# POWERDRAW

# DIGITAL SIMULATOR FOR POWER SYSTEMS

## USERS' MANUAL

### VOLUME - III

## REAL TIME SIMULATION OF POWER SYSTEMS

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# Chapter 1

# Digital Simulation of Power Systems

## 1.1 Introduction

This manual is to introduce the users to the power system simulation package, 'POWERDRAW' with all its power system related graphical and analytical capabilities. POWERDRAW is a comprehensive, versatile and easy-to-use software tool for different types of power system studies. The entire package is operated through a Graphical User Interface(GUI).

## 1.2 Organization of the Manual

The **Users' Manual** is divided into three volumes.

**VOLUME ONE contains:**

*** Introduction to POWERDRAW GUI**

*** Drawing of Single Line Diagram of Power Systems**

*** Generation of Data Files**

**VOLUME TWO contains:**

*** Off-Line Studies of Power System Operation**

**VOLUME THREE contains**

*** Real-Time Simulation of Power System**

In its present form the POWERDRAW software package has the following capabilities:

- Adheres strictly to **POSIX**©-compliant **UNIX**©, **X-WINDOWS**© and **OSF -MOTIF**© for platform and operating system independence
- Mapping of power system components to visual objects on the computer screen
- Constructing schematic maps of power system network with advanced features like drag & drop of various objects
- Provides animation to power system objects
- Display of schematic map at different tiers
- Manipulation of Network Data and attributes (color, position, status) through simple operation of mouse pointer
- Automatic preparation of Database from network connectivity for Real-Time/Off-line power system simulation study
- Automatic generation of user-defined substation diagram
- Dynamic representation of status changes of various objects on Graphical Display
- Displaying & reporting of current system conditions for better understanding on the part of operator

- Initiation of various in-built off-line system simulation engines & displaying results graphically for better insight

- On-line/Off-line scenario building

The entire overview of the POWERDRAW GUI is shown in Fig. 1.1
Each of these facilities will be described in detail later.

### 1.2.1 Communication with the Software

All communications with the software are through the graphical user interface (GUI). All commands either for developing the single line diagram or for carrying out any of the large number of system studies are to be communicated to the software through appropriate 'Dialog Boxes'. For this purpose a large number of necessary 'Child Windows' suitable for communicating with the software have been incorporated. Chapter-2 describes the 'POWERDRAW' graphical user interface with all the Menus, Sub-menus, Tools and other facilities available for communicating with the package.

### 1.2.2 Single Line Diagram of a Power System

One of the important features of the package is the drawing and development of a single line diagram of interconnected power systems. The network diagram may be drawn in a compact form. Alternatively, all the transmission lines and substations may be geographically disposed spatially. The drawing area can be expanded upto 32 window size X 32 window size. All these features are described in Chapter-3. That chapter also describes all the user-friendly facilities created to help the operator during running process. Predefined colour schemes for different voltage levels and specially created icons for different system components are also explained in this chapter.

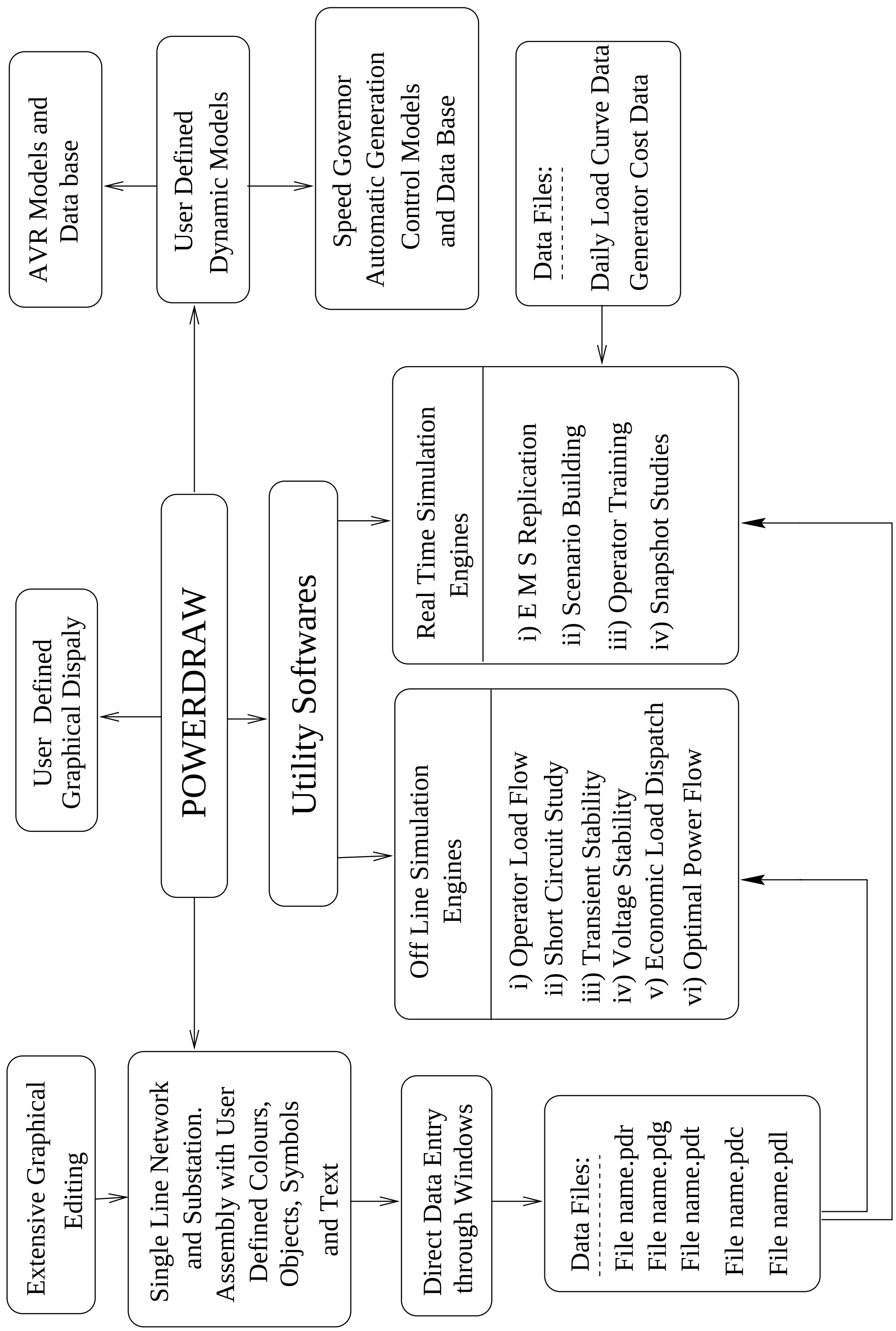


**Figure 1: The POWERDRAW Overview**

Figure 1.1: The POWERDRAW OVERVIEW

### 1.2.3 Generation of System Data Files

During the drawing process of the single line diagram, or even after completing the drawing process, there are facilities for generating the necessary data files for carrying out most of the studies. While data are provided through appropriate dialog boxes, the program generates three different data files as below:

<**filename.pdr**> ... File for the network drawing

<**filename.pdt**> ... File for the network data

<**filename.pdg**> ... File for generator data

<**filename.pdc**> ... File for load curve data

<**filename.pdl**> ... File for load model data

where

**filename** is a user-defined file describing the system to be supplied by the user.

The structure of these files will be described in detail in Chapter-4. For inputting data a large number of appropriate Dialog Boxes have been designed specially for easy understanding of the user. The data structure as stored in each of the files are also included. Detailed instructions about the way data are to be inputted are also described in that Chapter.

#### 1.2.3.1 Modeling for Static Simulation

For static analyses such as Loadflow, Short Circuit etc. following modeling has been included:

**Busbar** with variable loads, shunt loads, generation etc.

**Transmission Lines** with line connected reactors

**Transformer** with variable and fixed taps

**Static VAR System** with controllable slopes and limits

**High Voltage DC System** with all types of connection and modes of operation

Six different models are available for load modeling. A user can use any one of them. These are as given below:

**Load Model 1** = Basic Constant MVA model.

**Load Model 2** = Voltage and Frequency sensitive MVA model

**Load Model 3** = Includes Load Management in Model 1

**Load Model 4** = Includes Load Management in Model 1

**Load Model 5** = Includes Voltage Regulation in Model 1

**Load Model 6** = Includes all (Voltage and frequency sensitivity, Load Management, Voltage Regulation.)

#### 1.2.3.2 Modeling for Dynamic Simulation

The following components have been modeled as per the IEEE standard wherever available.

**Automatic Excitation Control System** of standard IEEE type

**Speed Governing System** for both hydro and steam plants

**Boiler Turbine System** for both hydro and steam plants

**Automatic Generation Control System**

**Power System Stabilizer**

**Static VAR System**

**High Voltage DC System** for different modes of operation control

**Protection System** over-current and impedance relay

**Generating Units** of round-rotor and salient pole type

## 1.3 Utility Softwares

Apart from the facilities for drawing single line diagram and data file preparation, this software package offers a large number of generalized and versatile programs for a variety of power system simulation studies. Theses studies are categorized into two groups:

**Off-line Simulation Engines**

**Real Time Simulation Engines**

### 1.3.1 Off-line simulation

The following is the list of off-line studies that can be carried out on a system whose single line diagram has been drawn and proper data files have been created:

* **Operator Load Flow**

* **Short Circuit Studies**

* **Transient Stability studies**

* **Voltage Stability Analysis**

* **Economic Load Despatch**

* **Optimal Power Flow**

### 1.3.2 Real time simulation

Real Time simulation can be carried out through either of the two alternatives:

* **Load Flow Analysis**

* **State Estimation**

For the purpose of using the Real Time Simulation engine through the State Estimation program it is necessary to connect the POWERDRAW GUI to an appropriate Data Acquisition System which will have to transmit the required data to the engine in the correct format and sequence.

## 1.4 Off-Line Simulation Engines

Different off-line studies are described in detail in different chapters. In this section only brief overview will be presented.

### 1.4.1 Operator Load Flow Studies

In Chapter-5 the facilities for carrying out load flow studies, be it off-line or on-line, is described. Load flow analyses can be carried out under the following three study modes:

* **Static Load Flow Analysis**

* **System Expansion Study**

* **Snap-shot on Real Time Operation**

In each mode a large number of changes, either in the topology of the network or in its parameters or in its operating states, can be incorporated and load flow can be repeated. The list of the changes is:

**a. Change in Load**

**b. Change in Generation**

**c. Change in Shunt Load**

**d. Change in Feeder Data**

**e. Change in Phase Shifter Data**

**f. Change in Control Bus Data**

**g. Tripping of a Generator**

**h. Putting in a Generator**

**i. Switching out a Feeder**

**j. Switching in a Feeder**

### 1.4.2 Short Circuit Studies

Short Circuit Analyses of electrical power systems network is an important requirement for both planning and operational purposes. The following types of faults can be applied as per the operator's requirement.

```
Type of fault            identifying number
*************            ******************

 SINGLE LINE TO GROUND FAULT        1
 LINE TO LINE  FAULT                2
 THREE PHASE FAULT                  3
 DOUBLE LINE TO GROUND FAULT        4
```

After the solution, all the three different phase-voltages and phase-currents are displayed in the display windows as explained later. The details are described in a separate chapter.

### 1.4.3 Transient Stability Studies

Transient Stability Analyses fall under the category of large disturbance studies which are required for both system planning purposes as well as for creating system operation strategies. Following a large disturbance the rotor angles, rotor speeds and accelerations of all the generating units get disturbed. Depending on the location of electrical distances, different units are affected to different extent.

Since the entire solution of all the different components of the system cannot be achieved in real time, this is essentially an off-line study.

Descriptions about supplying data for, and running procedure of the transient stability program is presented in this chapter.

There are option to plot the transient variation of the following quantities in graphical form for the duration of the solution:

* **Rotor angles of selected generators**
* **Power output of selected generators**
* **Voltage magnitude at selected busbars**
* **Frequency variation at selected generator busbars**
* **Impedance seen by a distance relay of selected line**

In each plot it is possible to include as many monitoring points as desired.

#### 1.4.3.1 Voltage Stability Study

Voltage collapse is characterized by a slow variation in system operating point due to increase in loads in such a way that the voltage magnitude gradually decreases until a sharp accelerated change takes place. The problem ofbf voltage collapse may simply be explained as the inability of the power system to supply the reactive power or by an excessive absorption of reactive power by the system itself. An effective voltage collapse bf proximity index which indicates how far the current operating is from voltage collapse and which busbars are the most vulnerable is of much help to the system operating engineer in taking corrective measures.

At any operating condition of the system this program selects a set of busbars which are, according to selected criteria, are vulnerable to voltage collapse. It shows the current load at those buses and also the approximate laodability margin along with the proximity index.

#### 1.4.3.2 Optimal Power Flow

This analytical tool minimizes the active power losses in the transmission and distribution system. For a given optimum active power allocation based on economic generation schedules, this program minimizes the line losses by optimally rescheduling the reactive power outputs of the generating units. While doing this it also improves the system **voltage profile.**

## 1.5 Real Time Simulation of Power System

Real time simulation of power system is an important constituent of the Digital Simulation of power system. Apart from replicating the EMS environment, the real time simulation engine provides extensive facilities for the training of power system operators.

Two major needs for which training can be very effective are:

**Training for Operation During Normal Condition**

**Training for Operation During Severe Disturbances**

### 1.5.1 Scenario Building for Real Time Simulation

For the purpose of operator training pre-defined scenarios are generally created by the instructor so that the trainee can respond interactively for restorative purposes.

Fourteen different types of individual scenarios can be created with the help of this Dialog box. With suitable combination of these individual cases a large number of practically realizable scenarios can be created. These individual scenarios are:

**1 Change in Load**

**2 Change in Pset Value**

**3 Change in Shunt load**

**4 Change in Feeder/Transformer Data**

**5 Change in Phase Shifter Data**

**6 Change in Control Bus data**

**7 Bringing back a generator**

**8 Tripping off a generator**

**9 Switching out a feeder/transformer**

**10 Switching in a feeder/transformer**

**11 Switching out a DC link**

**12 Switching in a DC link**

**13 Changing DC link power**

**14 Change in Governor Mode**

All the scenarios as described above can also be created interactively during the time when real time simulation is proceeding.

The real time simulation of a power system under normal condition will generally follow a predicted load curve. A real time dynamic simulator will be the most effective mechanism to train control engineers in the handling of severe disturbances.

A real time dynamic simulator will be the most effective mechanism to train control engineers in the handling of severe disturbances to increase confidence, to improve knowledge of the technical characteristics of the system and to train for procedures for handling emergency situations.

This chapter describes in detail all the aspects of real time simulation of a power network. It highlights how and what data are to be supplied to the simulation program, how to run the program and how to interrupt the real time simulation to carry out snap-shot studies. It also describe the various aspects of operator training process such as the preparation of training scenarios, interpretation of results and how the trainee can take certain supervisory actions in an attempt to bring the system to healthy condition after some disturbances.

## 1.6 Intended Audience

This manual is intended as a guide for using the 'POWERDRAW' software package. Any person familiar with an electrical power network should be able to use the manual for going through various stages of the software package and use it for his own purpose purely mechanically. But for a better understanding of various functions and their inter-relationships among one another, it is assumed that the user will be familiar with the functioning of an integrated power system and different types of associated problems it is likely to face under normal and abnormal operating states. Some analytical background relating to power system modeling and simulation would be of advantage.

Some knowledge of UNIX operating system and its file structure is also a basic requirement.

The associated publication 'Technical Manual' provides the details of mathematical relationship involved in modeling and simulation of different components and systems as used in this package. Inter-relationship of the various processes are also available in that manual.

Those who would be involved in modifying and upgrading the package, would be expected have a thorough understanding of the Technical Manual. They should also be able to understand the source codes written in FORTRAN-77 and C language. The graphical aspects of the package has been developed using X-WINDOW and MOTIF library functions.

The POWERDRAW will be useful to:

**Power system managers**

**Power system operators**

**Teachers**

**Researchers**

**Advanced students**

## 1.7 Team of Personnel

The following personnel in the

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were involved in the development of the package:

**A. Faculty:**

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**2. Professor A K Sinha**

**B. Research Scholars:**

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**2 Dr. Jayanta Kumar Mandal**

**3 Dr. Anutosh Maitra**

**4 Mr. Durlav Hazarika**

**C. Graduate Students:**

**1 Mr. C S S Ravi**

**2 Mr. S Misra**

**3 Mr. Amit Kumar Sil**

**4 Mr. Ashok Reddy**

**5 Mr. Chinna Narayan**

**6 Mr. Pavan Kumar**

**7 Mr. Rajnish Chauhan**

**8 Mr. A K Kishore**

**D. Undergraduate Students:**

**1 Shital Meheta**

**2 Kaushick Niyogi**

# Chapter 2

# Real Time Simulation of Power System

## 2.1 Introduction

Real time simulation of power system has assumed significant importance in the recent past because of the ever increasing complexity of power system operation and control. Even the most experienced of power system operators cannot supervise to-day's power system intuitively. Varieties of technical, economic and other related constraints have made control of a system so complex that an operator needs some on-line assistance to help him take quick and correct decision. An efficient real-time simulation package can provide such assistance to the operating engineer.

There are two major functions of the real time simulator.

**It replicates the Energy Management System(EMS) centre**

**It provides extensive operator training facilities**

The basic idea of a real time simulator is to simulate the operation of an integrated power system for any length of time provided a forecasted daily load curve for the system and all other necessary data files are available. Necessary file systems are explained later.

For a complete understanding of the real time simulation it is assumed that the operator has have gone through Volume One and Volume Two of the Operators Manual. Some of the references made in this Volume are available in detail in those two volumes.

### 2.1.1 Replication of EMS

In replicating the functions of an Energy Management System centre, the simulator provides the user with all the information as he would be getting when he is in a control system centre. The state of the system in terms of voltage magnitudes, generator output and power flows through the lines and transformers would be refreshed at regular intervals in the GUI as is done in a wall board diagram. Alarm signals will also be displayed in a separate windows to inform the operator so that he can take any supervisory decision and action if necessary.

### 2.1.2 Operator Training Simulation

The other area where a real time digital simulator can provide help is in the area of Operator Training. While the system is running in real time an operator can create a large number of properly selected contingency scenarios and impose them into the system at selected time and see the response of the system to such disturbances. Initially, an instructor should help in creating the scenarios .

When such contingencies are imposed into the system through these scenarios, the operator has to respond by taking certain actions to maintain the system in healthy condition. It is not expected that a learner will always take correct decisions thereby quite often resulting in system going out of desired operating state. The flexibility of the real time simulator is that the operator can easily repeat the entire process and educate himself at his own pace.

