DYNAMIC SIMULATION OF POWER SYSTEM

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
ELECTRICAL ENGINEERING

By

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CANDIDATE'S DECLARATION

I, hereby declare that the work which is being presented in the dissertation entitled, 'Dynamic simulation of power system,' in partial fulfilment of the requirements for the award of the degree of Master of Engineering in Electrical Engineering with specialisation in SYSTEM ENGINEERING AND OPERATIONS RESEARCH, submitted in the Department of Electrical Engineering, University of Roorkee, Roorkee, is a record of my own work carried out for a period of eight months from September 1988 to April 1989, under the supervision of Dr. J.D. SHARMA, Professor, Department of Electrical Engineering, University of Roorkee, Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma.

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DATED: 15/6/89 (NILADRI CHOWDHURY)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ACKNOWLEDGEMENT

Before proceeding any further, I wish to express my indebtedness and obligation to Dr. J.D.SHARMA. Without his guidance, it would have been impossible to bring this thesis work to fruition. I am deeply thankful to him for the immense help and cooperation that he extended towards completion of this work.

like so many others, "I get by with a little help from my friends". They, as always, were there whenever I needed them.

This thesis report was typed so well by Mr. D.C. Bhardwaj. I thank him for doing it in such a short period.

NILADRI CHOWDHURY

ABSTRACT

A power system simulator is a simulation package for electrical generation, transmission and distribution systems. The software provides an environment for the development and testing of on-line analysis and control algorithms, and also has potential for application in operator training. Dynamic and algebraic models of power system elements are described. Numerical techniques are used which helps in obtaining solutions with acceptable accuracy for medium sized networks using micro computer hardware.

The stability of the system under emergency conditions are observed and recorded. A power system example taken comprising of 93 buses has been considered for this purpose. The software has been written in the FORTRAN language.

CONTENTS

CHAPTER - 1

INTRODUCTION

The study of power system dynamics forms one of the oldest and most important applications of simulation. Power systems cannot be designed or operated without the help of some kind of simulation and the simulation problem itself is challenging. The power system components are too expensive to allow any experimentation on the system which could conceivably cause damage. Any experiment which causes a generator or a transmission line to be taken out of service even temporarily can be very expensive. Since it is not feasible to experiment on the system, the most practical alternative is to simulate, even though the system is nonlinear and involves differential equation of higher order.

Initially hand calculations were performed to obtain the numerical solutions of the power system dynamic equations. later an elaborate form of Analog computer called a network analyzer was developed. But all these proved to be tedious and difficult to maintain and handle. Then with the advent of digital computer, simulation of power systems were conducted on it. This proved to be very helpful and was highly successful.

A real time power system simulation can be used to provide a test bed for energy management software, and to provide a realistic operator training environment. If sufficient computational resources are available a simulation may also be initiated as part of an online security assessment facility. Interest in on line simulation has increased in recent years and has attempted to consider the complete power system rather than individual elements. Two fundamental approaches to the problem have been adopted.

(a) Using a low flow technique to solve the network equations and to evaluate the nodal voltages which in turn are used in solving the network dynamic equations.

(b) Solving the network dynamic equations simultaneously and in conjunction with the network algebraic equations.

The former method can be faster, but it is less accurate especially for the allocation of power demands to generators. It also introduces problems if network Islanding is to be considered because the load flow algorithm is not independent of the network reference node. The latter method is numerically more stable, robust and inherently capable of handling islanding and fault analysis. The simulation technique incorporated in the thesis is based on the second approach for a number of reasons.

(i) the simulator is numerically more stable and accurate,

(ii) there is a tight time coupling between the network algebraic and dynamic equations.

The thesis presents the detailed mathematical modelling of the system components together with a suitable numerical technique for the solution of the equations.

