. 8 Model IEEESN power system stabilizer.

C) Power system stabilizer with Fig. 9 as its block diagram, identified as IEEE standard PSS in TSSP

Stabilizer #,313

Input type indicator

$A_1, A_2, A_3, A_4, A_5, A_6$

$T_1, T_2, T_3, T_4, T_5, T_6$

K_S, V_{MIN}, V_{MAX}

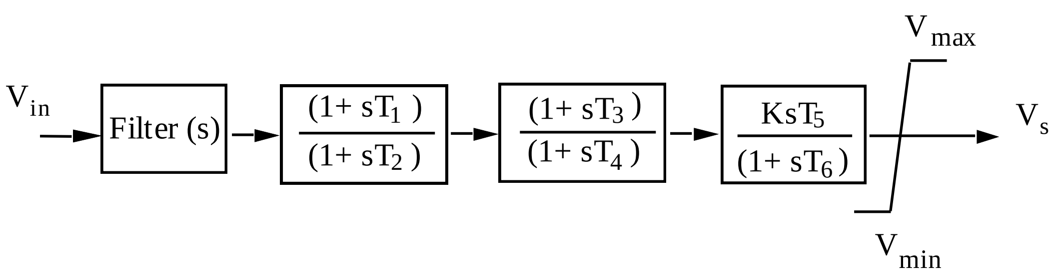


Fig. 9 IEEE standard PSS model.

where the transfer function of the filter in the diagram can be expressed by:

$$\frac{(1 + A_5 s + A_6 s^2)}{(1 + A_1 s + A_2 s^2)(1 + A_3 s + A_4 s^2)}$$

Chapter 5. Numerical Examples

5.1 The Sample System

The WSCC simplified three machine system [12] is used to illustrate how to prepare the data files needed to perform load flow and stability studies. The system has three generators, three loads and nine buses. A single line diagram of the system is given in Fig. 10. Complete system data and generator parameters can be found in [12]. A three phase to ground fault on line 5-7 near bus 7 for a period of 5 cycles (0.083s) is applied to the system. The fault is cleared by opening the line. This scenario can be used to study the effects of various power components.