### 2.1.3 Functions of a Training Simulator

Two major needs for which training can be very effective are:

**Training for Operation During Normal Condition**

**Training for Operation During Severe Disturbances**

#### 2.1.3.1 Training for Operation During Normal Condition

The training required is essentially in the technical aspects of system operation. It may include the following tasks:

Load following/frequency control
Economic dispatch and trading
Monitoring of system conditions
Use of contingency analysis
Operational loadflow facilities
Interpretation of alarm displays
Load management

To provide all the facilities listed above means that the simulator must have access to many of the computational aids available to the control staff in real time operation.

The real time simulation of a power system under normal condition will generally follow a predicted load curve. With variation of system load it will, if required, modify network topology, change generation at appropriate time to meat load demand and reserve requirement and to maintain system frequency. The simulator starts by determining an unit commitment schedule for the predicted load curve. The output of generators will be dictated either by scheduling priorities or on economic basis. If the load demand deviates considerably from the predicted values, the operator may have to intervene to balance out the schedule.

Interpretations of the alarm signals and to decide whether any supervisory action is necessary is also a task of the normal operating condition. The flow chart for using all the computational packages is shown in Fig. 1.

#### 2.1.3.2 Training for Operation During Severe Disturbances

A real time dynamic simulator will be the most effective mechanism to train control engineers in the handling of severe disturbances. The broad area of the training will be:

**To increase confidence** and ability under stress to weigh up situations and make and implement timely decisions.

**To improve knowledge** of the technical characteristics of the system under disturbed or degraded operating conditions.

**To train for procedures** for handling emergency situations.

A replica simulator incorporating much of the operational man-machine interface (MMI) as well as a model of the actual power system dynamically reacting in real time to internal and external signals is probably the only way in which the degree of technical and psychological realism can be achieved for a control team. Ideally, it should be possible to model the following types of incidents:

Multiple, coincident or sequential faults
Protection operation
Oscillatory conditions
System splitting and islanding

It is possible to impose any of these contingencies on the system operation during normal condition and create severe disturbances in order to study the response of the system in such situations. This will educate the operator about what action to be taken to bring back the system to normal state. There are automatic control actions such as tripping of generation and load under frequency excursions or tripping of lines and transformers on which the operator does not have any control. These are to be taken care of by the simulator itself and the trainee is simply an observer.

It is with these objectives that the Real Time Simulator has been designed.

## 2.2 Modeling and Software Requirement

The system and component models as well as application software have been developed in this simulator to achieve most of the objectives as mentioned above. The modeling details are explained in the Technical Manual. The application software engines cover some or all of the following analytical and other functions:

* Power flow calculation
* Total system energy balance giving system frequency variation (all machines swinging together)
* Protection performance (at the simplest, unit and overcurrent but ranging upto impedance)
* Low frequency demand reduction
* Other signal dependent demand reduction schemes
* SCADA modeling
* Levels of display (substation, system etc.)
* Automatic Excitation Control Systems
* Speed Governing Systems

* Turbine Boiler Systems

* Automatic generation control(AGC) with tie-line frequency and economic dispatch

* EMS applications, such as contingency analysis, unit commitment, demand prediction, security analysis, voltage stability assessment

### 2.2.1 Control System Models

Major primary automatic feedback control systems in a power system are:

* **Automatic Excitation Control Systems** controlling reactive power flow in the system. Additionally, they have considerable contribution in improving the stability stability of the system during large disturbances.

* **Boiler Turbine Governor Systems** controlling the active power generation in the power plants.

#### 2.2.1.1 Automatic Excitation Control Systems

Two different IEEE Type Automatic Voltage Regulators have been included in the present simulator as shown in Fig. 2.1 and in Fig. 2.2.

Any one of these AVRs can be attached to any one of the generating units. The data files for these Automatic Excitation Control Systems are given in the Appendix.

#### 2.2.1.2 Boiler Turbine Governor Systems

For speed governing purpose models of one hydro-governor and one thermal governor are included as shown in Fig. 2.3 and in Fig. 2.4.

The data files for these Automatic Excitation Control Systems are given in the Appendix.

The following turbine models are available in this simulator as shown in Fig. 2.5,in Fig. 2.6 and Fig. 2.7.

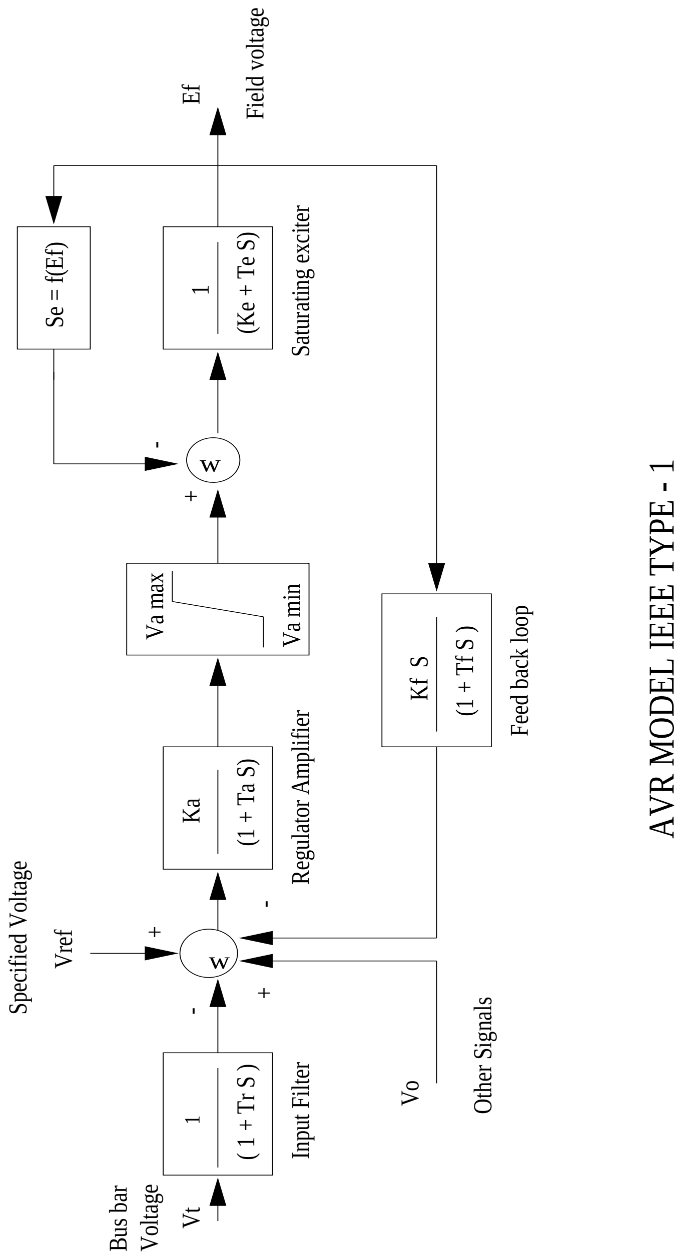


Figure 2.1: IEEE TYPE-1 AVR

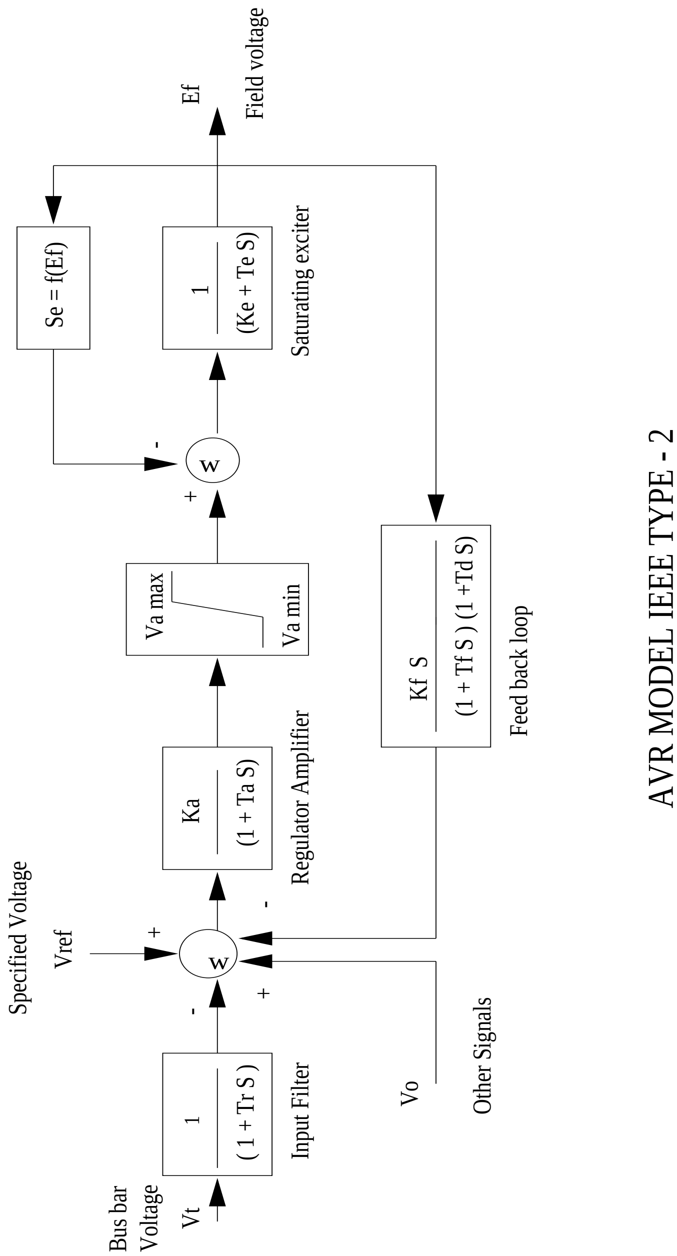


Figure 2.2: IEEE TYPE-2 AVR

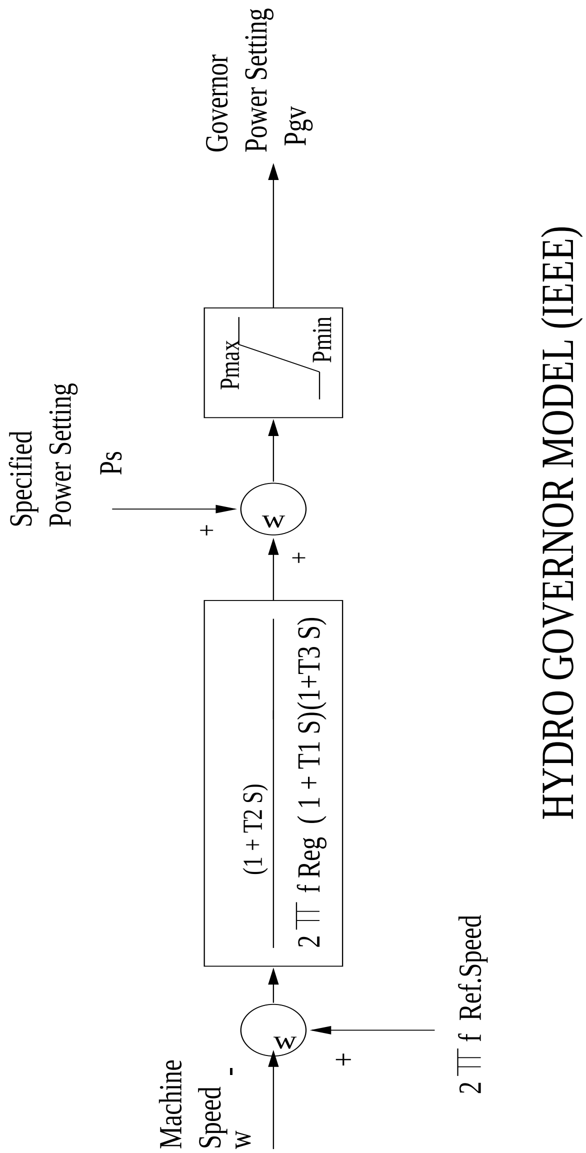


Figure 2.3: IEEE TYPE Hydro-Governor

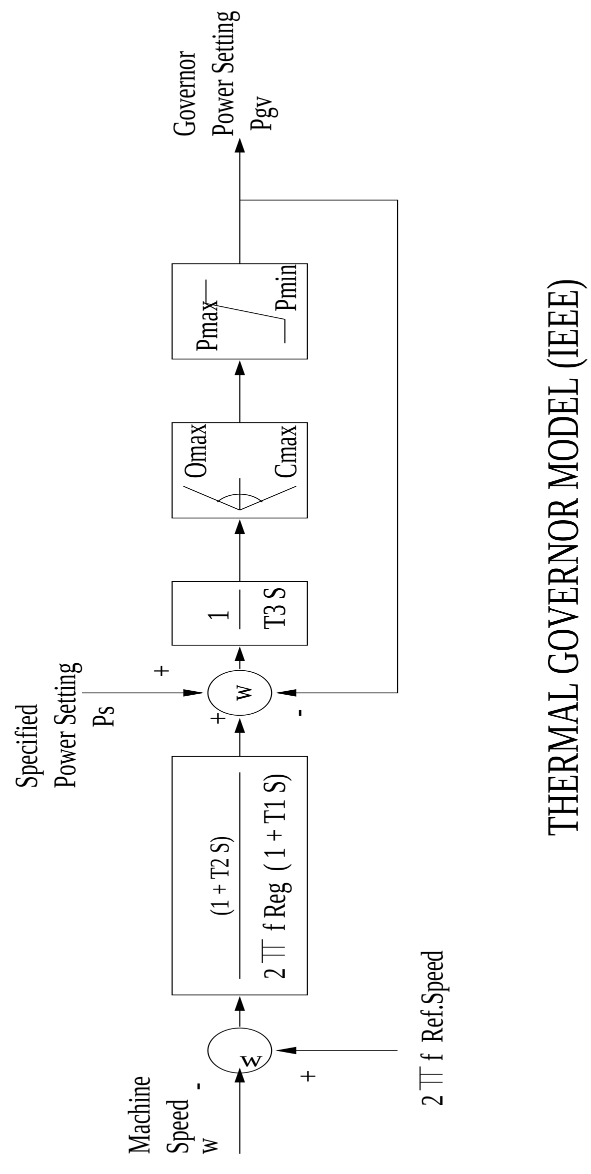


Figure 2.4: IEEE TYPE Thermal Governor

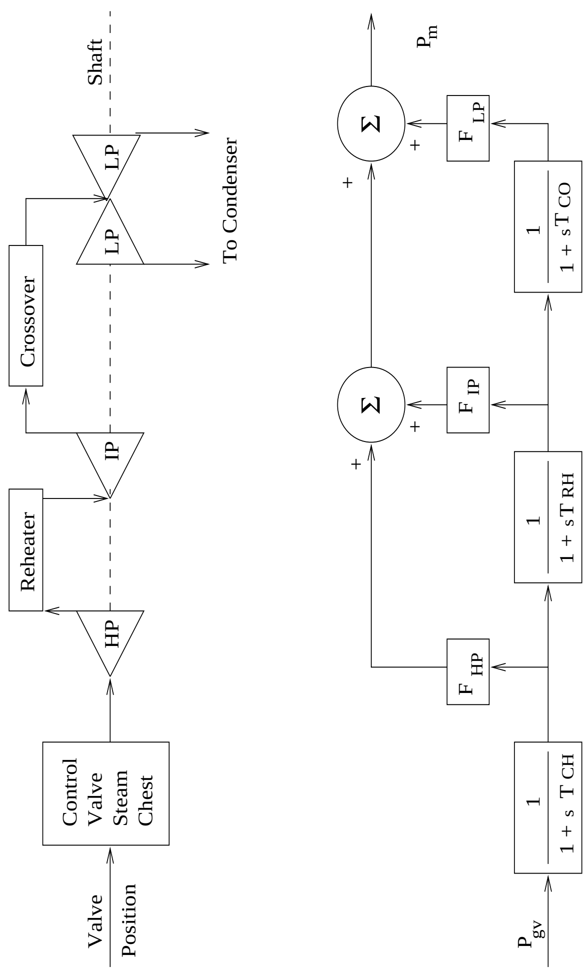


Figure 2.5: IEEE TYPE Single Reheat Turbine System

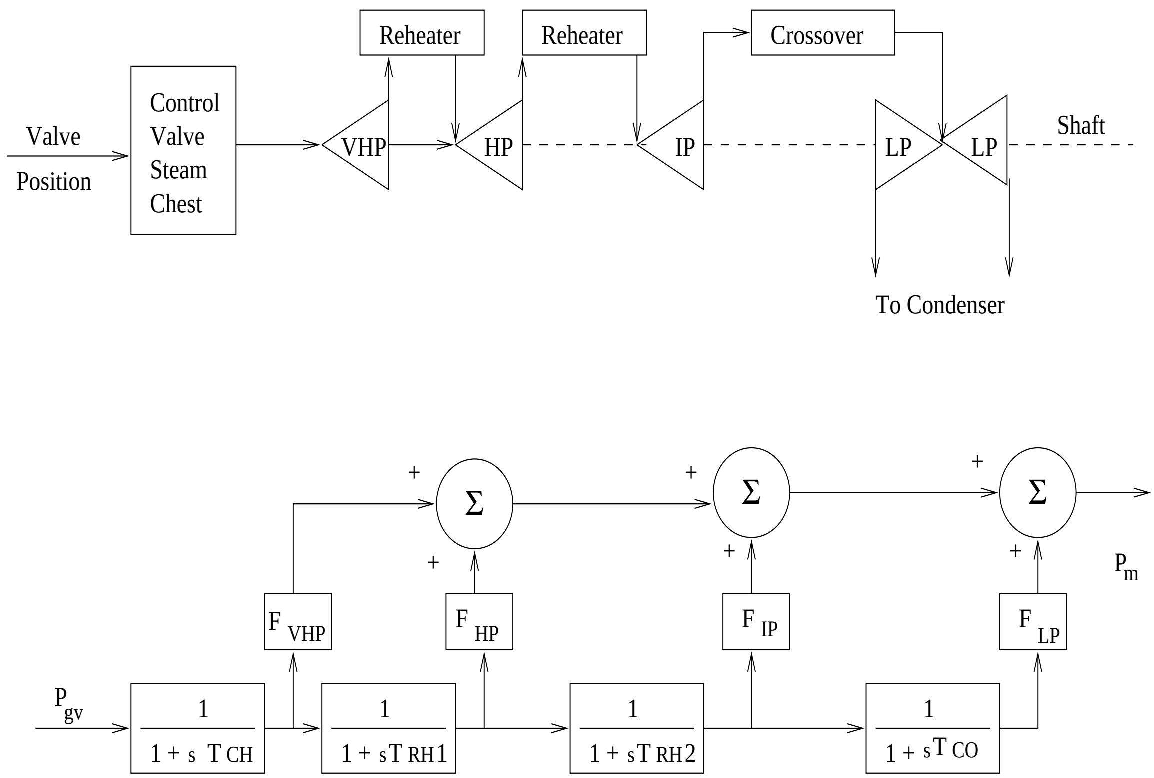


Figure 2.6: IEEE TYPE Double Reheat Turbine System

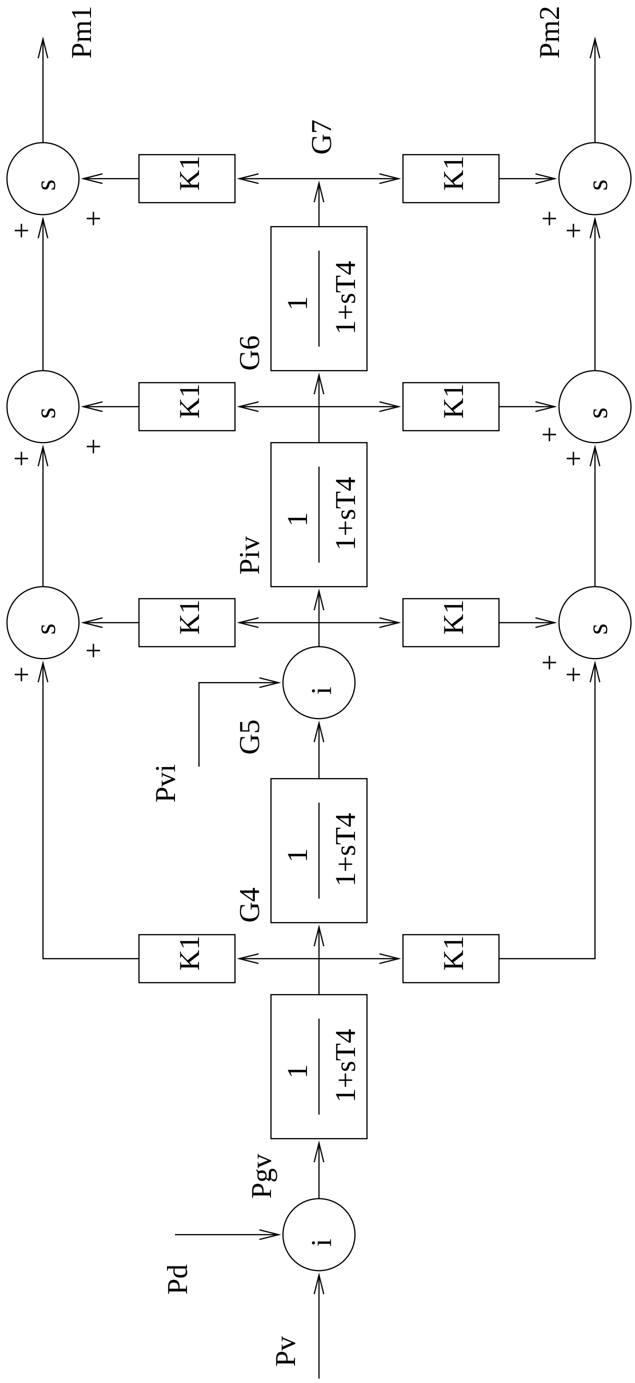


Figure 2.7: IEEE TYPE Cross Compound Turbine System

The data files for these Automatic Excitation Control Systems are given in the Appendix.