1.1 OVERVIEW OF POWER SYSTEM DYNAMICS

A power system never operates at a point of true steady state and thus is always characterized by dynamic behaviour. Whenever a disturbing event occurs on a power system, there is nearly instantaneous change in the state of the electric and magnetic fields of the system followed in seconds and minutes by the longer term electromechanical response of the rotating elements of the generator source and loads. But here short term responses are the subject of interests.

1.2 CLASSES OF POWER SYSTEM SIMULATION

There are three primary types of power system simulations: long term simulation, medium - term and short term simulations. These types of simulations are distinguished by the time frames of interest. For example, the models used for short term simulation are assembled using the following assumptions.

(i) Any variable which does not noticeably respond to simulation within 100 seconds is considered to be constant.

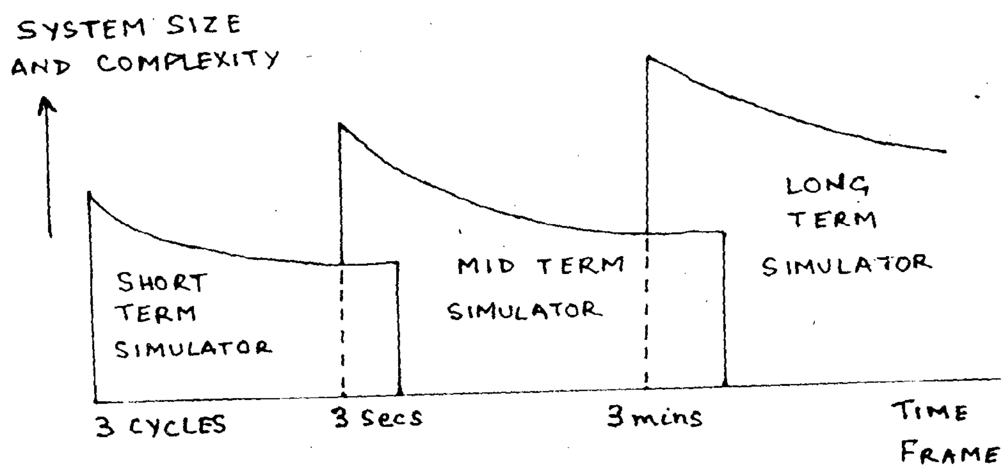


FIG.1 <u>THE DOMAIN OF APPLICATION OF POWER SYSTEM SIMULATION METHODS</u>

(ii) The duration of the simulation is limited to about 100 secs or less. Short term simulators are used to study high speed transients, and long term simulators are used to study slower phenomena. The cost of operation of a simulation program imposes some practical limits on the complexity of the system which can be simulated. Fig. [1] exhibits the limitations of complexity and duration of the simulation which are imposed on these three types of simulations by limiting the computer cost to about $ 500 per run. The complexity is measured in terms of the number of buses (nodes) in the network.

There are of course, many other factors which influence complexity such as the number of generators, the level of detail used in modelling of subsystem etc.

Long term power system simulations are used to study the slowest phenomena of power systems. The devices which contribute significantly to the dynamic response of the system during this long time frame are the automatic control of the generation system, the boilers and the boiler controls. During the long-term simulations the oscillations of the rotor are not included in detail. Consequently the step by step integration of the differential equations of the rotors is not used to determine the level of electric power delivered at any time instant. The power level for each generator is established by the governor set point and the state of the boiler. This allows the time step between network solutions to be as long as one second.

Short term power system simulations are the most highly developed and the most frequently used class of of power system simulations. The boiler or other prime energy source for the generators is assumed to have enough stored energy available so that long time constants (such as thermal time constants of steam boilers) do not have time to play a role in the dynamics. The dominant dynamic phenomena being simulated involve the mechanical dynamics of the combined generator and turbine rotor and the dynamics of the field or excitation control system of the generator. The rotor dynamics include the effect of the governor and the dynamics of the turbine. The excitation controls are designed for high speed regulation of voltage magnitude, but they frequently have auxilliary inputs (such as rotor velocity) which are used to produce variations that will damper rotor oscillations.