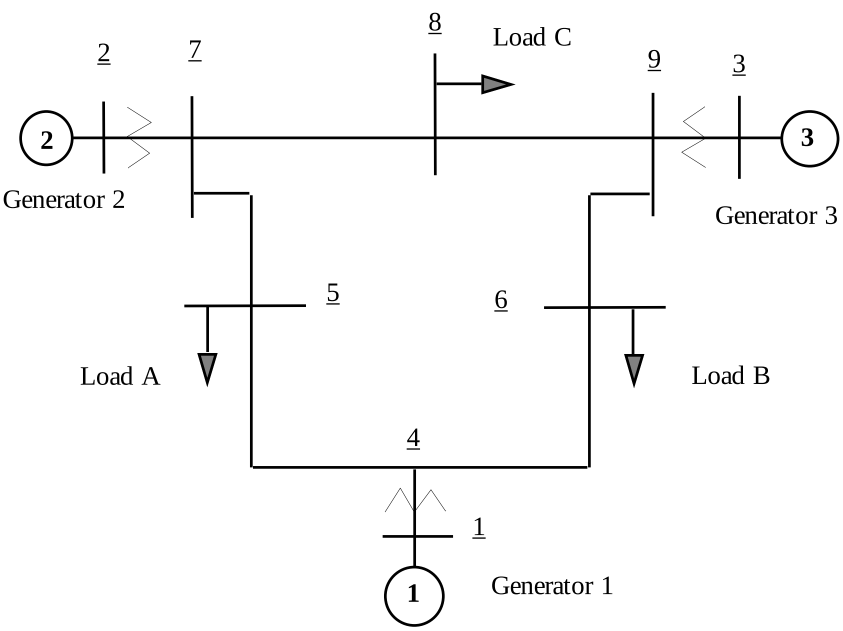


Fig. 10 Single line diagram of the WSCC system

5.2 Data file *pqlf.inp* and load flow results

```
!
!           Example: 3-machine 9-bus system
!          Data file for P-Q Decoupled LF studies
! ---------------------------------------------------------------------------------
! ⇒no of  |    max.     |  max. P, Q     |   ntwk   |   pu  (0)    |
!    buses  | iterations |  mismatch       |  switch  | MVA (1)    |
```

```
! -----------------------------------------------------------------------------------------
        9 ,       30       ,       0.0001    ,       0       ,         1     /
! -----------------------------------------------------------------------------------------
! ⇒Positive(+), negative(-) sequence network  data:
!    This block of data can be copied to or from the ntwk.inp file.
!    Attention should be paid to that the grounded
!    reactances of the generators used in ntwk.inp data file
!    are excluded here.
! -----------------------------------------------------------------------------------------
!      i,      j,       r(+),       r(-),        x(+),       x(-) ,   ratio/b/1.0/-1.0
! -----------------------------------------------------------------------------------------
      1,    -4,      0.000,     0.000,    0.0576,   0.0576,     1.000/
      2,    -7,      0.000,     0.000,    0.0625,   0.0625,     1.000/
      3,    -9,      0.000,     0.000,    0.0586,   0.0586,     1.000/
      4,     5,      0.010,     0.010,    0.0850,   0.0850,     0.176/
      4,     6,      0.017,     0.017,    0.0920,   0.0920,     0.158/
      5,     7,      0.032,     0.032,    0.1610,   0.1610,     0.306/
      6,     9,      0.039,     0.039,    0.1700,   0.1700,     0.358/
      7,     8,      0.0085,   0.0085,   0.0720,   0.0720,     0.149/
      8,     9,      0.0119,   0.0119,   0.1008,   0.1008,     0.209/
      0  /
! -----------------------------------------------------------------------------------------
! ⇒Bus data input includes the following:
! -----------------------------------------------------------------------------------------
!  bus  | bus     |   generation |       load         |  voltage     |
!  no   | type    |  PG       QG |  PL       QL       |   V(pu)      |
! -----------------------------------------------------------------------------------------
   1,       3,        0.0,      0.0,      0.0,      0.0,       1.04/
   2,       1,        163.0,  6.7,      0.0,      0.0,       1.00/
   3,       1,        85.0,   -10.9,    0.0,      0.0,       1.00/
   5,       1,        0.0,      0.0,      125.0,  50.0,      1.00/
   6,       1,        0.0,      0.0,      90.0,   30.0,      1.00/
   8,       1,        0.0,      0.0,      100.0,  35.0,      1.00/
   0 /
! -----------------------------------------------------------------------------------------
!                end of data file
!
```

The load flow FDLF program was executed, the following table lists generations (MVA), loads (MVA) and bus voltages (magnitude in p.u. and angle in degrees):

P-Q Decoupled LF converged at 9th iteration!

I	TYPE	PG	QG	PL	QL	V	ANGL
1	3	71.64069	27.03000	.00000	.00000	1.04000	0.00000

```
  2    1 163.00000    6.70000      .00000      .00000    1.02508    9.27864
  3    1   85.00000 -10.90000      .00000      .00000    1.02497    4.66492
  4    1      .00000     .00000      .00000      .00000    1.02580   -2.21676
  5    1      .00000     .00000  125.00000   50.00000     .99565   -3.98875
  6    1      .00000     .00000   90.00000   30.00000    1.01266   -3.68737
  7    1      .00000     .00000      .00000      .00000    1.02582    3.71904
  8    1      .00000     .00000  100.00000   35.00000    1.01591     .72731
  9    1      .00000     .00000      .00000      .00000    1.03234    1.96678
```