#### 2.2.1.3 Automatic Generation Control(AGC)

A power system can have three levels of automatic control for regulating the individual generator output:

* **Primary Control(Governor Droop Action)**

* **Secondary Control(AGC)**

* **Tertiary Control(On Line Economic Despatch)**

**Primary Control**

Primary Control is proportional and local to each generating unit. There always is a small frequency error.

**Secondary Control**

This is integral control with the control logic generally performed external to the power station at the energy control centre. Secondary control is superimposed onto the Primary Control, to eliminate the residual error left by the governor droop action.

Although AGC is a supervisor of the generator load set point it should not interfere with the Primary Control function.

**Tertiary Control**

Tertiary Control(Economic Despatch) acts as a supervisor of the AGC for economic operation. This third level of control computes the economic participation factors of the units under AGC control in order to maintain the most economic operation possible.

**Functions of Automatic Generation Control(AGC)**

AGC is used to achieve one or more of the following objectives:

* Maintenance of system frequency and time error

* Regulation of real power interchange with interconnected authorities

* Allocation of generation among individual units

* Interface with economic load despatch program to provide global dynamic economic despatch

* To provide security of transmission, through the control appropriate generator outputs, to constrain within specified values to power flow on the lines between regions

* Ramp a unit up and down to a specified value

The schematic diagram of Automatic Generation Control(AGC) is shown in Fig. 2.8.

#### 2.2.1.4 Dynamic Model of Static Var Compensator

Static Var Compensator is a localized automatic control mechanism that control the reactive power output of the compensator based on the local voltage variation. The modeling of the compensator for static load flow purpose has already been described in Volume - I of the Users' Manual. The block diagram in Fig. 2.9 shows the dynamic model of the compensator.

## 2.3 Simulation of Real Time Operation

The simulation of real time operation essentially replicate the EMS environment by updating different data at different time intervals. The complete solution of all the application modules are to be completed within the interval in between the two display updating.

### 2.3.1 Updating of Display

In this simulation package the following time intervals for updating the variables have been used:

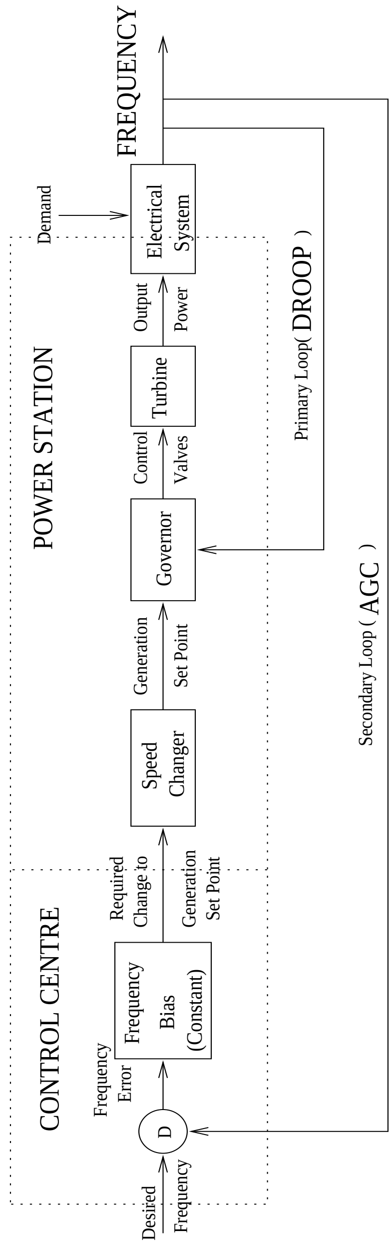


Figure 2.8: Automatic Generation Control(AGC

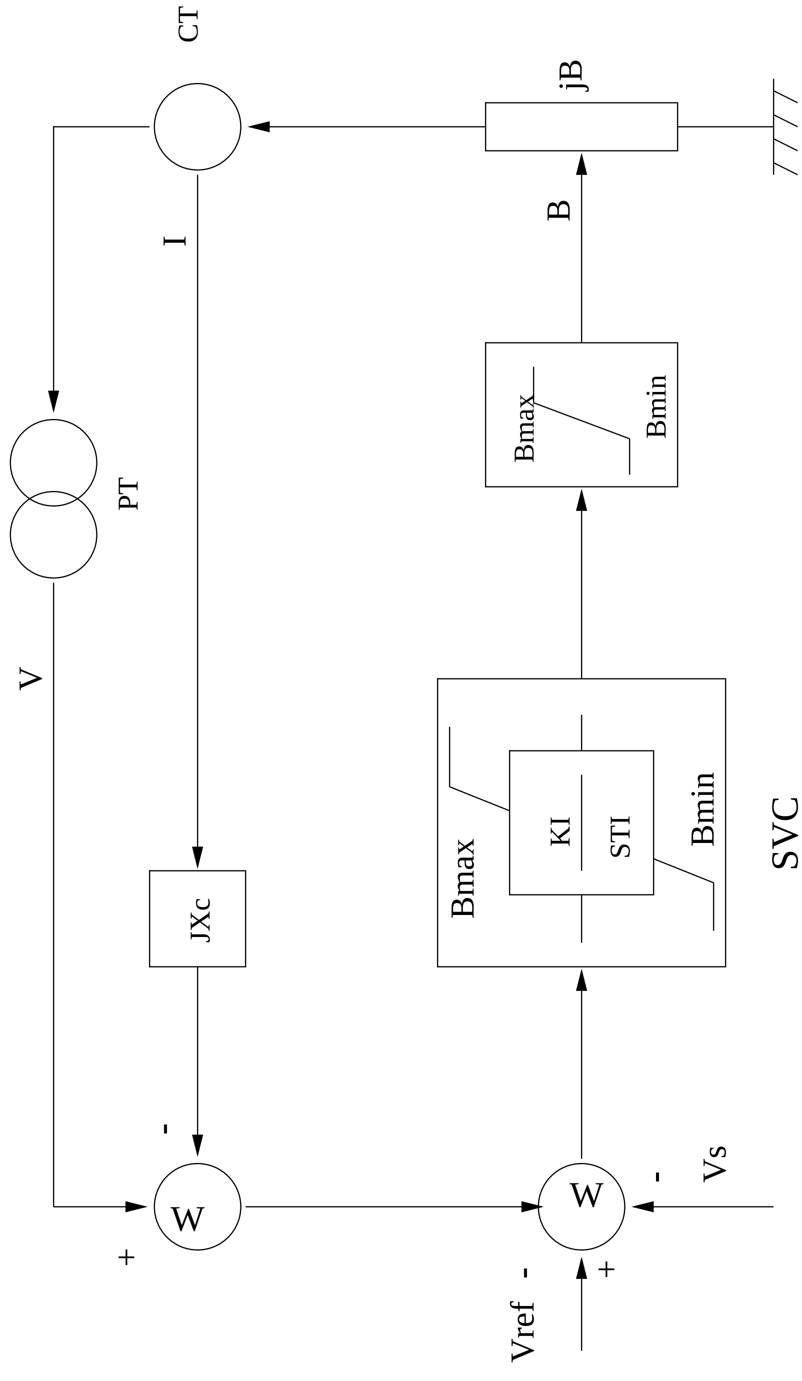


Figure 2.9: Dynamic Model of Static Var Compensator

**Network Variables ....................... 10 seconds**

**Frequency and other dynamics ..... 2 seconds**

Among the network variables the busbar voltage magnitudes are displayed on the single diagram along with busbar names. For displaying the line flows, generator outputs, shunt loads etc. corresponding Dialog boxes are to be used as explained earlier.

Among the dynamic variables the system frequency is displayed in the Information Menu bar and is updated every two seconds.

### 2.3.2 Preparation for Simulation

For running the Real Time Simulator certain preparations are necessary. There are three types of preparation:

* Preparation of necessary data and other information

* Scenario Building

* Initialization of the solution process

## 2.4 Preparation of Data

Real time simulation requires a large volume of data which are stored in the form of data files. These data files may be classified into three different sets:

* Data files relating to network of the system such as Filename.pdt and Filename.pdg.

* Data files relating to operational characteristics of the system over the time horizon of simulation such as Filename.pdl, Filename.pdu etc. as explained in Unit Commitment Schedule.

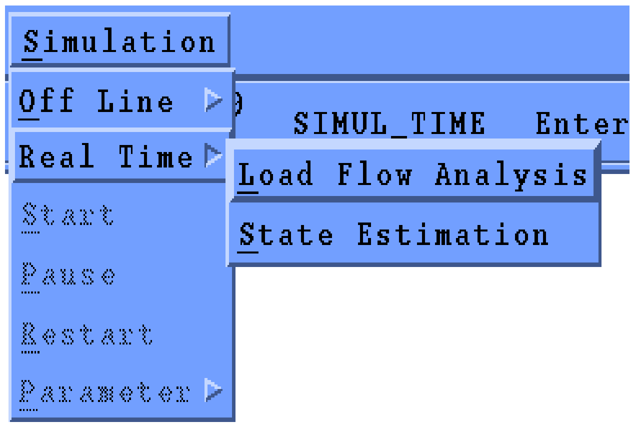


Figure 2.10: The Simulation Submenu

* Data files relating to simulation of dynamic systems such as Boiler, Turbine, Speed Governing System, Automatic Generation Control, , Load Modeling, power system stabilizer etc.

After opening a single line diagram in the main drawing area, if you take the cursor to the Main Menu Bar and press on 'Simulation', a new Dialog Box will be displayed with option for running 'Real Time' or 'Off Line' studies as shown in Fig. 2.10.

This Dialog Box has the following options:

**Off Line**

**Real Time**

**Start/Stop Simulation**

**Pause**

**Restart**

**Parameters**

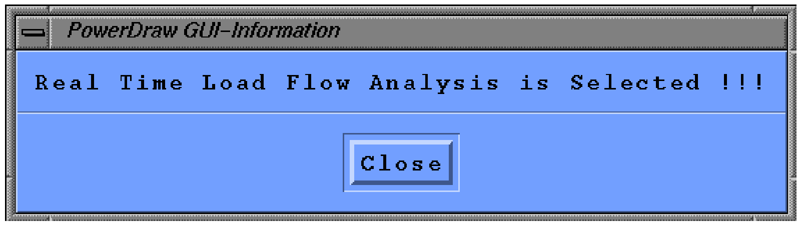


Figure 2.11: Load Flow for Real Time Simulation

For running the real time simulation engine you take the cursor to the option 'Real Time' and press the left mouse button. At that stage two alternatives will be displayed:

**Load Flow Analysis**

**State Estimation**

Since in this particular case the real time simulation engine is run in virtual reality without connecting it to a real time data acquisition system, you select the 'Load Flow Analysis' option. Immediately a small window will confirm that Load Flow Analysis has been selected as shown in Fig. 2.11.bf Close that window by clicking at the 'Close' button at the bottom of the window.

Before starting the real time simulation you have to arrange for all the data files. This is done through invoking the 'Parameters' options in Fig. 2.10 . When you click it with left mouse button, two options are shown:

**Set ....**

**Saved Case**

### 2.4.1 Saved-Case Data Files

The first option means that you have to set the real time operation parameters while the second option means that these parameters have already been

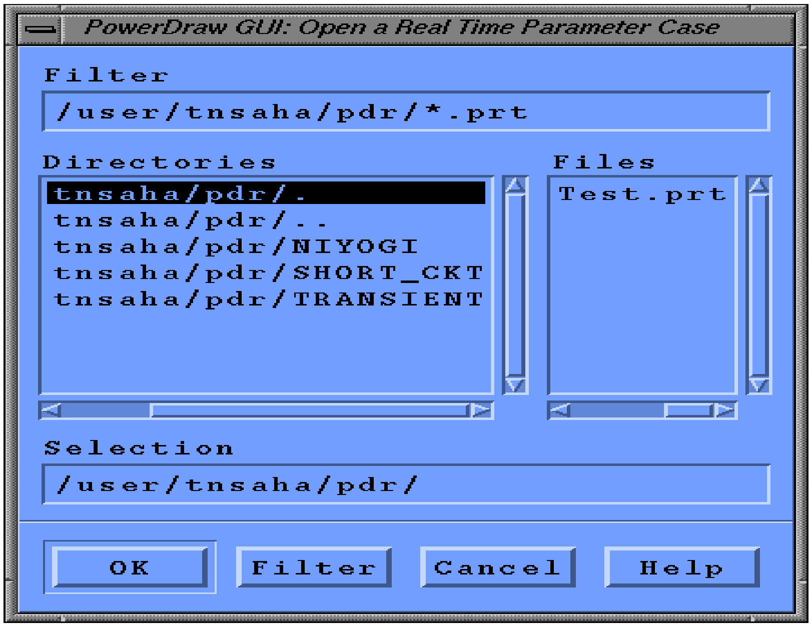


Figure 2.12: Saved Files for Real Time Operation

set and saved through 'Set' procedure in a file called 'Filename.prt' which can be used again. If you click at the 'Saved Case' option, a new FileSelection-Box which traverses through directories, subdirectories and views the files, appears on the screen for selecting the appropriate file. The FileSelectionBox is shown in in Fig. 2.12.

Among the files available in the file selection box you have to select the one that is appropriate for the system that is being studied. After selecting the file press the 'OK' pushbutton at the bottom of the FileSelectionBox. The file FileSelectionBox disappears appears and the Dialog box as shown in Fig. 2.13 appears. Take the cursor at the bottom of the Dialog box and press the 'Accept' pushbutton. The file is selected for its use for real time simulation.

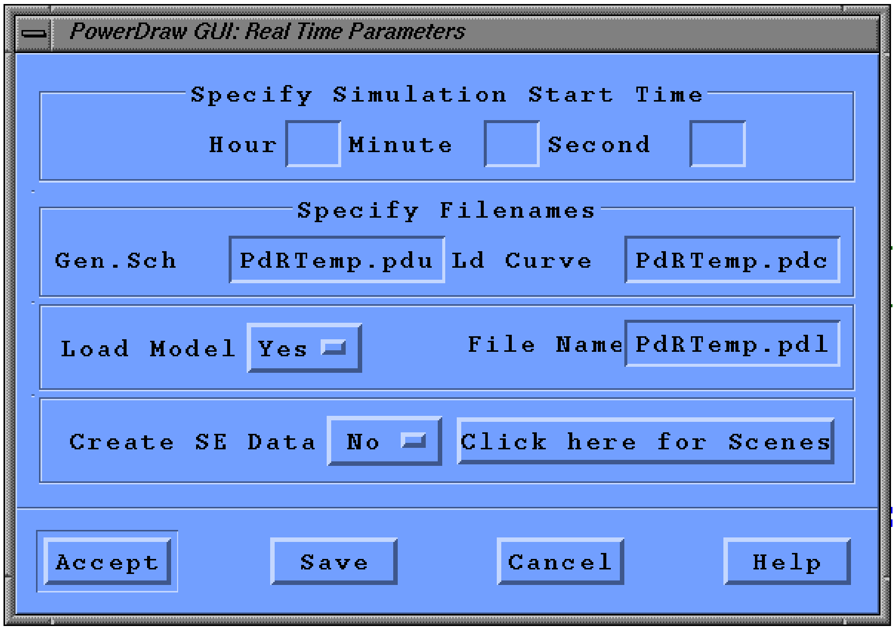


Figure 2.13: Setting of Real Time Parameters

### 2.4.2 Setting up New Data Sets

When you click on the 'Set' option another Dialog box is displayed on the screen for supplying different types of data. The Dialog box is shown in Fig. 2.13. As shown in the box, apart from supplying the simulation start time, there are three fields for supplying Filenames, two toggle buttons and another button for creating scenes.

**Simulation Start Time** This time relates to the point in the forecasted daily load curve from where the simulation will start. For example, you can start simulation of the system corresponding to 15.00 hours load condition in the daily load curve at any time of the day. The simulation engine will automatically pick up the load condition of the system corresponding to the specified time from the load curve.

The three filenames that are to be inputted relate to the following sets of data:

**PdRTemp.pdu** This is the file in which the output of Economic Generation Schedule program is stored.

**PdRTemp.pdc** This data file stores the 24 hourly load data obtained from Daily Load Forecast program.

**PdRTemp.pdl** This is an internally generated file and different data produced by running different programs are stored in it. The operator does not have any editing permission for this file.