1.3 SCOPE OF WORK

In this thesis out of the three classes of Power System Simulation, short term power system simulation has been developed. The designed power system simulator consists of the models of the power system components like generating units, loads, lines, transformers and protective relays. The generating unit consists of the generator, exciter and turbine governor system. Three types of generator models has been considered. Analog computer representation has been used to write suitable programs of the generator models, exciter models and governor turbine models. All these models along with their block diagrams has been described in the later chapters. Five classes of exciter models and three types of turbine governor system has been considered. All these model types can be brought into use in the program whenever required. An effective numerical technique for the solution of the various algebraic and differential equations has been used.

A distance, loss of excitation, under voltage protective relay schemes has been incorporated. A detailed relay representation has been given in the next chapter. The effect of the various faults, loss of excitation and loss of generation on the system is studied by the help of this simulator.

1.4 LITERATURE REVIEW

In IEEE committee report [1], the nomenclature and control system representation of the various exci-tation systems now available have been described. It has defined input data requirements for computer pro-grams and provides a consistent format in which manu-facturers can respond to requests for excitation system data to be used for system studies.

In IEEE committee report [2] the basic models for speed governing systems and turbines in power system stability studies have been described. Here the steam turbine and the hydro turbine models have been described in great detail keeping in view of their impor-tance in power system simulation for stability studies.

D.D.Gelopulos and G.Iddings's paper [3] on the major simulation errors of on line simulations emphasizes the importance of interface errors in power system simu-lations. These tend to dominate the other solution errors. They do not recommend the deletion of many sub-systems for on-line simulation. They triedto find out the areas where the computational task may be reduced without sacrificing accuracy of power system simulation. In one of their other paper [4] they describedthe several types of simulations used in power system. The mathematical require-ments for carrying out simplified short term power system simulation are described in detail. The paper also suggests several techniques for improving the efficiency of digital programs for this kind of simulation. Some of the techniques for the improvement of computational efficiency of simulation programs described in this paper are network reduction and parallel processing.

M.Rafian's treatise [5] on real time power system simulation describes the theoretical basis and application of a simulation package for electric generation, transmission and distribution systems. The result obtained by him shows that the simulator can be used to provide a test bed for energy management software. The simulator is also useful for operator training.

G.Z.Ben Yaacov in his paper [6] describes the data base approach to power system analysis studies. The practical use of a central data base management system, together with a library of application programs and an interactive computing environment contributed significantly to the power system planning process in which individual engineers can work effeciently and interact among themselves using common data and analysis tools.

R.D.Dunlop and D.N.Ewart in their paper [7] describes the uses of a digital computer program developed to simulate the long term dynamics of bulk power systems. The paper describes the simulation of an evolving disturbance of a hypothetical power system using both a conventional short - term simulation and new long term simulation program.

A Keyhani's paper [8] describes a power system simulator based on modular structure. The simulator modules are defined as mathematical operators which permit it to perform computation much like a calculator does. Applications of the simulator in identification of low frequency rotor oscillations and solution of fast decoupled load flow problems are presented.

R.Podmore and J.P.Britton's paper [9] describes a dispatcher training simulator which provides a realistic environment for system dispatchers to practice operating tasks and experience emergency operating conditions. Normal operating activities such as load following, voltage control and transmission dispatch can be practised easily. Apart from all this the simulator allows the operator to practice and observe procedures for abnormal conditions.

D.L.Elder in his paper [10] describes a method capable of simulating, interactively and in real time the dynamic behaviour of power system under emergency conditions. The modelling approach adopted is characterized by an interfacing scheme in which each unit is connected to the transmission network via an explicit generator model, with its own rotor angle and speed. Execution time has been minimised by simplifying the model in ways which are expected to be acceptable in the content of interactive training.