5.3 Data file *ntwk.inp*

```
!
!          Data file for short circuit calculations
! -----------------------------------------------------------------------------
! ⇒No of buses  , no of faults and no of events:
!    nbus ,  nfault , nevent/
! -----------------------------------------------------------------------------
     9     ,  1       ,  4 /
! -----------------------------------------------------------------------------
! ⇒Fault information input: ( time in seconds )
!    The sequence events of a disturbance are distributed on TIME-axis
!    as follows:
!    0.0 --------  .3  ------------ .4 ------------1.1 ---------------- 10.0
!    | pre-fault | fault period | post-fault | autoreclose  |
! -----------------------------------------------------------------------------
! |     |     | db/s|  start |   end   |              |               |
! |  i  |  j  | cir. |  time |  time  |    Zgnd     |   Zfault      |
! -----------------------------------------------------------------------------
   -7,  5,    0,   0.0,       0.0,    (0,0),      (0,0)    /
   -7,  5,    1,   0.0,       0.1,    (0,0),      (0,0)    /
   -7,  5,    1,   0.1,      20.1,    (0,0),      (0,0)    /
   -7,  5,    1,   20.0,     20.0,    (0,0),      (0,0)    /
! -----------------------------------------------------------------------------
! ⇒Fault type indicator input:
!    Choosing by deleting [ !  !!! ] at beginning of a line.
!    If no fault, no [ ! !!!] should be deleted.
! -----------------------------------------------------------------------------
3-phase-to-ground
!   !!!   1-phase-to-ground
!   !!!   2-phases-to-ground
!   !!!   phase-to-phase
!   !!!   1-phase-open
!   !!!   2-phases-open
! -----------------------------------------------------------------------------
! ⇒Positive(+), negative(-) sequence network  data:
```

```
!    See note in pqlf.inp data file.
! ---------------------------------------------------------------------------
!      i,     j,      r(+),       r(-),       x(+),     x(-), ratio/b/1.0/-1.0
! ---------------------------------------------------------------------------
     1,     -4,       0.000,     0.000,     0.0576,   0.0576,   1.0 /
     2,     -7,       0.000,     0.000,     0.0625,   0.0625,   1.0 /
     3,     -9,       0.000,     0.000,     0.0586,   0.0586,   1.0 /
     4,       5,      0.010,     0.010,     0.0850,   0.0850,   0.176/
     4,       6,      0.017,     0.017,     0.0920,   0.0920,   0.158/
     5,       7,      0.032,     0.032,     0.1610,   0.1610,   0.306/
     6,       9,      0.039,     0.039,     0.1700,   0.1700,   0.358/
     7,       8,      0.0085,   0.0085,   0.0720,   0.0720,   0.149/
     8,       9,      0.0119,   0.0119,   0.1008,   0.1008,   0.209/
     1,       0,      0.0,        0.0,         0.0608,   0.0608,   1.0/
     2,       0,      0.0,        0.0,         0.1198,   0.1198,   1.0/
     3,       0,      0.0,        0.0,         0.1813,   0.1813,   1.0/
     0 /
! ---------------------------------------------------------------------------
! ⇒ Zero(0) sequence network  data:
!
! 1) The non-grounded lines are:
!         Yo/Yo connected three-winding transformer branches;
!         Yo/Yo connected single-winding transformer branches;
!         Transmission lines.
!
! 2) The grounded zero sequence reactancs are:
!         generator grounding during a fault. Usually they
!         do not contribute to zero sequence currents
!         if the generator-transformers are in
!         Delta/Delta connection.
!
! 3) Other kinds of grounded reactances are:
!         Yo/Delta two-winding transformers;
!         tertiary windings of Yo/Yo/Delta
!         connected three -  winding transformers.
! ---------------------------------------------------------------------------
!        i,      j,    r(0) ,        x(0),        b/1.0/-1.0
! ---------------------------------------------------------------------------
       1,     4,   0.000,      0.0576,           1.0 /
       2,     7,   0.000,      0.0625,           1.0 /
       3,     9,   0.000,      0.0586,           1.0 /
       4,     5,   0.010,      0.0850,           0.176/
       4,     6,   0.017,      0.0920,           0.158/
       5,     7,   0.032,      0.1610,           0.306/
       6,     9,   0.039,      0.1700,           0.358/
       7,     8,   0.0085,     0.0720,           0.149/
```

```
      8,    9,   0.0119,    0.1008,         0.209/
      1,    0,   0.0,       0.0608,         1.0/
      2,    0,   0.0,       0.1198,         1.0/
      3,    0,   0.0,       0.1813,         1.0/
      0 /
! -----------------------------------------------------------------------------
! ⇒Input the bus numbers which are either in( 1 ) or not in( -1 )
!    the zero sequence network under the fault in concern.
!
!    The in_zero sequence network bus set is chosen here,
!    hence a '1/' is input as the first record of data in this
!    data block. Transmission lines will be automatically
!    connected to these buses, including line charges. If the fault
!    location changes, it may be necessary to modify this list.
!
!    This bus list is required for both 'during fault' period and
!    'fault cleared' period.
! -----------------------------------------------------------------------------
  -1 /                                                  / during fault
   0 /
  -1 /                                                  / fault cleared
   0 /
! -----------------------------------------------------------------------------
!                 End of data file
!
```