**Load Model** can be included or excluded by toggling the button between 'Yes' and 'No'.

**Create SE Data** facilitates creating a data file for running State Estimation Program.

**Click here for Scenes.** When this button is pressed a new Dialog box appears for creating different types of scenarios as explained in the next Chapter.

While Economic Generation Schedule is an integral part of the real time operation program, Daily Load Forecast program is not. It is assumed that a set of 24 hourly or 48 half hourly forecasted load data are available.

The default file names corresponds to the system under study. If another system is opened in the Main Window then the filenames for that system will be shown in this window for 'Real Time Parameters'.

### 2.4.3 Functions of the PushButtons

At the bottom of all the Dialog Box shown in Fig. 2.13 for supplying data there are four PushButtons. Their functions are as follows:

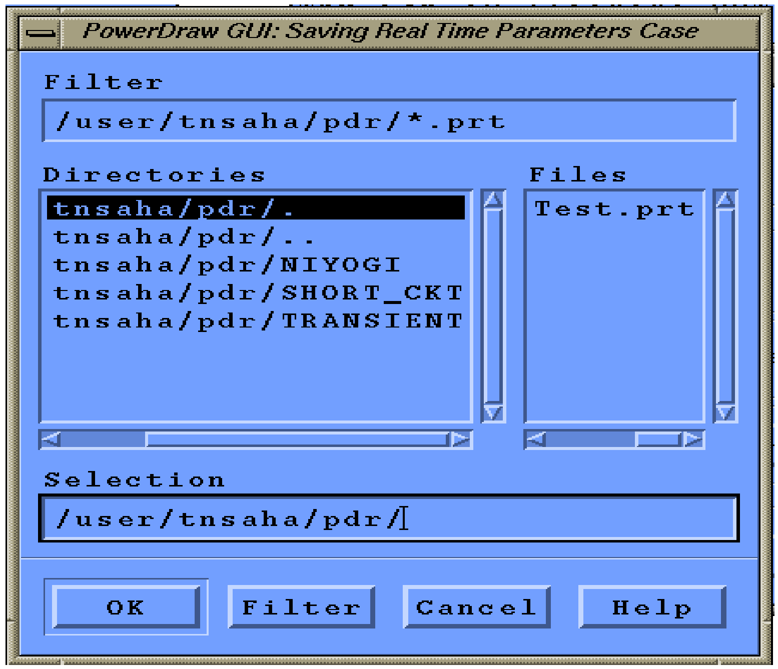


Figure 2.14: Saving Real Time Parameters

**Accept** When you push this button, data in the Dialog Box are accepted for the present study.

**Save** This button when pressed, saves the data into a file to be specified by the user.

**Cancel** Activating this button discontinue the current process of supplying data and removes the Dialog Box.

**Help** This pushbutton, when pressed, brings out the help messages in a separate window.

After supplying all the necessary data you press either the 'Save' or the 'Accept' button. If you press the 'Save' button, another window will appear for inputting the filename for saving the data as shown in Fig. 2.14.

After you have supplied the filename for saving the data and press the 'OK' PushButton, the dialog box disappears. Now you press the 'Accept' button in the in the dialog box as shown in Fig. 2.13. The data are selected for their use for real time simulation. At the same time the dialog box disappears from the screen.

The procedures for creating scenarios are described in the next Chapter.

# Chapter 3

# Scenario Building for Real Time Simulation

## 3.1 Introduction

A scenario consists of a base case and events that occur during the course of the training session. The base case of the scenario defines the starting time and state of modeling and control sub-systems including loading conditions, list of available and committed units, individual unit generation outage schedules for maintenance, loadflow of the network and exchange with with neighbouring utilities etc. The base cases can be constructed by the instructor or it can be a snap-shot of the EMS data. To define the course simulation a load-curve and distribution factors for individual bus load are needed as well as a list of all events that are not initiated by the trainee or the instructor.

Building of scenarios that simulate perturbations in the system operating conditions with different degrees of severities is an extremely complex process. The person or persons creating the scenarios must have a thorough knowledge and understanding of the operation of the system for which the scenarios are being created and also must have an idea of effects these scenarios are likely to create in the system.

Normally creating scenarios is the task of the instructor who is going to introduce the fresh operating engineer trainees to the system.

The degree of details of the scenario depends on the models used in the power system simulation software. For building and maintenance of scenarios some tools are of help. The scenario editor is a basic tool.

There are two ways of scenario building:

**Scenario Building in Advance** In this case scenarios are built in advance before starting the real time simulation.

**Interactive Scenario Changes** In this case scenarios can be created instantaneously when real time simulation is going on through interactive process.

## 3.2 Predefined Scenarios

When you take the cursor to the button 'Click here for Scenes' press the left mouse button, a separate Dialog box is displayed for creating scenarios. This Dialog box is shown Fig. 3.1.

Fourteen different types of individual scenarios can be created with the help of this Dialog box. With suitable combination of these individual cases a large number of practically realizable scenarios can be created. These individual scenarios are:

**1 Change in Load**

**2 Change in Pset Value**

**3 Change in Shunt load**

**4 Change in Feeder/Transformer Data**

**5 Change in Phase Shifter Data**


Figure 3.1: Setting of Real Time Scenarios

**6 Change in Control Bus data**

**7 Bringing back a generator**

**8 Tripping off a generator**

**9 Switching out a feeder/transformer**

**10 Switching in a feeder/transformer**

**11 Switching out a DC link**

**12 Switching in a DC link**

**13 Changing DC link power**

**14 Change in Governor Mode**

While the system is running in real time one or more of these scenes can be imposed into the system at any one or more than one operating time.

The general principle of creating these scenes is that when you place the cursor on any of these seventeen options and press the left mouse button, a Dialog Box corresponding to the nature of scene to be created appears on the screen. In these dialog boxes there are a few Text Fields shown in white background. These text fields must be filled up for the rest of the data to be accepted.

Each of these dialog boxes has three sections:

**Section 1** To be used for specifying the time when this particular scenario is to be activated.

**Section 2** Reference of the system element where changes are to created.

**Section 3** Details of the parameters that can be changed by typing for creating the scenario.

### 3.2.1 Functions of the PushButton

At the bottom of all the Dialog Boxes for creating scenarios there are four PushButtons. Their functions are as follows:

**Add** When you press this button, data in the Dialog Box are accepted and added to other scenarios already created.

**Val** If you press this button after typing the information required in the Dialog Box the present values of the parameters and the status is displayed in the Box. Also, if you have supplied some data and you are not sure whether you are correct, you can see the earlier data by pressing this button.

**Cancel** Activating this button discontinue the current process of supplying data and removes the Dialog Box.

**Help** This pushbutton, when pressed, brings out the help messages in a separate window.

Descriptions of each of the options are given below.

### 3.2.2 Changing Load at a busbar

The dialog box for changing load at a busbar is shown in Fig. 3.2.When you take the cursor to load bus and press left mouse button, the details of the busbar and current values of the active and reactive load is shown as in Fig.-3.3. You can only the active component or the reactive component or both. Load changes can be partial or total.

After making the necessary changes place the cursor on the pushbutton 'Add' and press left mouse button. The data will now be accepted for creating the scenario.

In case you have forgotten to specify the time for creating the scene and press 'Add' , then a small window will appear to remind you to specify the time as shown in Fig. 3.4

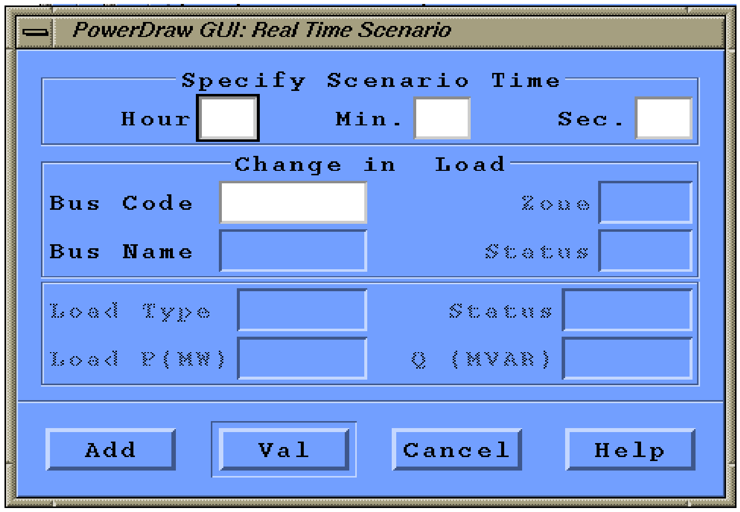


Figure 3.2: Changing Load in Real Time

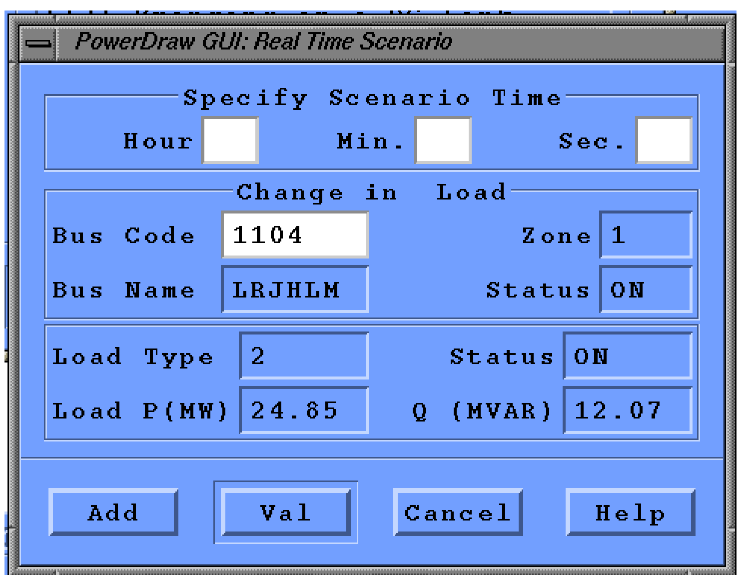


Figure 3.3: Details of Load at a Busbar

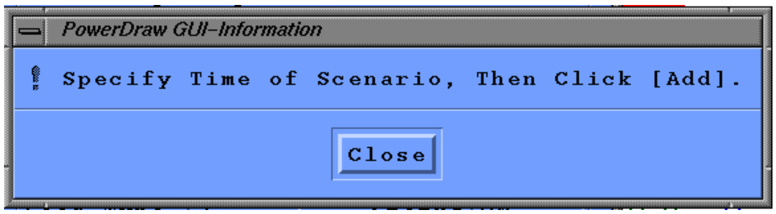


Figure 3.4: Message to input Scenario time

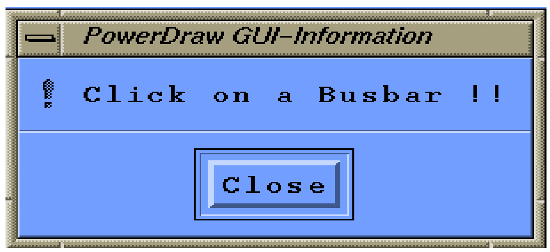


Figure 3.5: Message to click on a busbar

If your input data is not for the correct busbar you can always cancel the data by pressing the 'Cancel' push button and start afresh. In case you have, by mistake, clicked on something other than a busbar, an error message will be displayed to guide you to click on a busbar as shown in Fig. 3.5

You can then close the window and click on a busbar to supply data. You may change load at other busbars as well at the same time. Changes in load at a busbar is one of the simpler scenarios.

### 3.2.3 Changing Pset value of a generating unit

When a generating unit is working under free governor action, loading and unloading of the generator can be done by changing the reference setting of the governor valve known as the Pset value. While tripping out a generating unit makes a large changes in the input to the system, changes in the Pset values makes moderate dynamics in the system depending on the magnitude

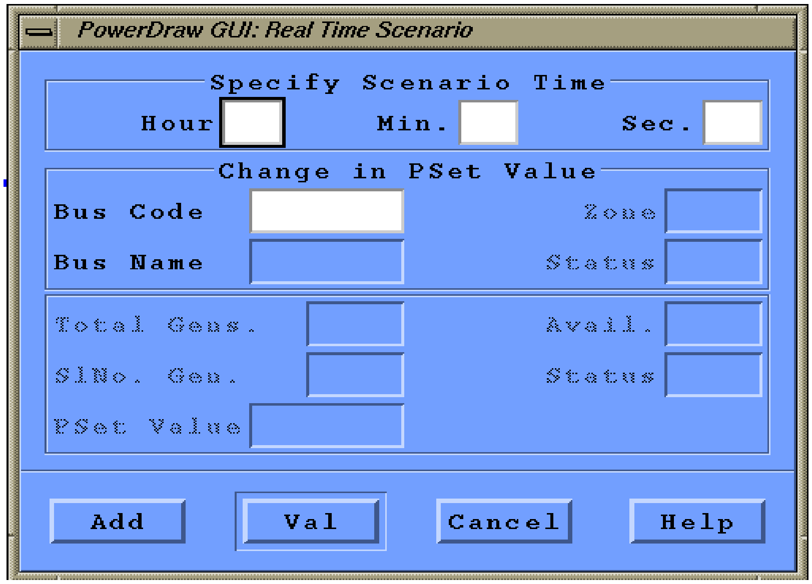


Figure 3.6: Changing Pset in Real Time

of the change.

The dialog box for changing the Pset value is shown in Fig. 3.6.

Then take the cursor to a generating icon and click with left mouse button. The details of the busbar along with the details of the power plant in term of number of units in the plant and the Pset value of unit no. 1 will be displayed as shown in Fig. 3.7. If you want to see the Pset value of any other generator, you type the serial number of the generator in the corresponding window and press the 'Enter' button on the key board.

In case you have, by mistake, clicked on something other than a generating icon, an error message will be displayed to guide you to click on a generator icon as shown in Fig. 3.8.

You can then close the window and click on the desired icon to supply data. You may change Pset values at other busbars as well at the same time. Changes in the Pset values are also simpler scenarios.

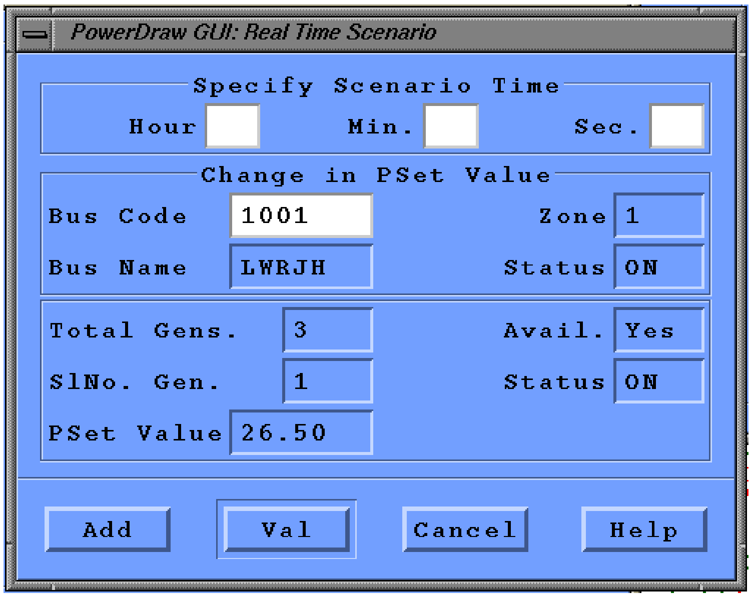


Figure 3.7: Current Pset value of a generator-1

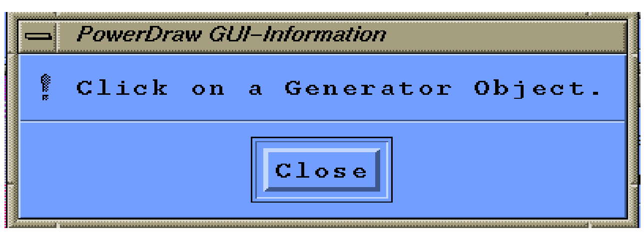


Figure 3.8: Message to click on a generator icon

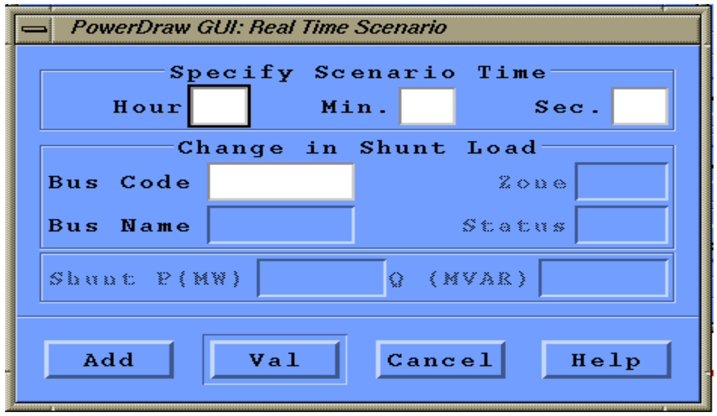


Figure 3.9: Changing Shunt Load in Real Time

### 3.2.4 Changing Shunt Load at a busbar

The dialog box for changing shunt load at a busbar is shown in Fig. 3.9.

Again take the cursor to a busbar having shunt load and click the left mouse button. The busbar details along with the magnitude of the shunt load will be displayed in the dialog box as shown in Fig. 3.10. You can change these values by new values.

In case you have, by mistake, clicked on something other than a busbar with shunt load, an error message will be displayed to guide you to click on a busbar having shunt load as shown in Fig. 3.11

### 3.2.5 Changing data of a feeder or a transformer

The dialog box for changing the data either of a transformer or of a transmission line is similar to the one used for supplying data at the time of building the data file as shown in Fig. 3.12.

If you now place the cursor on a transmission line and press the the left mouse button, the window gets enlarged and is filled up with data for that line as shown in Fig. 3.13.