D.Gelopulos and G.Idding's paper [14] discusses a novel point of view from which a qualitative comparative analysis of integration algorithms may be performed. In addition to comparing the effectiveness of integration algorithms, the manner in which the structure of the simulafed system is deformed by the various integration procedures is also discussed. This has two advantages, one advantage is that improved integration procedures may be synthesized and tailored for specific systems by the evaluation of counterfeit systems. A second advantage is that errors due to the integration algorithm are exhibited in the form of modified parameters which facilitates a comparison of the algorithm errors with the uncertainity concerning model parameter values.

CHAPTER - 2

MATHEMATICAL MODELLING

For modelling purpose a control system block diagram is considered. This block diagram representation is converted into analog computer representation for developing mathematical model to be used in the simulation.

There are several advantages of this model over the mathematical approach such as the state space one. They are as follows -

(i) The analog computer formulation requires a minimal amount of manipulation on the original model.

(ii) Solution is obtained as a function of variables with a physical meaning.

(iii) The model variables are easily available for operations such as saturations, and data output.

(iv) Changes are isolated in an analog computer model hence this can be very easily incorporated in the program.

(v) Complex operations such as non linear function generation, time delays and variable differentiation can be easily included.

(vi) The program development becomes very easy due to the simplicity of the approach.

On the analog model of machine and controller units, the integrator outputs correspond to the state variables and the inputs are the time derivatives of the state variables.

The time derivative of the state variables are calculated from the known values of the state variables. The procedure for modelling is described below -

(i) An analog model is drawn.

(ii) The variables at integrator outputs are named. The variables should be named systematically so that the relationship between the variables are obvious.

(iii) Expression for the initial values of the integrator outputs are obtained by taking the integrator inputs zero, during the steady state.

(iv) The subroutine for the machine and controller models consists of two sections. One calculates the initial conditions of the state variables and controller set points prior to the simulation and the other calculates the time derivatives of the state variables at each integration step. The statements for calculating the time derivatives of the state variables are generated to execute the following steps.