5.4 Data file *mach.inp*

```
!             Example: 3-machine 9-bus system
!                 Data file for stability study
! -----------------------------------------------------------------------------
! ⇒ No of machines, time step, print interval
! -----------------------------------------------------------------------------
             13         ,     0.002  ,      0.02     /
! -----------------------------------------------------------------------------
! ⇒Machine no, model no and corresponding parameters
!    (for detail, please refer to the user's manual)
!    Data input examples:
!  1, 4/                                    / generator no, Model #:
!  13.2 ,  2.24  ,  0.0  ,   0.326           / Mbase, H, R, Xl
!   1.05,  0.3818,  0.344,   0.741, 0.344   / Xd,Xdo',Xdo",Xq,Xqo"
!   2.62,  0.0500,  0.060                   / Tdo', Tdo" , Tqo"
```

```
!   0.00,  0.2470,  0.5612,  -1               / damp,s(1.0),s(1.2),-1
!
!   11, 2/                                    / Gen #, Model #:
!    3.0,  2.7   ,  0.0   ,  0.0              / Mbase,  H  , R, Xl
!  0.876,  0.272 ,  0.5                       / Xd  , Xdo', Xq
!   2.27                                      / Tdo'
!   0.00,  0.179 ,  0.43  ,  -1 / damp,s(1.0),s(1.2),-1
!   13, 0                                     /   infinite bus
!   100                                       /   capacity of system
! -----------------------------------------------------------------------------
   1, 3 /
   245.7,  23.64,     0.0,        0.0336      /
   0.146,  0.0608,   0.0969,   0.0969      /
   8.96 ,   0.001                             /
   0.0,      0.0,        0.0                  /
   2, 3 /
   192.0,  6.4 ,        0.0,        0.0521    /
   0.8958,0.1198,   0.8645,   0.1969      /
   6.0,      0.535                            /
   0.0,      0.0,        0.0                  /
   3, 3 /
   128.0,  3.01,       0.0,        0.0742     /
   1.3125,0.1813,   1.2578,   0.25         /
   5.89,    0.6                               /
   0.0,      0.0,        0.0                  /
! -----------------------------------------------------------------------------
!⇒ Exciter model no and its parameters
!    (for detail, please refer to the user's manual)
!    Data input examples:
!
!  1  , 41 /                                  / Gen #, AVR model #
!   56.0 ,  1   ,  1                          / Ke, neg. logic, busfed
!    0.0 ,  1.0 ,  1.0,  0.035                / T1,   Ta ,  Tb,  Te
!   -3.94,  3.94                              / Emin   ,  Emax
!
!   10 , 14 /                                 / EXDC2B model
!    369.0,  1.000, 0.022                     / Ka, Ke, Kf
!    1.000,  0.226, 0.000 , 2.000, 1.0        / Tc, Tb, Ta, Te, Tf1
!    -3.97,  4.960                            / Vrmin, Vrmax
!    1.830,  0.108, 2.3570, 0.506 , -1        / E1, S1, E2,  S2,  -1
!
!     13,  888 /                              / no AVR
! -------------------------------------------------------------------------------
   1, 11 /
   25.0,    -0.044, 0.0805                    /
  0.0,       0.0,       0.20,     0.50,     0.35     /
```

```
 -1.0,      1.0                             /
 0.0016, 1.465                              /
 2, 11 /
 400.0,   -0.17,   0.0400                   /
 0.0,       0.0,      0.05,    0.95,    1.00    /
 -3.5,      3.5                             /
 0.0039, 1.555                              /
 3 , 41 /                                   /
 56.0 ,     1   ,      1                    /
 0.0 ,      1.0 ,     1.0,      0.035       /
 -3.94,   3.94                              /
! ---------------------------------------------------------------------------
!⇒ Turbine governor model no and its parameters
!    (for detail, please refer to the user's manual)
!    Data input example:
!   1 ,  222 /                              / Gen #, governor model #
!   0.620,  0.320,  3.290,  33.150          / Tw,   T1,   T2,   T3
!   20.0                                    / K
!   0.00 ,  1.05                            / Gmin,  Gmax
!
!   8 , 221 /                               / Gen #, governor model #
!   1.05,  0.05,  0.24,  4.2                / Tw,     Tp,  Tg, Tr
!   0.03,  0.55                             / perm-R, temp-r
!   -0.16, 0.16,  0.00,  1.0                /Ġmin,Ġmax, Gmin,Gmax
!
!   13 , 888/                               / no governor here
! ---------------------------------------------------------------------------
 1, 212 /
 0.1,       5.0,   0.35                     /
 0.3,       0.4,   0.3,      20.0           /
-2.0,       2.0,   0.0,      1.05           /
 0.2,       0.0,   0.0                      /
 1, 221 /
 1.05,     0.05,  0.24,   4.2               /
 0.03,     0.55                             /
-0.16,     0.16,  0.0 ,     1.1             /
 1,  222 /
 0.62,     0.320,3.290, 33.15               /
 20.0                                       /
 0.000,   1.05                              /
! ---------------------------------------------------------------------------
! ⇒Power system stabilizer and its parameters
!    (for detail, please refer to the user's manual)
!    Data input example:
!   1, 311 /                                / Gen #, PSS model #
!   3 /                                     / input 3: elec. power
```

```
!   0.014                                          / Ta1
!   0.000,  0.025,  4.4,  4.4,  5.0,  5.0     / T1,T2 ,T3, T4, T5,T6
!   -0.05,  -0.100,  0.100                     / Ks ,Vsmin , Vsmax
!
! ----------------------------------------------------------------------------
  1, 312 /
  1/
  .0000                                           /
  .2230,    .0310,   .2230,    .0310, 8.0,  8.0   /
 4.0000,   -.1000,  .1000                         /
  2, 312 /
  1 /
  .0000                                           /
  .2465,    .0342,   .2465,    .0342, 8.0,  8.0   /
 4.0000,   -.1000,  .1000                         /
  3, 312 /
  1 /
  .0000                                           /
  .2230,    .0310,   .2230,    .0310, 8.0,  8.0   /
 4.0000,   -.1000,  .1000                         /
! ----------------------------------------------------------------------------
!          End of data file
!
```