If on the other hand you place the cursor on a transformer and press the

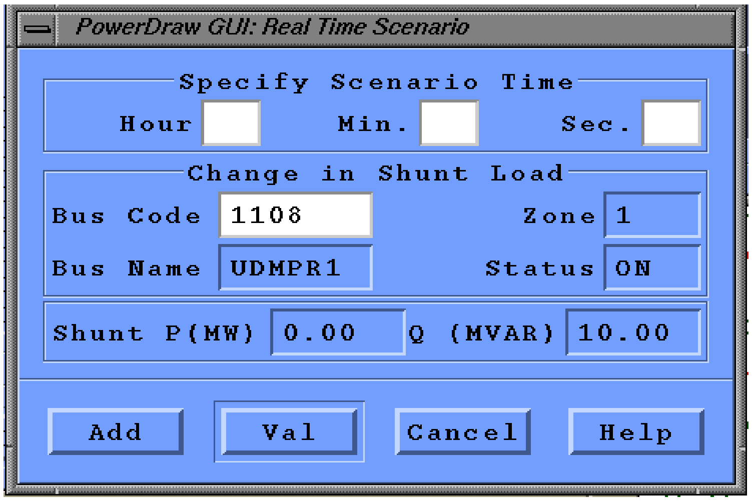


Figure 3.10: Current Shunt Load at a busbar

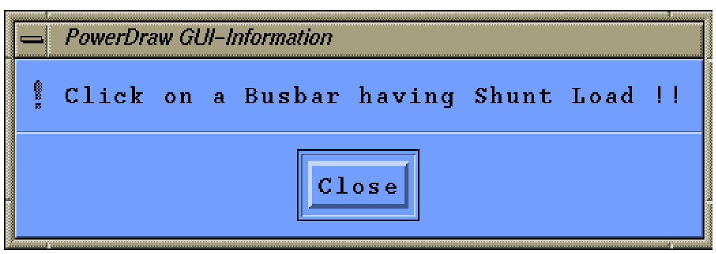


Figure 3.11: Message to click on a busbar Having Shunt Load

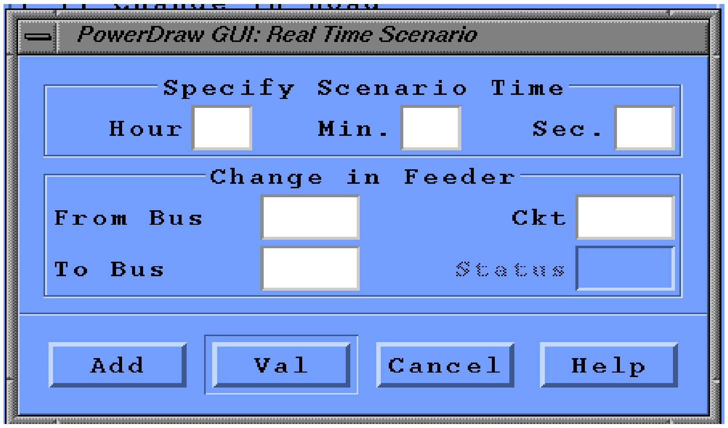


Figure 3.12: Changing Feeder Data in Real Time

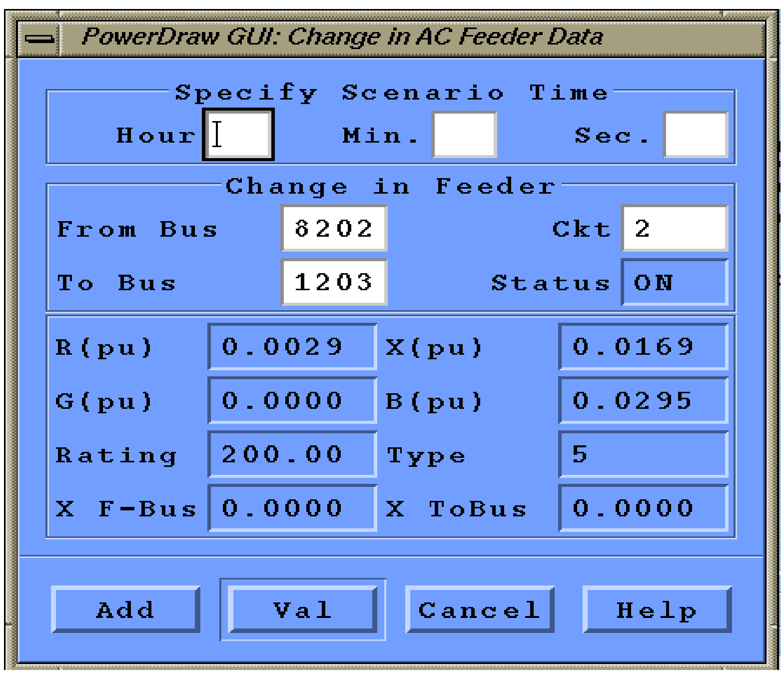


Figure 3.13: Current data of a transmission line

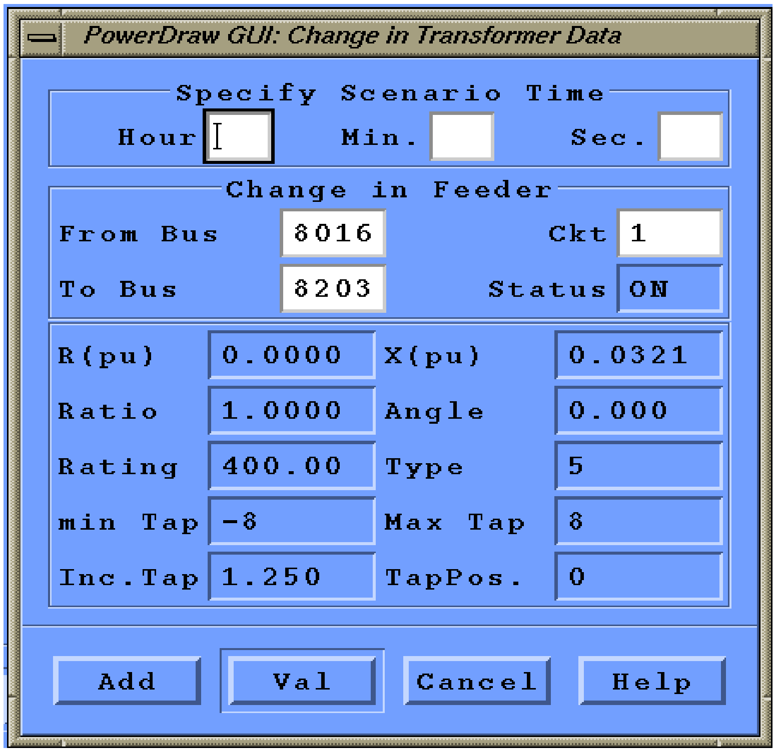


Figure 3.14: Current data of a transformer

left mouse button, the same window gets enlarged and is filled up with data for that particular transformer as shown in Fig. 3.14.

You can change any of the parameters in Section 3 of the window. The usual warning about giving the time of the scene apply here also.

### 3.2.6 Changing data of a Phase Shifting Transformer

The dialog box for changing the data of a phase shifting transformer is shown in Fig. 3.15.

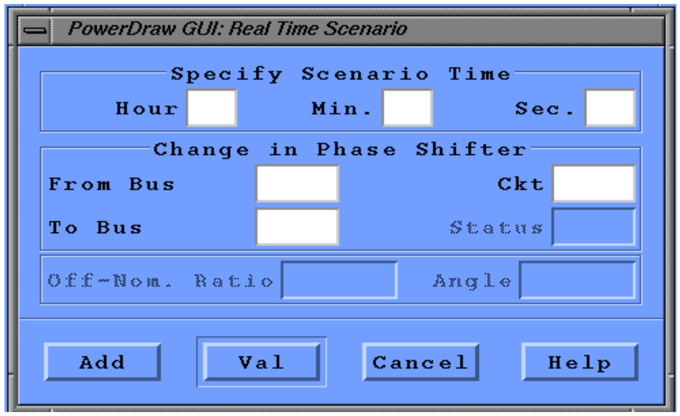


Figure 3.15: Changing Phase Shifter Data in Real Time

### 3.2.7 Changing data at a Voltage Control busbar

The dialog box for changing the data of a voltage control busbar is shown in Fig. 3.16.

To get the details of the voltage control busbar whose parameters you want to change, take the cursor to that busbar and press the left mouse button. the window will be filled by the current values as shown in Fig. **??**.

After making the necessary changes close the window by pressing the push button 'Add'.

If by mistake you have pressed on elements other than a voltage control busbar, a small window will appear to warn you that this is not a P-V busbar as shown in Fig. 3.18.

### 3.2.8 Switching in a generator in a plant

It is not necessary that in a power plant all the units should be in operation and supply power to the system. Normally, the unit commitment schedule is prepared on the basis of a predicted load curve. In real operation the actual load may deviate from the predicted value and it may be necessary to add additional generating units to supply the extra load.

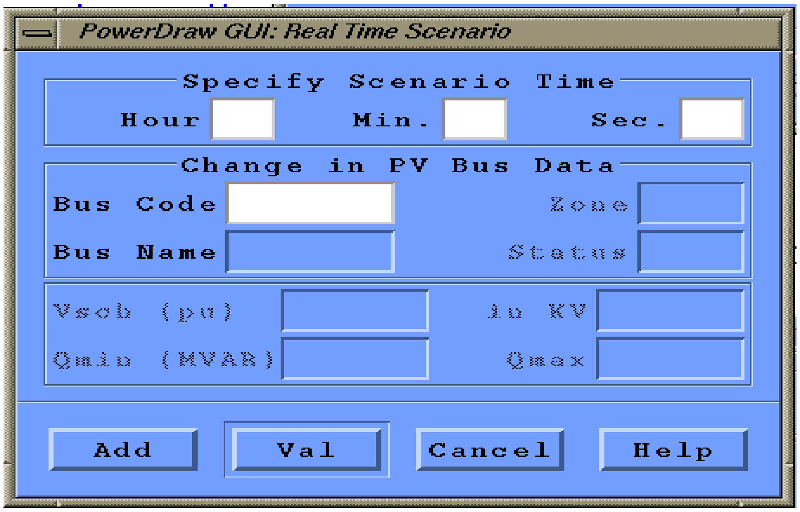


Figure 3.16: Changing P-V bus data in real time

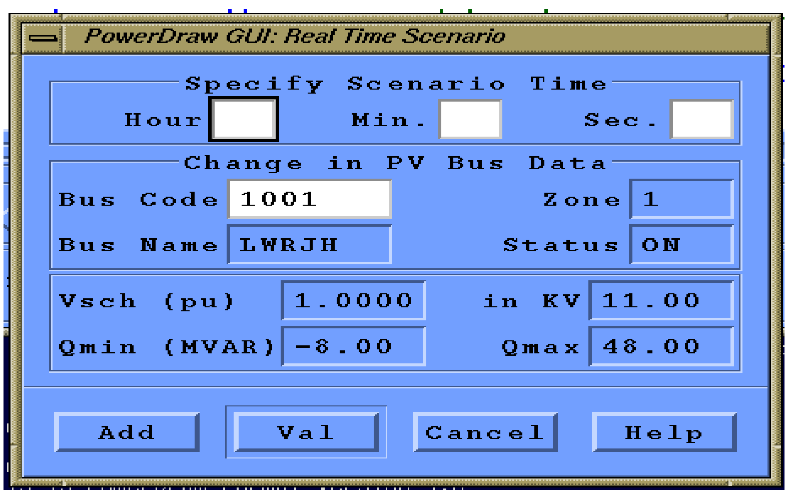


Figure 3.17: Current Values of P-V bus parameters

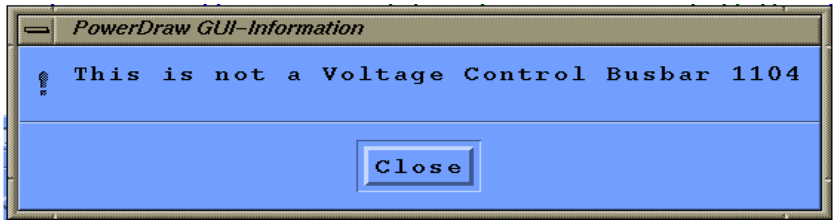


Figure 3.18: Warning to click on a P-V busbar

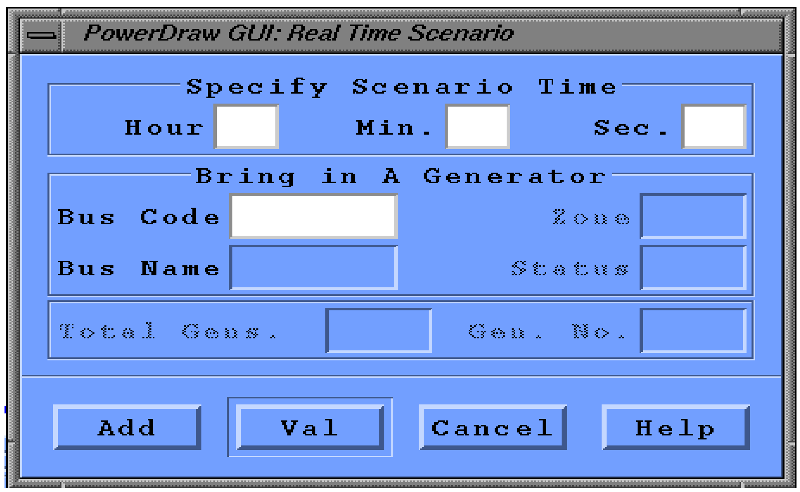


Figure 3.19: Switching in a generator in Real Time

The dialog box for bringing in a generating unit is shown in Fig. 3.19. After specifying the scenario time take the cursor to the generator icon and press the left mouse button. The details of the power plant is now displayed as shown in Fig. 3.20.

You can now type the unit number that you want to bring in in the appropriate text window.

In case you have not clicked on a generator icon a warning message will be displayed as shown in Fig. 3.8.

You can switch in only any one of those generators that were not con-

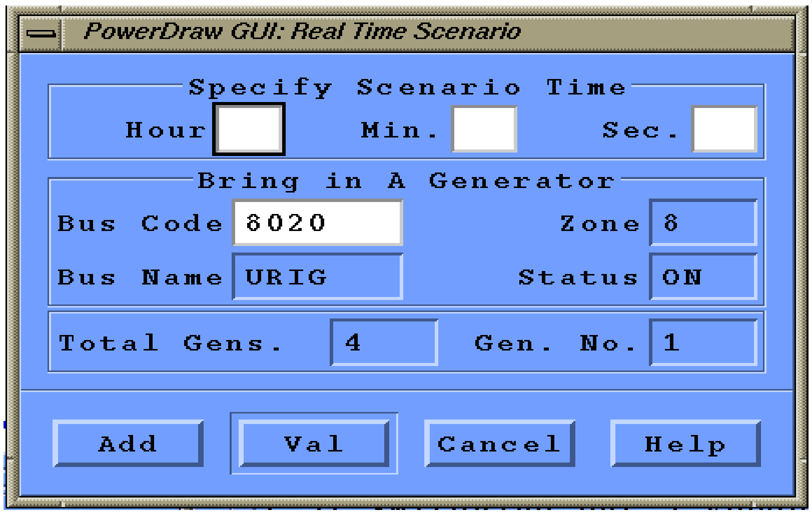


Figure 3.20: Current Generator status in the station

nected to the system earlier. And after bringing in a unit you have to change its Pset value to load the unit.

Once you have change the Pset value, the loading will be limited by maximum ramp rate.

### 3.2.9 Switching out a generator in a plant

For similar reasons as given for switching in a generator tripping out a generating unit becomes necessary.

The dialog box for switching out a generating unit is shown in Fig. 3.21. Data are to be supplied in the same way as in the case of bringing in a generator as shown in Fig. 3.22.

When you switch out a generator its output will suddenly become zero. So, for that particular generator this is a large disturbance.

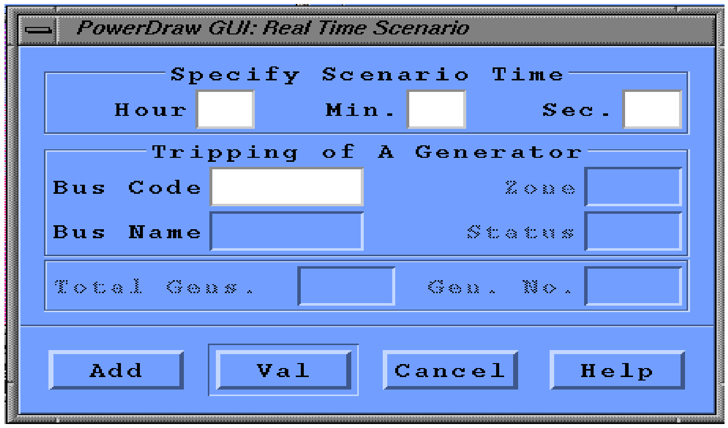


Figure 3.21: Tripping a Generator in Real Time

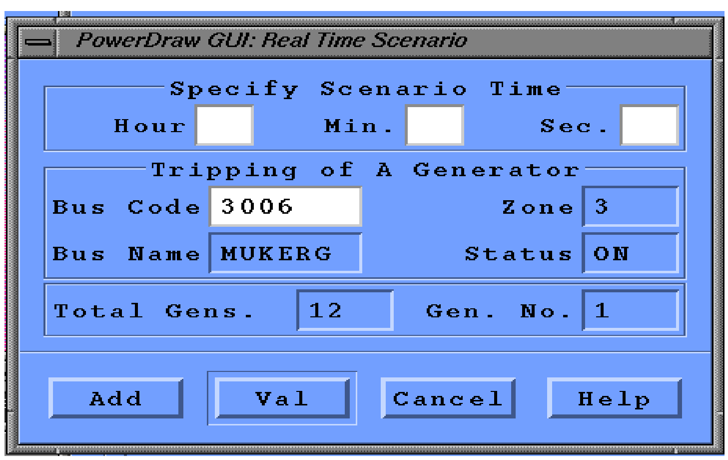


Figure 3.22: Current Generator status in the station

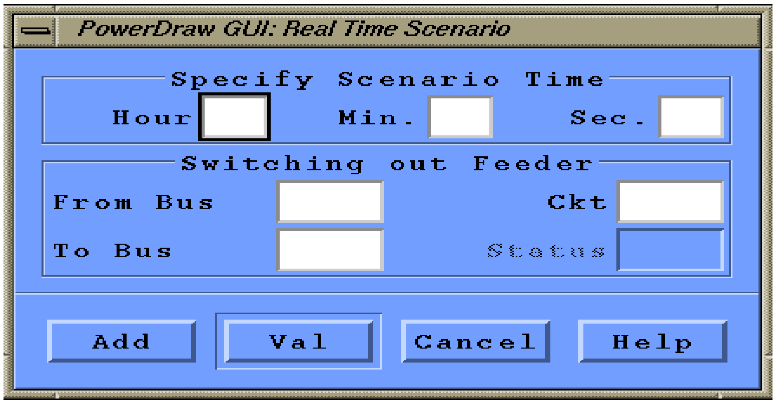


Figure 3.23: Tripping a Feeder in Real Time

### 3.2.10 Switching out a Transformer or a Line

Switching out a transformer or a transmission line may some time lead to very severe disturbances. While tripping out a lightly loaded line or transformer may not pose any major operational problem for the system, switching out a heavily loaded trunk line can create large disturbances such as line overload, voltage stability problem, even system segregating into different areas leading to system collapse.

Therefore one has to be careful about the intention of selecting the line to be tripped out.

The dialog box for switching out a line or a transformer is shown in Fig. 3.23. If you take the cursor to feeder or a transformer, the details are displayed as shown in Fig. 3.24. If you want to trip the feeder take the cursor to the push button 'Add' and press the left mouse button. Do not forget to specify the time when the feeder is to be tripped.

If, by mistake, you have clicked on something other than an AC feeder/transformer a warning message will be displayed to click on an AC feeder as shown in Fig. 3.25.