I. Definition of variables at integrator outputs.

II. Calculation of variables at intermediate points in analog diagram.

III. Calculation of net integrator inputs.

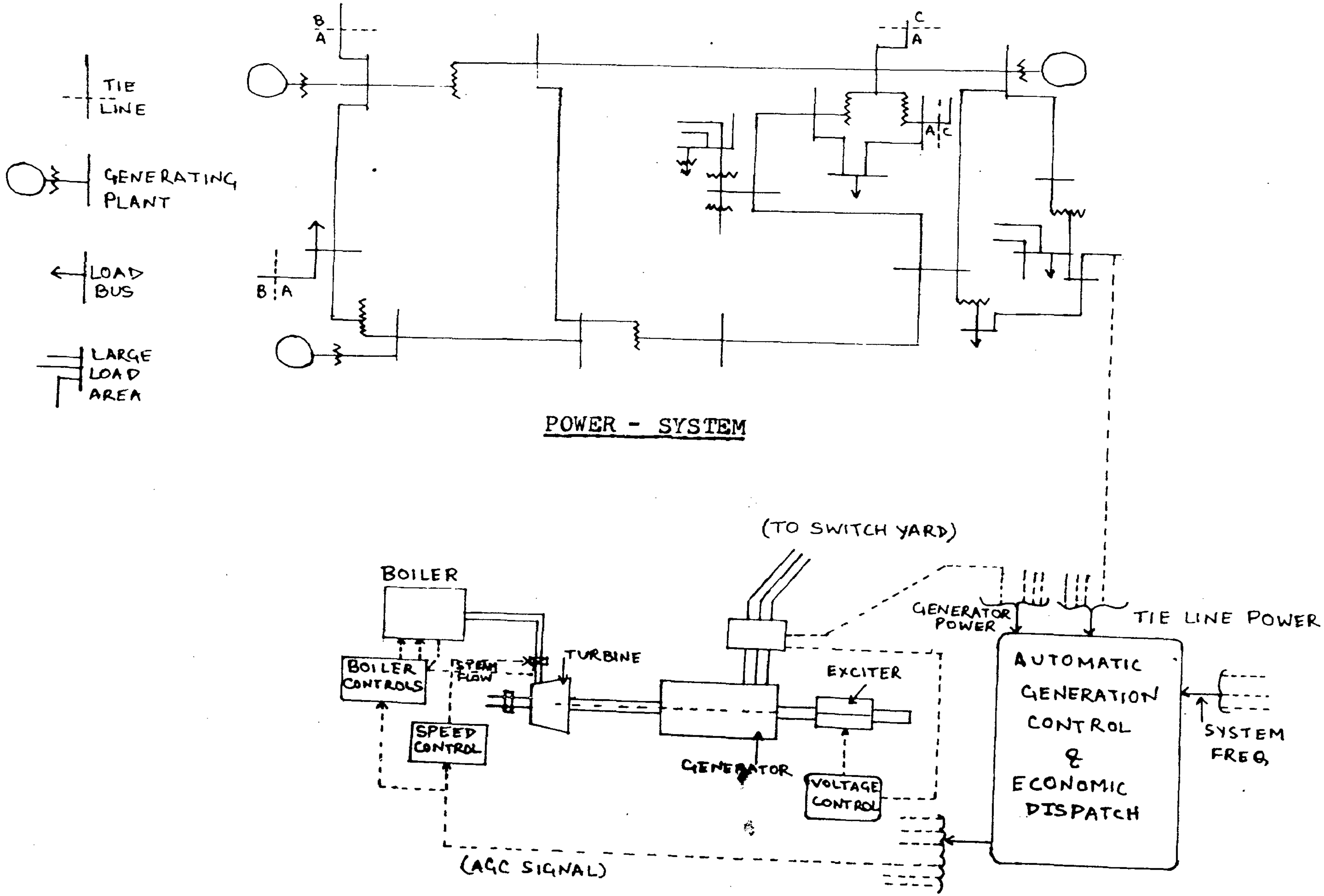


FIG.2 BASIC ELEMENTS OF POWER SYSTEM AND ITS CONTROL

2.1 ELEMENTS OF SYSTEM DYNAMIC BEHAVIOUR

The power system which relate to system dynamic performance are illustrated in the functional block diagram of Fig. (2). The generation control area may be either a single system or a pool consisting of several power systems operating under mutually beneficial contractual arrangements. The control area consists of geographical area with boundaries usually along corporate lines within which generation is continuously controlled to meet loads plus or minus any scheduled net interchange across the boundaries. The major elements of the power system are the generation sources, the loads, and the transmission network which interconnects them.

The generation sources consists of few large synchronous generators, are driven by hydro, gas, or steam prime movers and are closely coupled electrically through the transmission network.

The total system load is made up of elements of varying size and widely dispersed throughout the network. The individual loads are not under the direct control of the service utility, but follow seasonal, weekly and daily cycles as influenced by weather and other factors. The manner in which loads respond to changes in system voltage and frequency is important in gaining an understanding of power system dynamic behaviour. The influence of the loads on system dynamic performance is very dependent on the nature and location of the disturbance. In many cases the behaviour of the apparant composite load as supplied by the high voltage network is the most im - portant consideration in viewing power system dynamics.

In providing the connection between the generating sources and the loads the transmission system determines the character of system dynamic performance. Since all generating sources are electrically coupled together through the common transmission network, dynamic interaction between individual generators and between the generators and the loads is very dependent on the nature of the trans-mission network and its control.

Since most power system loads are composed of equip-ment which is designed to utilize the energy at a given voltage and frequency, the power system is designed to supply the energy subject to constraints on the variation of voltage and frequency. Feedback control is important in meeting this objective. The effestiveness of the various control system in bringing about the desired performance is subject to such factors as limits on the maximum change or rate of change which the controlled units can tolerate and the inherent dynamic characteristics of the controlled units.