5.5 Application of plotting utility programs

The results obtained from the simulation package (TSSP) is stored in the file *simu.out*. In order to facilitate the analysis of the results, plotting utility programs in TSSP can be used to plot and/or sort the variables of interest.

5.5.1 The WPLOT program

For analyzing the variables of a specific generator, the WPLOT program can be employed to plot a maximum of five variables at a time. To start the program, type WPLOT at the DOS prompt and press the <<ENTER>> key. The following display will be brought up on the screen.

```
*******************************************
****        Welcome to TSSP software          ***
*******************************************


Enter the total number of machines          :
Enter the specific machine number           :
Enter the number of variables               :
(variable list, ex., ang, Ed', Eq'', etc.)

Enter the 1st variable string               :
Enter the 2nd variable string               :
...
Enter the 5th variable string               :
```

To plot the variables of interest, the following information is entered first:

The total number of machines in the system (there are 3 machines), **3**
The specific machines of interest (say machine #2), **2**
The number of interested variables of that machine (say 1), **1**

Then, the variable strings are entered exactly the same as given in the variable list. A maximum of five variables can be entered and plotted at a time. An example is given below.

Enter the 1st variable string (rotor angle), **ang**

The <<ENTER>> key must be pressed to enter each item of the above stated information. The rotor angle (absolute value in degrees) and terminal voltage (in per unit) of generator #2 in the sample system can be displayed as follows by entering the variable identifying information. Figure 11 shows the absolute rotor angle of generator #2. Similarly, the terminal voltage of generator #2 is shown in Fig. 12.