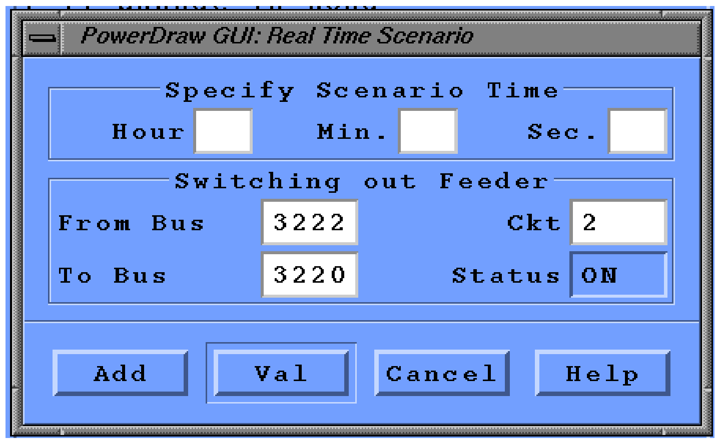


Figure 3.24: Details of the feeder to be tripped

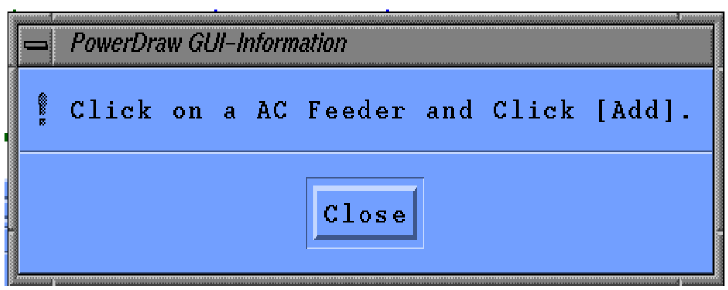


Figure 3.25: Warning to click on a AC Feeder

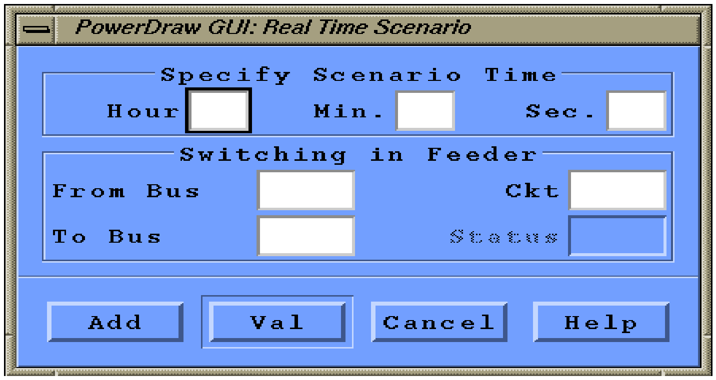


Figure 3.26: Bringing in a Feeder in Real Time

### 3.2.11 Switching in a Transformer or a Line

A transmission line or a transformer which was earlier taken out of the system, can be brought into the system with the help of the dialog box as shown in Fig. 3.26.

The procedure for bringing in a feeder or a transformer is similar to that described in the case of switching out a feeder or a transformer.

Connecting a feeder or a transformer is a much safe operation and this is likely to release overload conditions of other feeders and a transformers. However, one has to be careful about connecting a long EHV line to an unloaded generating unit. Due to the large amount of charging current the generating unit may be pushed to highly leading power factor region and thereby increasing the terminal voltage beyond limit.

### 3.2.12 Switching out an HVDC Link

A HVDC link cannot be switched out by the operation of circuit breakers. For any reason, either a fault in the link or anywhere in the dc system, the dc link can be taken out only after reducing the current flowing through the link to zero value by controlling the firing angle.

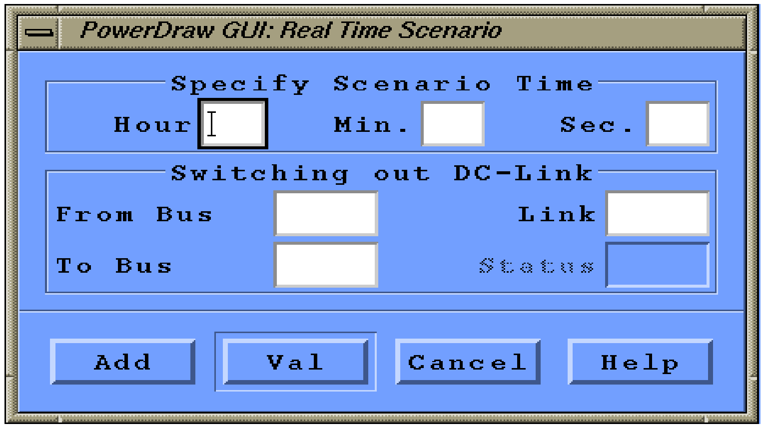


Figure 3.27: Switching out a HVDC Link

There are many implications of a DC feeder going out of operation. In a bi-polar system the other feeder load will get changed. If there are other AC feeders in parallel, their power flow will also change and may cause overloading. All these depend on the operational strategy of the system.

The magnitude of disturbance naturally depends on many other factors. It is interesting to assess the effect of such topological changes in the system.

The dialog box for switching out a HVDC link is shown in Fig. 3.27. When you take the cursor to the HVDC link and press the left mouse button, the details of the link is displayed box. You can then press the 'Add' push button to save the scenario data.

If by mistake you have pressed on elements other than a a HVDC link, a small window will appear to warn you that this is not a dc link and ask you to click on a dc link as shown in Fig. 3.28.

### 3.2.13 Switching in a HVDC Link

A HVDC link which was earlier taken out of the system, can be brought into the system with the help of the dialog box as shown in Fig. 3.29.

However, connecting a dc feeder does not necessarily means that power

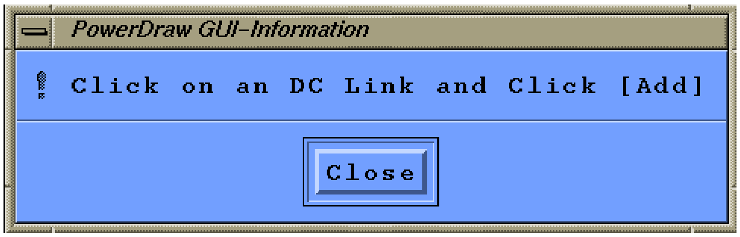


Figure 3.28: Warning to click on a DC Link

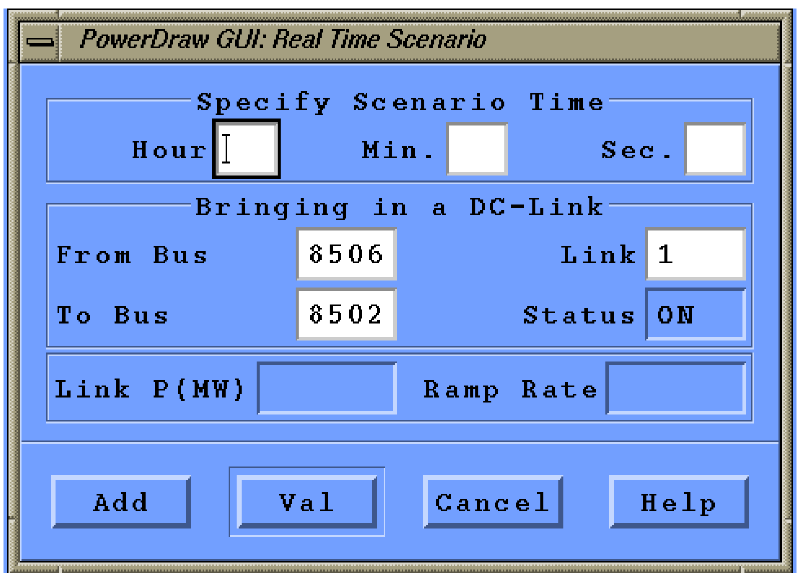


Figure 3.29: Switching in a HVDC Link

will start flowing through the feeder. When the feeder was taken out its controlling parameters were so set that the power output was reduced to zero value as explained above. Therefore, those parameters are to be reset through the appropriate window before the feeder starts delivering power.

### 3.2.14 Changing Converter/inverter operation mode

As explained earlier there are four modes of converter/inverter operation. These are:

**Constant Power Mode — 1**

**Constant Voltage Mode - 2**

**Constant Angle Mode — 3**

**Constant Current Mode - 4**

Though changing the mode of operation from one to the other is not so simple, it is possible to change the mode when operational constraints demand.

The dialog box for changing the mode of operation is shown Fig. 3.30.

Following the procedure as above place the cursor on the converter/inverter icon whose mode is to be changed and press the left mouse button. The details of the complete converter/inverter unit is displayed in the window as shown in Fig. 3.31.

In the third section of the window you can first select the serial number of the converter/inverter whose mode you want to change. Then take the cursor to the button 'Op Mode'. When you press the left mouse button, the four modes of operation are displayed. You have to select the one that you intend the converter/inverter to operate on. Your selected mode will now be displayed against the button 'Op Mode'.

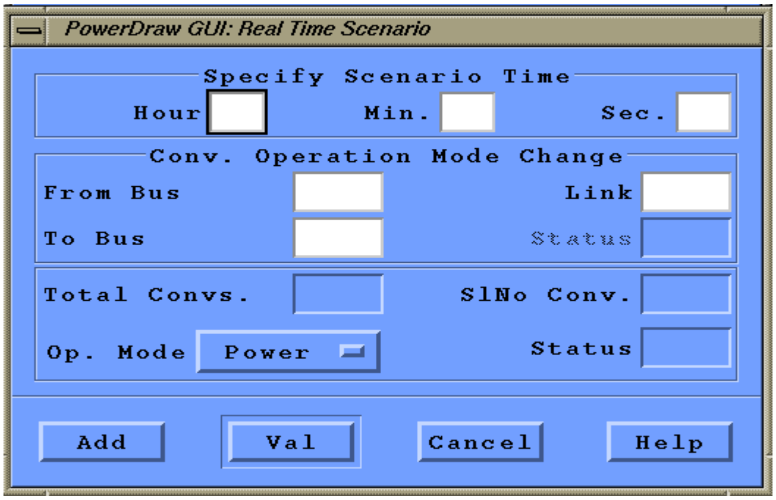


Figure 3.30: Changing Converter/inverter operation mode

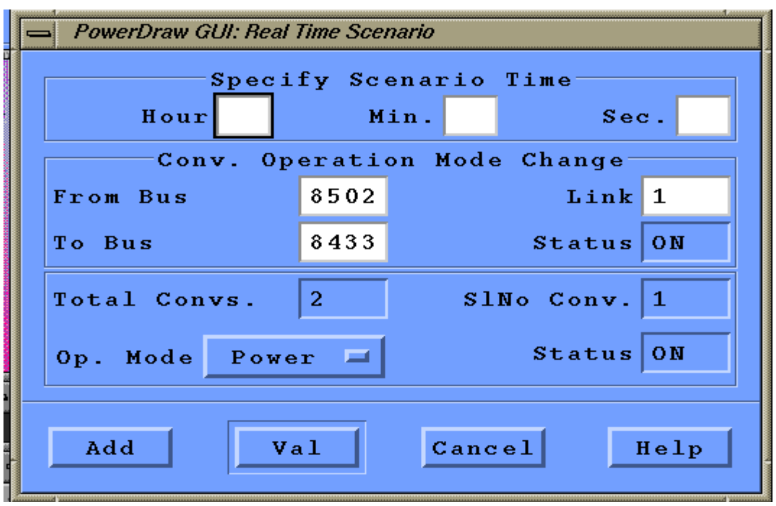


Figure 3.31: Details of Converter/inverter

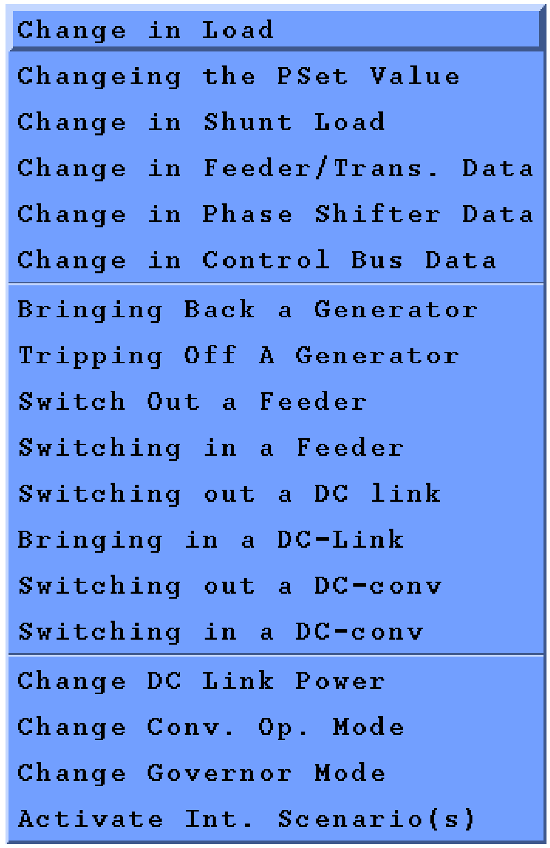


Figure 3.32: Interactive Scenario Building

## 3.3 Interactive Scenario Building

All the scenarios as described above can also be created interactively during the time when real time simulation is proceeding. If you take the cursor anywhere in the POWERDRAW screen and press the RIGHT mouse button a set of Shortcut buttons is displayed. These buttons have the same scenario building facilities as those described in the last Section. This set of buttons are shown in Fig. 3.32.

There are the same 14 scenario building facilities as described in last Section. Additionally, there is one button to 'Activate' the scenarios.

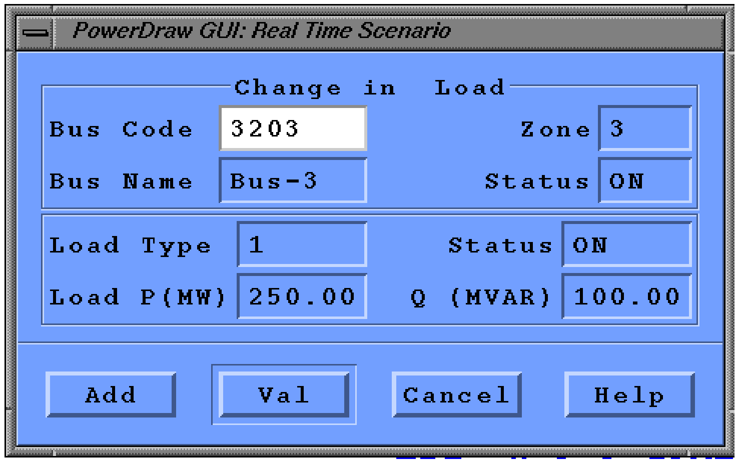


Figure 3.33: Changing Load in Real Time

When you take the cursor to any one of these buttons and press the left mouse button another dialog box appears for supplying the requisite data. For example, if you press the button for 'Change in Load', the Dialog box that appears is shown in Fig.-3.33.

There is an important difference between the Dialog box shown here and the one shown in Fig.-3.3. In the present Dialog box there is no space for supplying the time for activating the scenario. This is because that in the case of interactive scenario building the scenarios get implemented as soon as you press the button 'Activate'. These scenario building facilities have been specifically designed for the operator's intervention during certain contingencies for taking supervisory action to eliminate the possibilities of the system going towards emergency conditions. While the a-priori scenarios are created by the instructor for situations where he expects the trainee operators to respond for taking corrective measures, the interactive scenarios are for the trainees to take restorative actions.

Once the scenario building process is over you are ready for running the real time simulation which is described in the next Chapter.

It is to be noted that building scenarios is not an absolute necessity to simulate the system in real time. A system can run in normal conditions without any contingencies being imposed on the system.

# Chapter 4

# Running Real Time Simulation of Power System

## 4.1 Introduction

Having supplied all the data and created all the scenarios you are now ready to start the real time solution. For that take the cursor to the Simulation Menu and press the 'Start' option with left mouse button. Immediately, the process of initialization starts. It takes a few seconds to initialize all the static and dynamic variables. therefore the display of the variables are started after a few seconds from the start.

If, however, any of the necessary files or other information are missing, simulation will naturally not proceed correctly and corresponding information will be displayed in the screen. You have then to go to the simulation menu, which has now got modified as shown in Fig. 4.1, and stop the simulation process.

When real time simulation is proceeding normally, the operator simply observes what are happening in the system. Assume that the operator is in a Control System Centre of an interconnected power system which has a SCADA system connected to it. Through the Data Acquisition system the state of the system will be monitored and information will be displayed

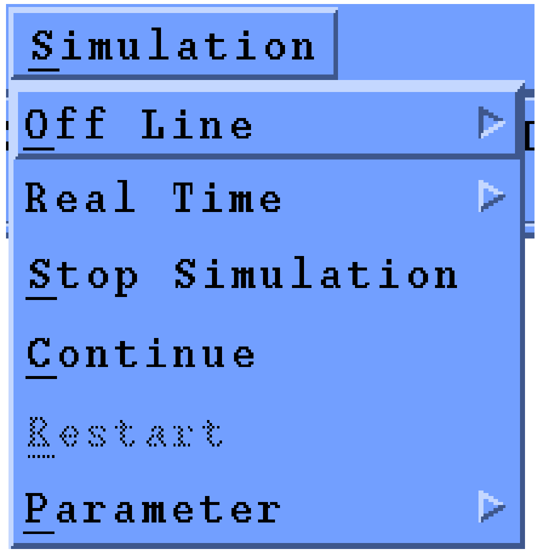


Figure 4.1: Modified Simulation Submenu

either on the wallboard diagram or on the monitor-screen at regular intervals. Generally, the following information are displayed at regular intervals:

**Major Substation Voltage Magnitude**

**Power Flow Through Transformers and Lines**

**Output of different Generating Units**

**Loads at strategic Points**

**Alarm Indications Regarding Overload Conditions**

**System Frequency**

There may be other useful information relating to the peculiarities of individual power system. These are generally monitored through the operator intervention. For doing sufficient dialog boxes have been arranged to view the results.

### 4.1.1 Display of Control Action

While the operator is monitoring the system, he will be provided with information for two types of control action.

#### Information regarding Automatic Control Action

#### Information regarding Supervisory Control Action

For example, tripping of a line due to circuit breaker operation subsequent to a fault is an automatic control action on which the operator has no function to play. Similarly, the operator can play hardly any role during tripping of load or generation by frequency sensitive relay. These information come to him as report.

On the other hand when certain equipment, whether it is a line or a transformer, gets overloaded the operator may have to take certain corrective action. These are information for supervisory action where the operator can play a crucial part in the performance of the system. During the peak hours he may have to take quick decision regarding the availability of total generation capacity.

This simulator has been designed to train the operator in simulating all these operational functions and to help him take decision at his own judgment.

## 4.2 Display of System State during Real Time Simulation

Unlike in the cases of Off-line studies where simulation results are displayed in a separate window, real time simulation is carried out in the main window as shown in Fig. 4.2.