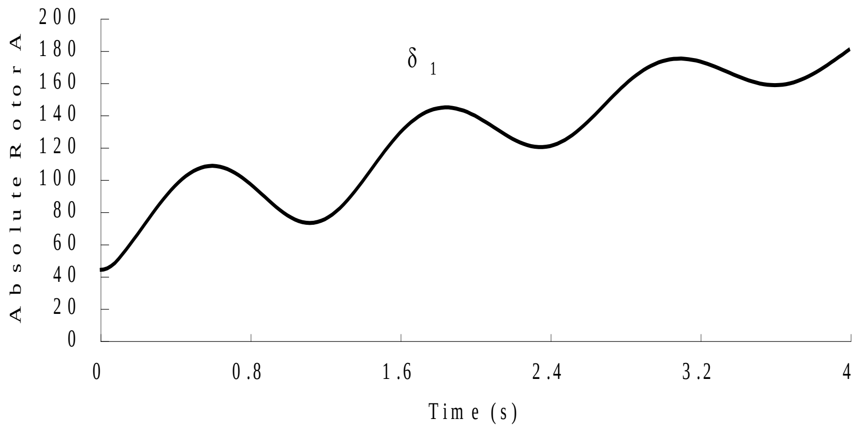


Fig. 11 Absolute rotor angle plotting of generator #2

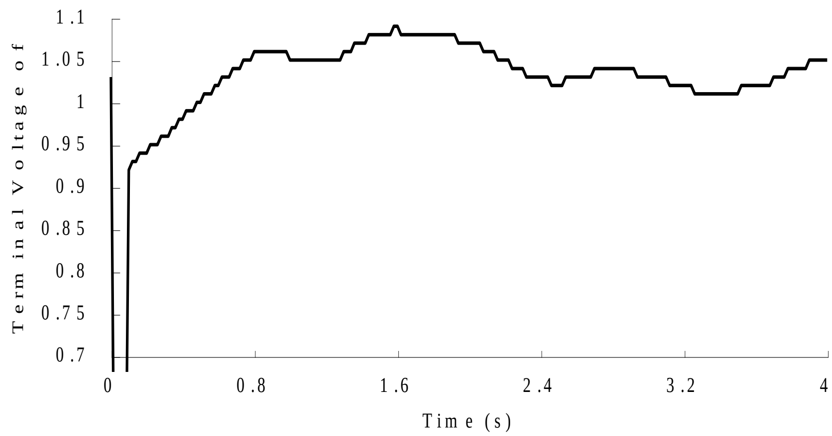


Fig. 12 Terminal voltage of generator #2

5.5.2 The SORT Program

It may be interesting or necessary to compare the same variable, for example, the machine shaft speed, of several generators in analyzing the results. The SORT program can be used to plot and/or sort out a maximum of twelve variables of different generators at a time. Generator rotor angles in respect to any generator in the system can be plotted.

To start the program, type SORT at the DOS prompt and press the <<ENTER>> key. The following display will be brought up on the screen.

Input filename of results from TSSP : ***simu.out***
Input filename for storing sorted data : **angspd23**
Input reference machine no. : **1**

```
******************************************
****            Welcome to TSSP software              ***
******************************************


Enter the total number of machines                    :
Enter the number of interested machines               :
Enter the specific machine numbers                    :
Enter the number of variables                         :
(variable list, ex., ang, Ed', Eq", etc.)

Enter the 1st variable string                         :
Enter the 2nd variable string                         :
...
Enter the 5th variable string                         :
```

To plot the variables of interest, the following information is entered first:

The total number of machines in the system (there are 3 machines), **3**
The number of interested machines (say 2), **2**
The specific machines of interest (say machines #2 and #3), **2, 3**
The number of interested variables of each machine (say 1), **2**

Then, the variable strings are entered exactly the same as given in the variable list. A maximum of five variables can be entered and plotted at a time. An example is given below.

Enter the 1st variable string (rotor angle), **ang**
Enter the 2nd variable string (rotor angle), **spd**

The <<ENTER>> key must be pressed to enter each item of the above stated information. The relative rotor angles (referred to generator #1, in degrees) of generators #2 and #3 in the sample system can be displayed as shown in Fig. 13, after entering the variable identifying information accordingly.

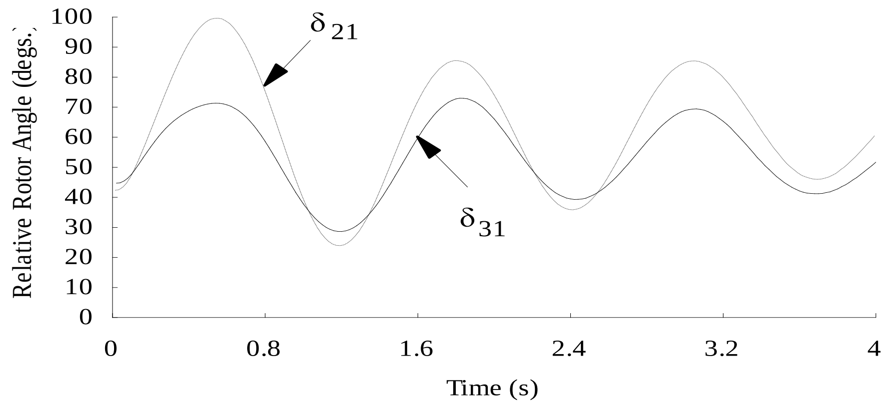


Fig. 13 Relative rotor angle swings of generators #2 and #3

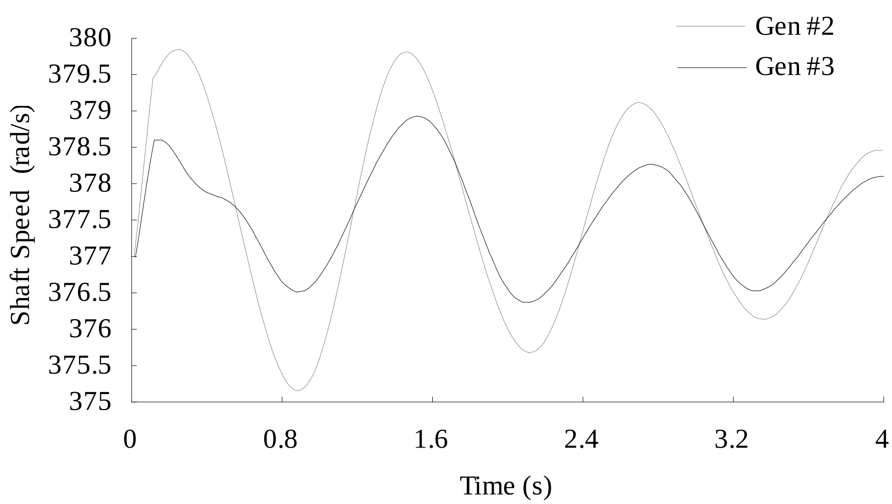


Fig. 14 Machine shaft speed of generators #2 and #3.

Appendix Interface with User-defined Module

If the module of a power component or a controller is not available in the TSSP, it is required to derive its transfer function. A block diagram can be built with integrators according to the transfer function. Then the block diagram can be programmed into a module. The name of the module is the name of the component, (for instance, SGTS), plus the identifying number corresponding to it as given in Table A.1. A dumb variable is required to identify the machine on which the component is installed. Other parameters for the module are passed through the input data file *mach.inp*. These parameters are stored in three different arrays. They are AVR(#, 20), TUR(#, 20), PSS(#, 20), where # is the identifying number of the machine on which the component or controller to modeled is to be installed. A maximum of tweenty parameters can be stored for each device. Parameters are compactly placed in its corresponding array according the definition of the data input format which is also defined by the user.

For example, a module for the simplified hydro speed governing and turbine system is to be programmed. The block diagram of the transfer function is given again in Fig. A.1.

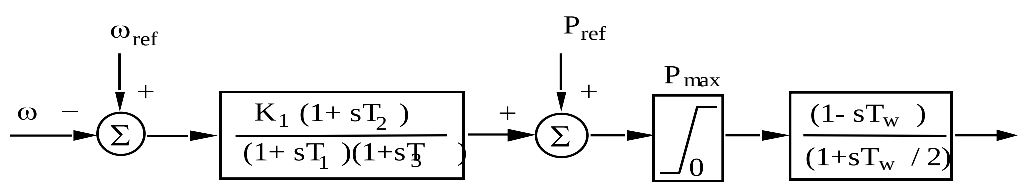
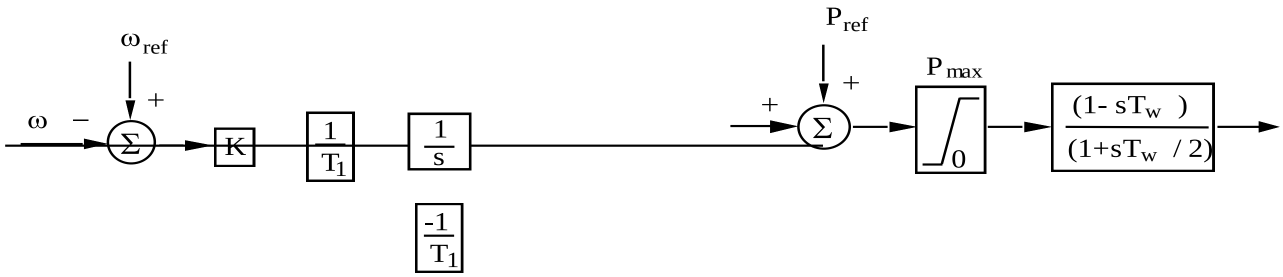


Fig. A.1 Simplified representation of hydrogovernor turbine system.