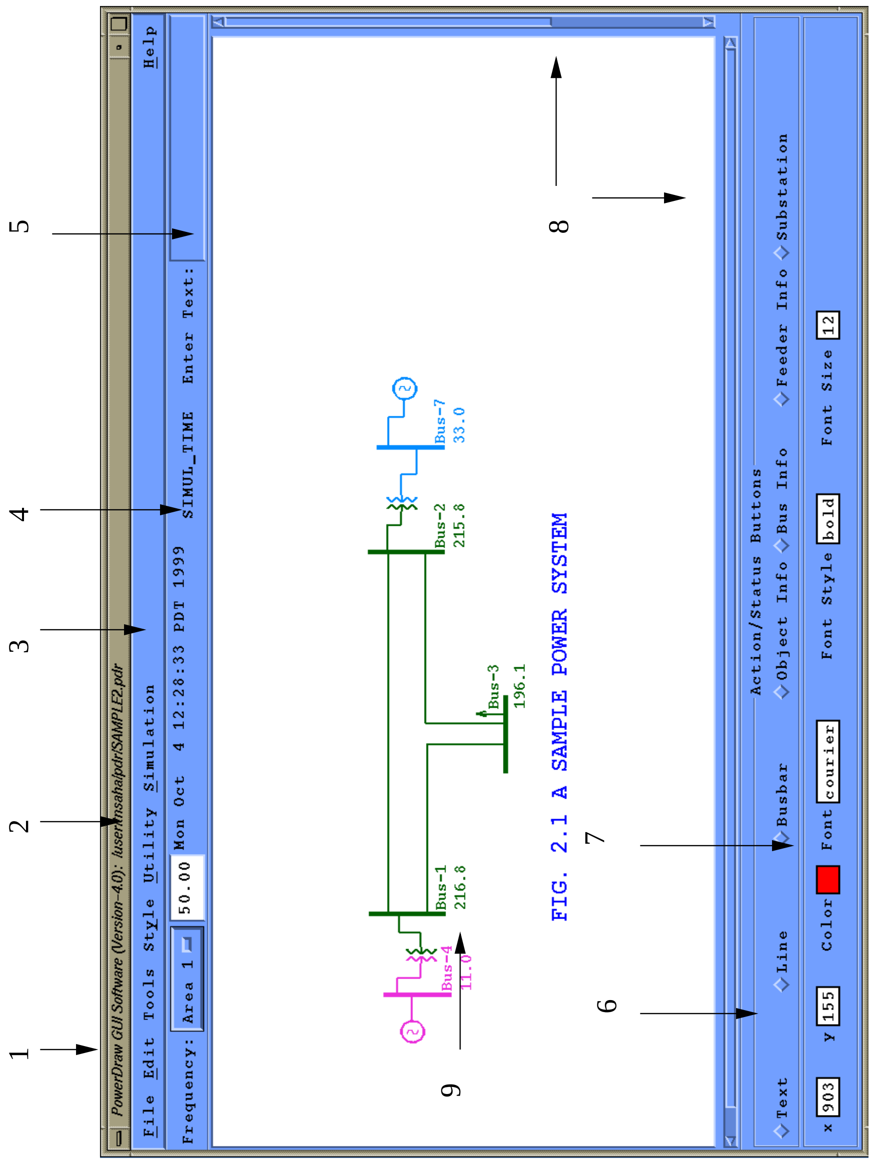


Figure 4.2: Powerdraw Main Window

### 4.2.1 Display During Normal Operation

In this window the busbar voltage magnitudes are updated every 10 seconds. Instantaneous frequency of the system is shown in the Frequency window. A part of the window with the display of results is shown in Fig. 4.3.

You can also monitor the details of individual busbars, feeders, transformers and generating units by utilizing the functions of:

**Bus Info**

**Feeder Info**

**Object Info**

'Action Buttons' respectively. The mode of using them has been described in Volume 2 of the Operator's Manual.

#### 4.2.1.1 Frequency Display

Additionally, frequency variation during the past 10 minutes is shown graphically in a separate window as shown in Fig. 4.4.

This frequency display is for a duration of 10 minutes. As soon as it comes to the end of the window, the graph is shifted by a five minute duration and the display continues.

#### 4.2.1.2 Text Window Display

If you are interested in monitoring any other variables such as line flows,shunt flows,inter-zonal flows etc. at any particular instant of time, you have to take the cursor to the 'Off Line' option of the Simulation Menu and press the left hand mouse button. This action takes a snap-shot of the system condition at that instant of time and utilize all the 'Text Window' display facilities available for 'Operator Load Flow' study as explained in Volume 2 of the Operator's Manual.

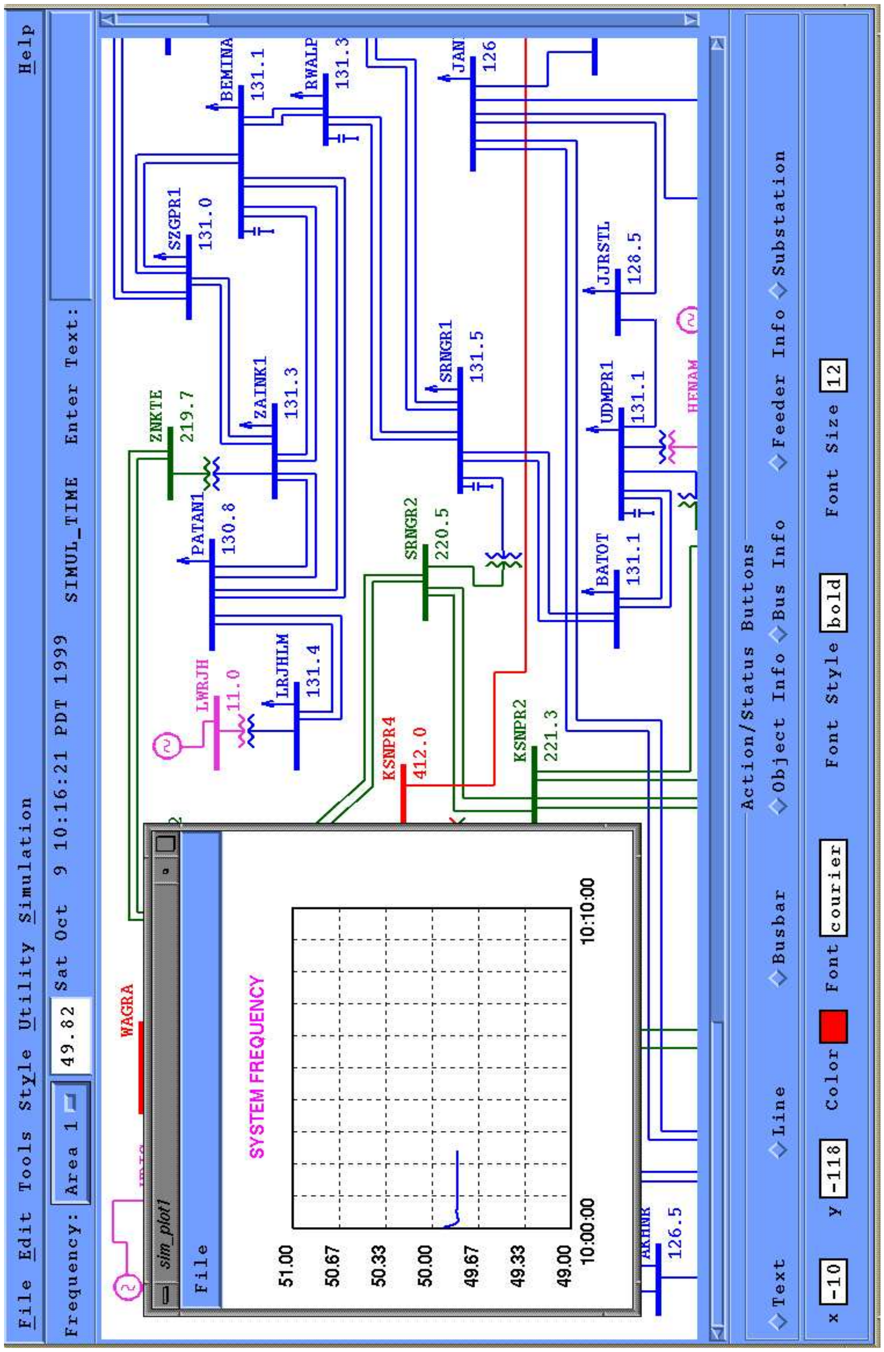


Figure 4.3: Display of Real Time Solution

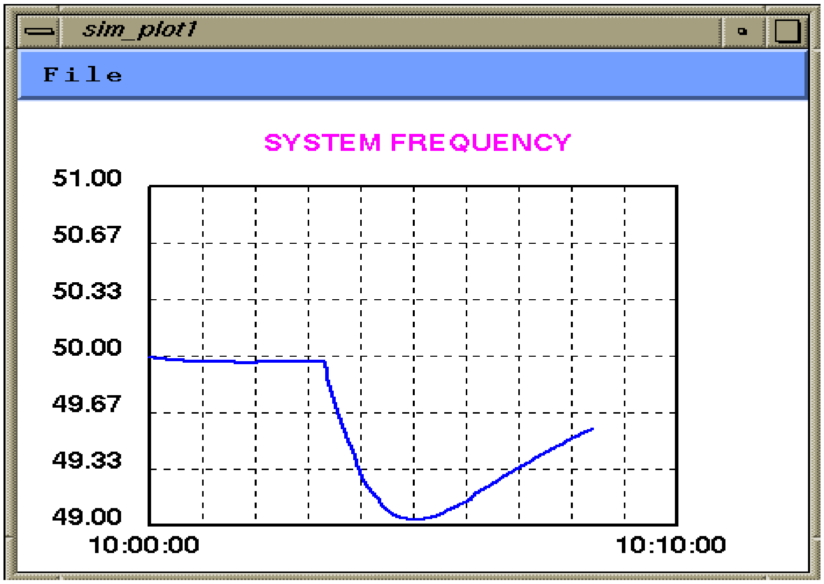


Figure 4.4: Record of System Frequency

The limit violation and overload conditions are displayed every 10 seconds on the screen. Information regarding any scenario action taking place or any automatic control action taken by the simulator are also instantaneously displayed.

#### 4.2.1.3 Substation Mode Display

Additionally, facilities are available for the display of power flows through graphical substation diagram as shown in Fig. 4.5

In this substation diagram the flows are in MW and MVAR. The top value is for the real power flow and the bottom value is for the reactive power flow. A negative sign indicates flow into the busbar and a positive value indicates flow out of the busbar.

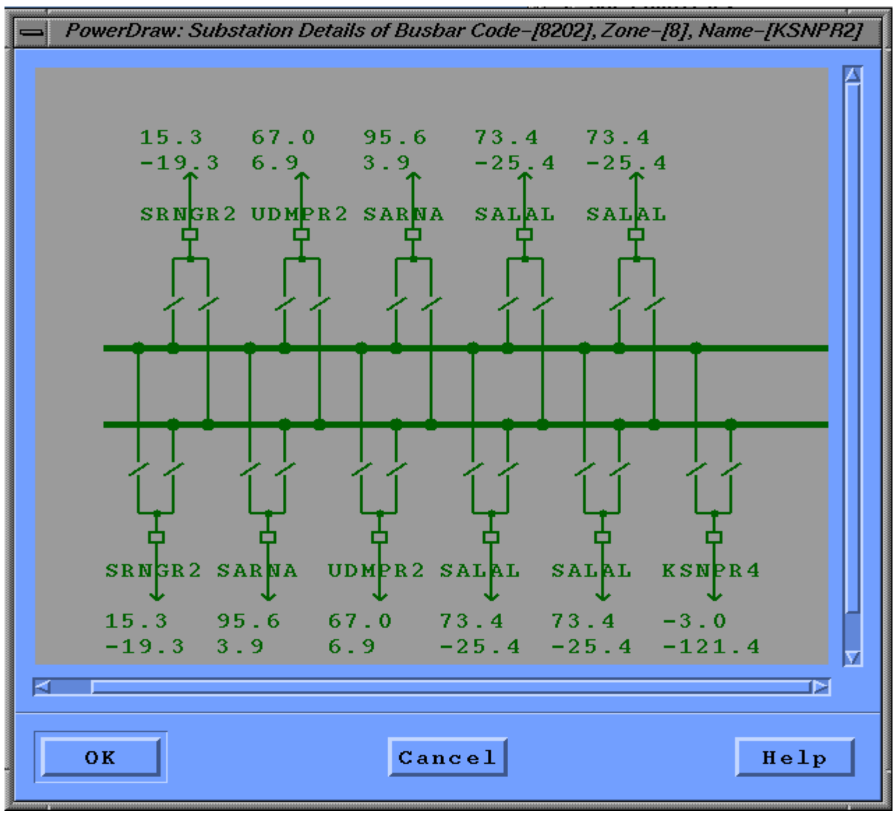


Figure 4.5: Graphical Display of Power Flows

### 4.2.2 Display During Abnormal Operation

During normal condition when the system operates within a narrow band of the predicted daily load curve, there is not much excursion of the frequency from the desired value. The system frequency remains within a narrow band around the normal value. However, unforeseen disturbances can take the system from the normal to the abnormal condition. The severity of the abnormal operation depends on the nature and location of the disturbance. The most important thing to observe during such situations is the system frequency.

Apart from violation of voltage limits and line flows, there may be frequency sensitive load shedding and generation outages. Lines and transformers may trip by the operation of over voltage and distance relays. In the worst possible scenario there may be system segregation leading to system islanding.

## 4.3 Off-line Studies During Real Time Simulation

It is possible to carry out the following off-line studies while real time simulation is proceeding. This is done by taking a snap-shot of the real time data at the instant of initiating the off-line study.

* **Operator Load Flow**

* **Short Circuit Studies**

* **Transient Stability studies**

* **Voltage Stability Analysis**

* **Optimal Power Flow**

Since Economic Load Despatch is an integral part of Real Time Simulation, it is not necessary to carry out this as an off-line Study.

For example, if you want to carry out an 'Operator Load Flow' while real time simulation is going on, take the cursor to the 'Simulation' Menu and press at the 'Off-Line' option. Then from among the different possible studies select the 'Operator Load Flow' and press the left mouse button.

Then you can carry out all possible 'Editing of Data' and repeat load flow analyses over and over again. This is not going to interfere with the real time simulation which is running independently at the back ground. The details about carrying out 'Operator Load Flow' are described in**Volume II** of the **Users' Manual**.

When you click at 'Operator Load Flow' or any other Off-Line study, a snap shot of the system operating state at that instant is taken for these studies.

## 4.4 Real Time Simulation in Operator Training Mode

As mentioned earlier Real Time Simulation can be conveniently be used for **Operator Training** both during normal condition as well as severe disturbances.

In the preliminary stages the operator may be trained to observe to what can happen to a system by the imposition of certain contingencies while the system is running in the normal load following mode. An example will be taken up here to demonstrate such a situation.

### 4.4.1 Generation Loss During Normal Operation

During the normal operation the system operates in the load following/frequency control mode. This means that at every instant of time there is a balance between total generation and load plus losses. As load varies system frequency is determined by the action of the speed governing systems action if they are present in the system. At the same time loads at all the busbars also adjust due to their sensitivity to voltage magnitude and frequency variation. In case the speed governing systems are not present the balance between generation and load will be entirely controlled by the adjustment of loads by frequency and voltage magnitude variations.

#### 4.4.1.1 System With Speed Governor Action

When speed governors are present in the system the system frequency variation is controlled by their droop characteristics which, in turn, control the opening and closing of the steam valve. Simultaneously, loads also get affected by the changes in frequency and voltage magnitudes. The combined effects of all these are shown in Fig. 4.6.

In this figure the variation of frequency due to the outage of one generator at ANPARAB station supplying 420 MW is shown. A few minutes later a load of 213.4 MW and 125 MVAR gets rejected. Due to the action of speed governing system the frequency variation is not much.

#### 4.4.1.2 System Without Speed Governor Action

In this scenario the system is operating without the presence of any speed governing system. Same contingencies as in the above case is imposed on the system. The combined effects of all these are shown in Fig. 4.7. It is evident that the frequency variation is much larger in this case. This is because the balance between generation, which remains unchanged because of the absence of speed governing system, and load is entirely due to the load adjustment by their sensitivity to frequency variation.