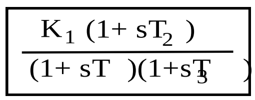


Table A.1: Module identifying numbers in the TSSP.

AVR	SGTS	PSS
11 - DC 1 12 - DC 2 13 - DC 3 14 - EXDC2B 21 - AC 1 22 - AC 2 23 - AC 3 24 - AC 4 31 - ST 1 32 - ST 2 33 - ST 3 41 - SCRX 42 - SCRXIL 51 - 55 User - Defined	211 - NR 212 - TCSR 213 - TCDR 214 - CCSR-A 215 - CCSR-B 216 - CCDR 221 - Hydro A 222 - Hydro B 231 - 235 User - Defined	311 - IEEEST 312 - IEEESN 313 - IEEE standard Input Identifier: 1 - Deviation of speed 2 - Deviation of frequency 3 - Electrical power 4 - Accelerating power 5 - Deviation of voltage 321 - 325 User - Defined

```
C
C  ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
C  ~    hydro turbine and governor systems      ~
C  ~             IEEE model                     ~
C  ~  ( simplified speed - governor model )     ~
C  ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
```

```
      SUBROUTINE SGTS231(I)
C
      INCLUDE    'CMM.DM'
C
      double precision  OME
      DOUBLE PRECISION  X0, X1  , X2  , X3 , X4 , X5 , X6, X7, X8
C
C   define integrator output
C
      OME = OUT(I,1)
      X2  = OUT(I,9)
      X4  = OUT(I,10)
      X6  = OUT(I,11)
C
C   calculate intermediate variables
C
      X1  = TUR(I,6) * ( WREF(I) - OME )
      X3 = X2 + X1 * TUR(I,4) / TUR(I,3)
      IF ( TUR(I,5).LT.0.0001 )  X4 = X3
      X5 = GREF(I) - X4
      IF ( X5.GT.TUR(I,8) )   X5 = TUR(I,8)
      IF ( X5.LT.TUR(I,7) )   X5 = TUR(I,7)
      X8  = 1.5 * X5 - X6
      X7  = X5 - X8
      PM(I) = X7 * TUR(I,1) / 100.0
C
C   define integer inputs
C
      PLUG(I,9)  = ( X1 - X3 ) / TUR(I,3)
      PLUG(I,10) = ( X3 - X4 ) / TUR(I,5)
      PLUG(I,11) = X8 / TUR(I,2)
      PVAR(I,12) = X5
      RETURN
C
C   initialize the system variables
C
      ENTRY initializeSGTS231(I)
C
C   define default time constants
C
      IF ( TUR(I,3).EQ.0.0 )    TUR(I,3) = 1.0E+6
      IF ( TUR(I,4).EQ.0.0 )    TUR(I,4) = 1.0E+6
      IF ( TUR(I,5).LT.0.0001 ) TUR(I,5) = 1.0E-6

      X0       = PM(I) * 100.0 / TUR(I,1)
      GREF(I)   = X0
```

```
      OUT(I,9 ) = 0.0
      OUT(I,10) = 0.0
      OUT(I,11) = 1.5 * X0
      WREF(I)   = OUT(I,1)
C
      IF ( X0.GT.TUR(I,8) )  WRITE( *, 10) I
      IF ( X0.LT.TUR(I,7) )  WRITE( *, 10) I

10    FORMAT( ' Gate limits exceeded at governor', i4/ )

      RETURN
      END
```

Reference

[1] IEEE Committee Report,"Excitation System Models for Power System Stability Studies," *IEEE Transactions on Power Apparatus and System*, Vol. PAS-100, pp. 494-507, February 1981.

[2] IEEE Committee Report,"Dynamic Models for Steam and Hydro Turbines in Power System Studies," *IEEE Trans. on Power Apparatus and System*, Vol. PAS-92, pp. 1904-1915, November 1973.

[3] P. M. Anderson, A. A. Fouad, *Power System Control and Stability*, The Iowa State University Press, Ames, Iowa, U.S.A., 1977.