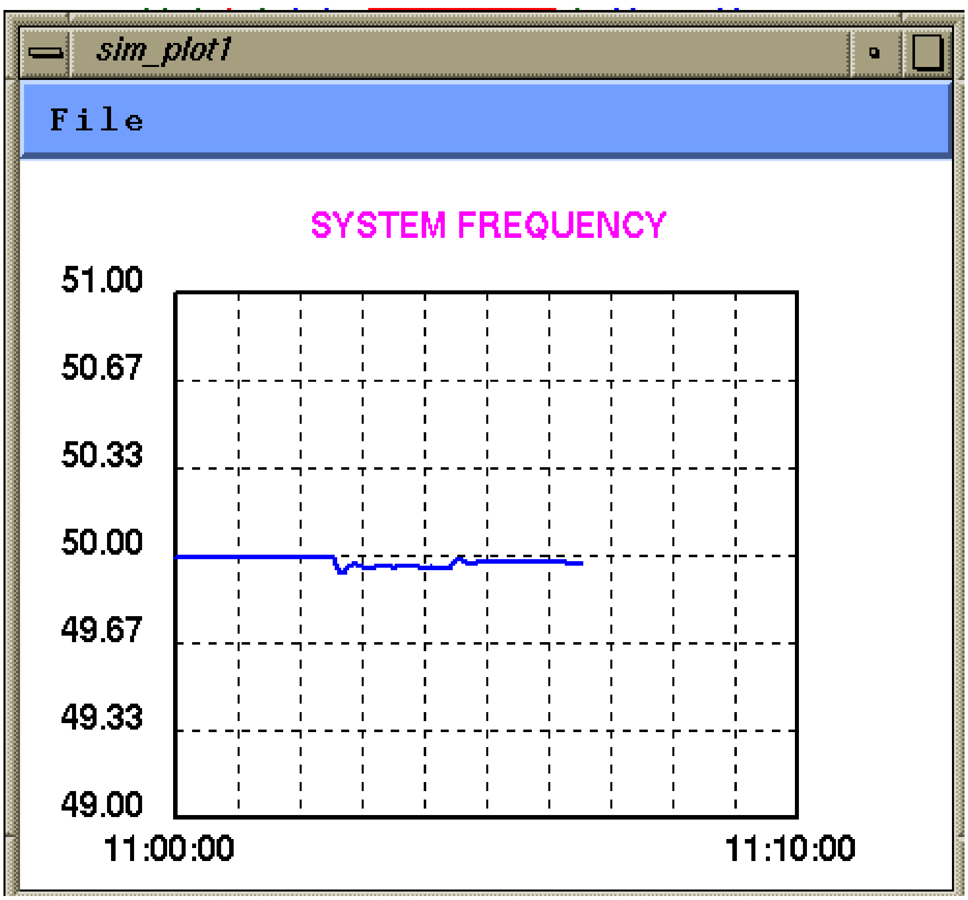


Figure 4.6: Effect Generation and Load Rejection with Governor

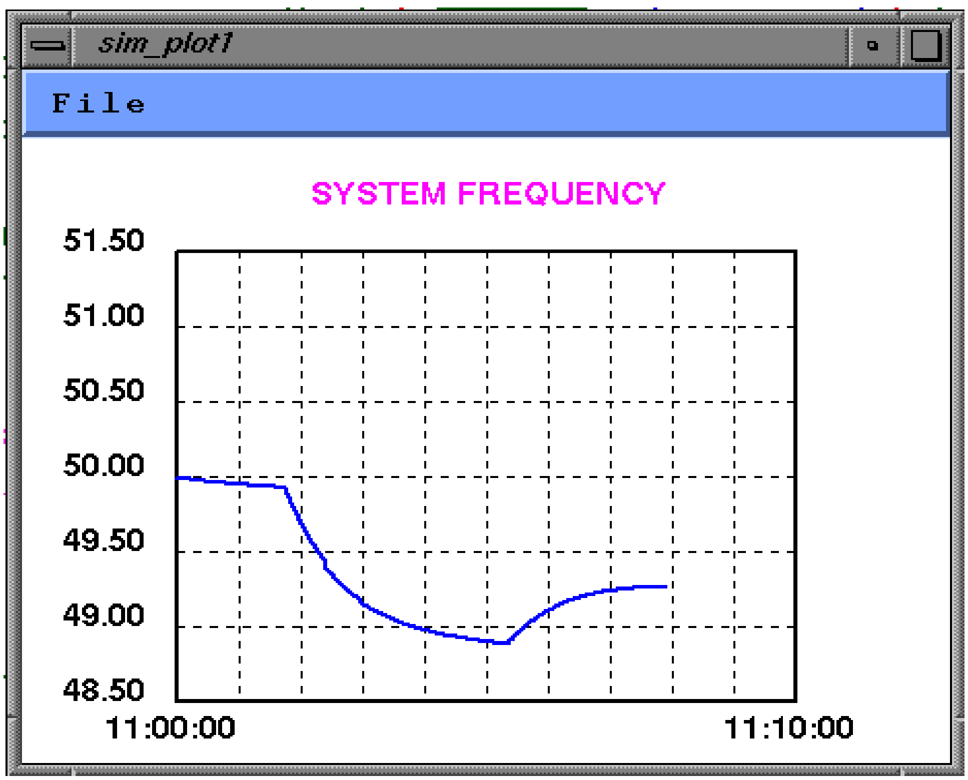


Figure 4.7: Effect Generation and Load Rejection without Governor

# Appendix A

# Preparation of Data Files for Automatic Control Systems

## A.1 Preparing Data File

For preparing data file the following steps are to be performed.

1. A block diagram of the model which is to be simulated has to be drawn.
2. Unique number has to be assigned to each block in any oder with the only restriction that the external inputs should be numbered at the last.
3. For each block the cerresponding block type has to be assigned depending upon the transfer function. The block types available with the simulation package are:
4. For all the blocks, all the individual parameters are to be found out. The table below indicates the input data required for each individual block.

Table A.1: The blocks available for simulation

| Linear blocks | Nonlinear blocks | other blocks |
|---|---|---|
| f First order | l Limiter | g Gain |
| h Higher order | d Deadband | s Summer |
| i Integrator | b Backlash | c Clubbed model |
| p Differentiator | k Lookup table | |
| n Limited integrator | r Rate limiter | |
| | v Low value gate | |
| | t Square root | |
| | Time delay | |
| | m Multiplier | |

5. External inputs are to be selected from the signal generators available, as given in the table A.3.
   Combination of any of these types of inputs can also be selected ( by using a summer after he inputs ).

6. The simulation start time ( which is normally 0.0 ) and the stop time ( time upto which the simulation should be done ) has to be provided.

7. The integration time step has to be selected properly, because this is the most important factor determining the stability of the solution. It should be chosen depending upon the time constants of the model and also the choice of integration method; otherwise the result may diverge if a large time step is selected.

8. The choice of integration is to be given depending upon the time available for simulation. The integration methods available in the simulation package is given in table A.4.

There are 6 sets of data required for simulation program.

Table A.2: Input data required for each block

| Block Tpye | Block Name | Block Transfer function | Input data required |
|---|---|---|---|
| Linear blocks | | | |
| f | First order | $\frac{G(1+sT_z)}{1+st_P}$ | $G, T_z, T_p, X_0$ |
| i | Integrator | $\frac{G}{s}$ | $G, X_0$ |
| p | Differentiator | s | $X_0$ |
| h | Higher order | $\frac{num(s)}{den(s)}$ | N (order of the system ), Numerator coeff. & Denominator coeff. in decreasing order of s, $X_0$ |
| n | Limited integrator | $\frac{G}{s}$ | G,$X_0$, Upper & Lower limits |
| Nonlinear blocks | | | |
| b | Backlash | | $X_0, Y_0$, width (Initial input & output ) |
| l | Limiter | | Upper & Lower limits |
| d | Deadband | | Set & Change ($\pm$) values |
| k | Lookup table | | Number of data, Input & Output vectors |
| m | Multiplier | | Number of Inputs,input block numbers |
| r | Rate limiter | | Upper and Lower rate limits |
| y | Time delay | | Delay time & simulation step |
| t | Square root | | |
| Others | | | |
| g | Gain | G | G |
| s | Summer | | Number of Inputs,Input block numbers |
| c | Clubbed model | | Data file name |

Table A.3: Signal generator available in simulator package

| Signal type | Signal name | Input data required |
|---|---|---|
| sin | Sine wave ($PSin(wt)$) | Peak, Frequency (rad/sec.) |
| cos | Cosine wave ($PCos(wt)$) | Peak, Frequency (rad/sec.) |
| sqr | Square wave | Peak, Frequency (rad/sec.) |
| saw | Saw tooth wave | Peak, Frequency (rad/sec.) |
| step | Step Input | Step time, Initial value, Final value |

Table A.4: Integration methods available in the simulation package

| choice No. | Integration Method |
|---|---|
| 1 | Eulerś method of integration |
| 2 | Theta method ( Trapezoidal rule ) |
| 3 | Runge-Kutte method ( Third order ) |
| 4 | Runge-Kutte method ( Fourth order ) |
| 5 | Runge-Kutte method ( Fifth order ) |

1. Connection data :- This data basically includes the block number, block type and the input block number, i.e., the block the input is coming.
2. Transfer function data :- This data gives the detail about each of the blocks in the model. This data should be given in the same order as the connection data was given.
3. External input data :- This data includes the total number of esternal inputs. Then for each input the detailed data is given.
4. Simulation data :- This gives the simulation start time, stop time and step for simulation.
5. Output data :- This gives the block number of the model which gives the final output.
6. Choice of integration :- This is the flag which selects the method of integration.

Though so many types of methods are available, *Theta method ( Trapezoidal rule )* is found to be the most efficient for large time step of integration, i.e., less time to solve the model even if time constants are small campared to the step of integration. Though the *Trapezoidal method* gives an overshoot at first time step, after some time steps it stabilises.
For example

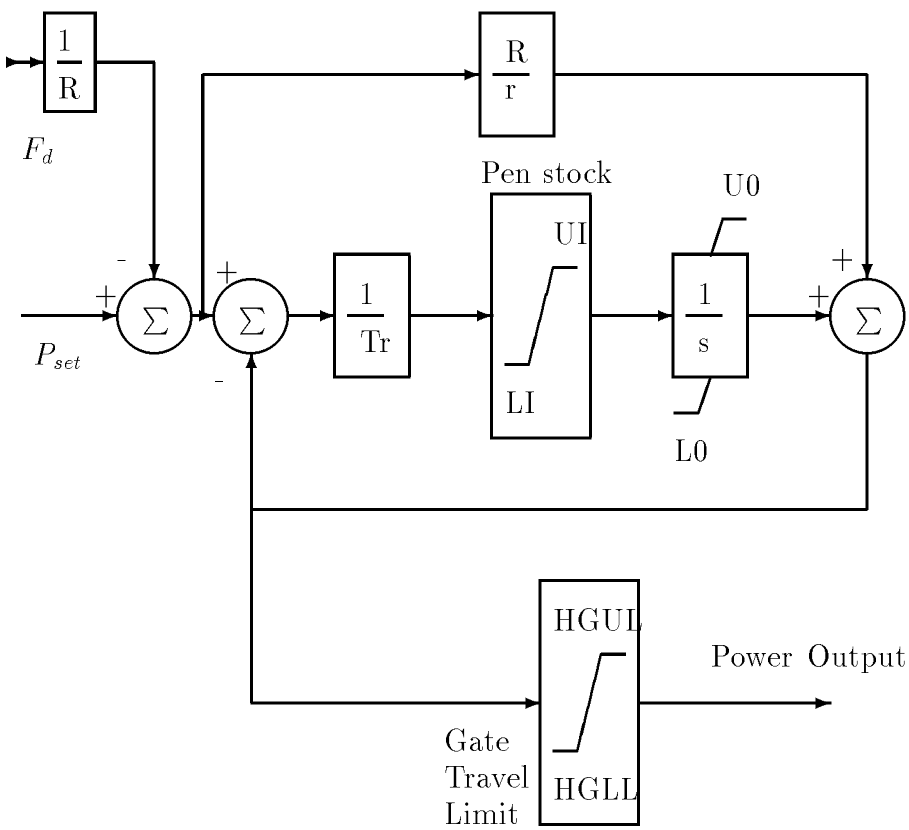


Figure A.1: Block diagram of second tier Hydro turbine system

For the figure of second tier hydro turbine model shown in figure A.2 , the data file can be prepared in the following format.
The detailed data is given in table A.5.

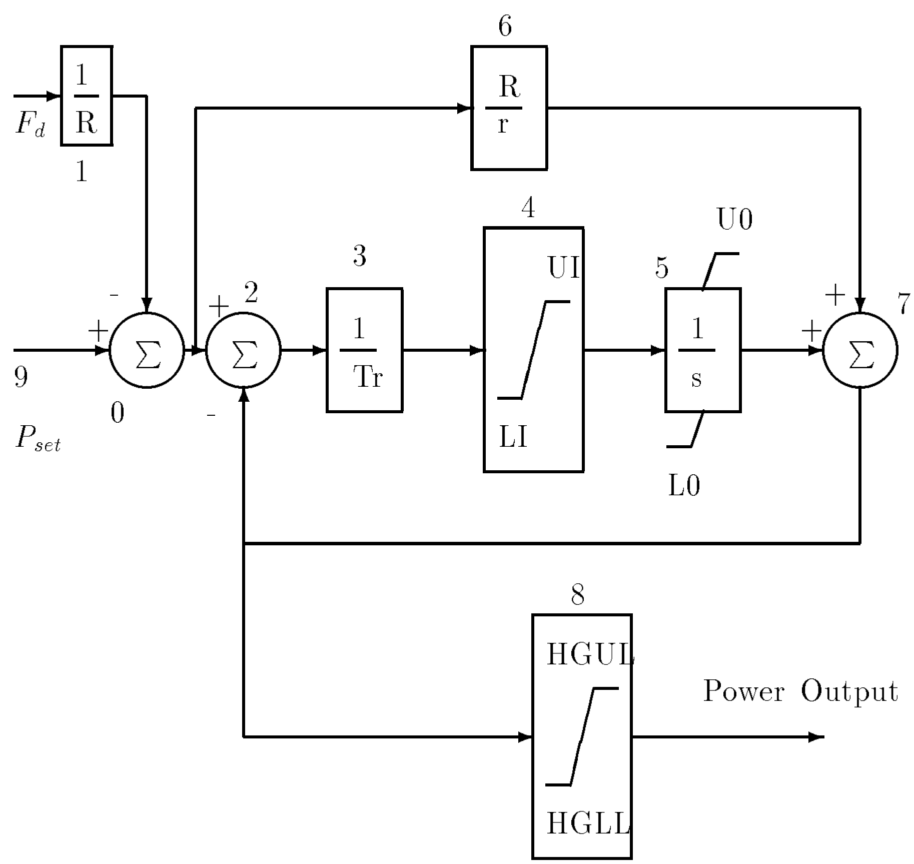


Figure A.2: Block diagram of second tier Hydro turbine system

Table A.5: Data set for second tier hydro model

| | Step 2 | | step 3 | | | | step 4 |
|---|---|---|---|---|---|---|---|
| 0 | s | 0 | 2 | -1 | 11 | | 2 |
| 1 | g | 10 | 2 | | | | 10 step 0 0 0 |
| 2 | s | 0 | 2 | 0 | -7 | | 11 step 0 0 1 |
| 3 | g | 2 | 0.125 | | | | step 5 |
| 4 | l | 3 | -0.00875 | 0.00875 | | | 0.0 |
| 5 | n | 4 | 1 | 0 | 0.875 | -0.875 | 200 |
| 6 | g | 0 | 0.125 | | | | 0.1 |
| 7 | s | 0 | 2 | 5 | 6 | | step 6 |
| 8 | l | 7 | 0 | 1 | | | 8 |
| 9 | * | 9 | | | | | |

step 1

All the blocks are numbered as shown in the figure A.2.

# Appendix B

# Data Files for Dynamic Models

```
0 s 0 (from file speedgov.d)
(This is only for the Speed
Governor Type - 1)
Connection Data
1 g 0
2 l 1
3 i 2
4 l 3
6 * 6
Transfer Function Data
2 5 -4
1
-.2 .2
1 0
-.04 .04
Input Data
0
Output Block
4
```

```
SpeedGoverner ( from file spgov.d )
(This is only for the Speed
Governor Type - 2)
Connection Data
0 f 14
1 s 0
2 g 1
3 l 2
4 i 3
5 l 4
6 f 5
7 g 6
8 f 6
9 g 8
10 f 8
11 s 0
12 s 0
13 g 10
15 * 15
Transfer Function Data
1 0 .2 0
3 0 -5 15
1
-4 4
1 0
-5 5
1 0 .25 0
.3
1 0 7.5 0
```

```
.4
1 0 .4 0
2 7 9
2 11 13
.3
Input Data
2
14 step  0 0 .1
15 step 0 0 0
Out Block for display
12
```

```
SpeedGoverner ( from file spgov1.d )
Connection Data
0 f 12
1 s 0
2 g 1
3 l 2
4 i 3
5 l 4
6 f 5
7 g 6
8 f 6
9 g 8
10 f 8
11 s 0
12 s 0
13 g 10
16 * 16
```

```
Transfer Function Data
10 .1 .2 0
3 0 -5 14
2
-5. 5.
1 0
0 1.2
1 0 .25 0
.3
1 0 7.5 0
.4
1 0 .4 0
3 7 9 13
1  15
.3
2
14 step  0 0 1
15 step 0 0 .01
0 2.0
0.1
Out Block for display
11
```

```
SpeedGoverner ( from file spgover.d)
Connection Data
0 f 16
1 g 0
2 s 1
3 g 2
4 l 3
```

```
5 i 4
6 l 5
7 f 6
8 f 7
9 g 7
10 f 8
11 g 8
12 g 10
13 s 0
14 s 0
15 g 19
16 d 15
17 * 17
Transfer Function Data
1 1 0.2 0
1
3 -1 -6 18
1
-0.1 0.1
1 0
0 1.2
1 0 0.25 0
1 0 7.5 0
0.3
1 0 0.4 0
0.4
0.3
2 9 11
2 13 12
-33.33
0 0.00002
```

```
Input Data
2
18 step 0 0 1
19 step 0 0 0
Output Block
14

SpeedGoverner ( from file spgtandom.dat)
( This is for Speed Governor with
Tandem Compound Single Reheat Turbine)
Connection Data
0 f 15
1 s 0
2 g 1
3 l 2
4 i 3
5 l 4
6 f 5
7 g 6
8 f 6
9 g 8
10 f 8
11 s 0
12 s 0
13 g 10
14 g 17
15 d 14
18 * 18
Transfer Function Data
1 1 .2 0
3 0 -5 16
```

```
1
-1.60 1.6
1 0
-1.60 1.6
1 0 .25 0
.3
1 0 7.5 0
.4
1 0 .4 0
2 7 9
2 11 13
.3
-33.33
0 0.02
Input Data
2
16 step  0 0 1
17 step  0 0 0
Output Block
12



0 f 15
1 s 0
2 g 1
3 l 2
4 i 3
5 l 4
6 f 5
7 g 6
```

```
8 f 6
9 g 8
10 f 8
11 s 0
12 s 0
13 g 10
14 g 17
15 d 14
18 * 18
1 1 .2 0
3 0 -5 16
1
-1.60 1.6
1 0
-1.60 1.6
1 0 .25 0
.3
1 0 7.5 0
.4
1 0 .4 0
2 7 9
2 11 13
.3
-33.33
0 0.02
Input Data
2
16 step  0 0 1
17 step  0 0 0
Output Block
12
```

```
SpeedGoverner (from file spgtandomdouble.dat)
( This is for Speed Governor with
Tandem Compound Double Reheat Turbine)
Connection Data
0 f 19
1 g 0
2 s 1
3 g 2
4 l 3
5 i 4
6 l 5
7 f 6
8 f 7
9 g 7
10 f 8
11 g 8
12 g 10
13 s 0
14 s 0
15 f 10
16 g 15
17 s 0
18 g 23
19 d 18
20 * 20
Transfer Function Data
1 1 0.2 0
1
```

```
3 -1 -6 22
1
-0.1 0.1
1 0
0 1.2
1 0 0.25 0
1 0 7.5 0
0.22
1 0 7.5 0
0.22
0.3
2 9 11
2 13 12
1 0 0.4 0
0.26
2 14 16
-33.33
0 0.00002
Input Data
2
22 step 0 0 1
23 step 0 0 0
Output Block
17
```

```
SpeedGoverner( spgcrossdouble.dat)
( This is for Speed Governor with
Cross Compound Double Reheat Turbine)
```

```
Connection Data
0 f 21
1 g 0
2 s 1
3 g 2
4 l 3
5 i 4
6 l 5
7 f 6
8 f 7
9 g 7
10 f 8
11 g 8
12 g 10
13 g 10
14 s 0
15 s 0
16 f 10
17 g 16
18 g 16
19 s 0
20 g 24
21 d 20
22 * 22
Transfer Function Data
1 1 0.2 0
1
3 -1 -6 23
1
-0.1 0.1
1 0
```

```
0 1.2
1 0 0.25 0
1 0 7.5 0
0.22
1 0 7.5 0
0.22
0.14
0.14
2 9 12
2 11 13
1 0 0.25 0
0.14
0.14
4 14 15 17 18
-33.33
0 0.00002
Input Data
2
28 step 0 0 1
29 step 0 0 0
Output Block
19
```

# Index