The feedback control function can be divided into primary and secondary control. Primary controls are feedback control loops which initiate action at the local generating unit based on local measurements. The most important of these in system dynamic consideration are the voltage control, the speed control and the boiler control.

System voltage control at the generator sources, at the loads is achieved through power factor correction, and at the intermediate points in the supply system by means such as fixed and switched capacitors, synchronous condensers, shunt reactors and transformers with variable voltage ratio (tap changing) under load. The coupling of synchronous machines through the transmission network creates many lightly damped resonant modes whose frequency ranges from about 0.2 Hz to 3 Hz. The ability of a generator to ride through network disturbance, such as short circuits and line switching is dependent to a degree on voltage regulator and exciter response characteristics.

The speed control system adjusts flow into the turbine in response to changes is shaft speed. Since operation on a large interconnected network maintains all generating units at the same average electrical speed, the individual speed control systems do not actually control speed, but rather the power with which turbine generator contributes to the network. This control is of importance for large system disturbances but is too slow to have a significant effect for short lasting network disturbances such as short circuits, Considerable interest exists however for speed controls to initiate fast closures and reopening of intercept valves on large steam turbines following short circuits near the unit to aid in maintaining synchronism.

In response to changes in demand for steam energy, boiler controls and auxiliaries maintain the flow of fuel, air and water into the boiler. These elements should not be limiting factors in overall plant response during normal or emergency conditions.

Secondary control on the other hand act to initiate control at a local level based on remote measurements. The automatic generation control and economic dispatch function is important for successful operation of interconnected systems. Automatic generation control acts to regulate the power output of the electric generators within the control areas in response to changes in system frequency etc.

2.2 ABNORMAL OPERATIONS

There are two classes of disturbances identified for convenience. One will result in loss of transmission system elements and/or significant loads or load areas and those very unlikely events which leadsto islanding of a portion of the system where significant load generation unbalances may exist within the island. The first will be referred to here as network disturbances and the latter as load/generation unbalance or islanding.

Network disturbances - Network disturbances are commonly caused by short circuits on the transmission system. The magnitude and duration of the resultant dynamic response of the system is dependent on the type and location of the fault, on the time required for normal protective apparatus to respond and isolate the faulty element, and on the manner in which the system and its controls respond to the initial disturbance and its subsequent removal.

Short circuits or faults which occur on the trans - mission system close to the generator bus have the most severe effect on the performance of the generator. Three phase faults, although much less likely to occur, have a far greater impact than the more common occurrence of a single line to ground fault. The fault is generally removed within 0.1 secs. However, during this time system voltage on the faulted phases is very low in the general vicinity of the fault, and voltage measured at the terminals of nearby generators is also affected significantly. After the fault is cleared, system voltage returns to near normal levels. If automatic reclosing is employed, then reclosing into a permanent fault further perturbs the system.

The electromechanical response of generators in the vicinity of the fault is characterized by a rotor angle transient. The angle is oscillatory about the normal unit speed corresponding to the normal system frequency (50Hz). Usually this deviation does not exceed a value of ± 2 %. unless the disturbance is severe. In this case the affected generators could become unstable (lose synchronism with the rest of the generators).

The impact of network disturbances may be summarized as follows -

1. The duration of the resulting transients are of the order of 10 secs or less and are characterized by oscillations in the rotor angle and speed about the normal operating point.

2. The mechanical torque developed by the prime mover does not change appreciably because the speed deviations are oscillatory in nature and occur too rapidly for the speed control system to follow.

3. The abrupt transient torques may be magnified by the torsional response of the turbine - generator shaft and must be taken into account in the design of rotor shaft and turbines.

4. The voltage regulator be applied in a way so as not to cause negative damping of the rotor oscillations. In fact, it is possible to utilize dynamic variables in addition to voltage error to cause positive damping of the rotor angle oscillations and thereby improve

stability of the generating unit and system.

5. The rather large temporary voltage dip which occurs during such disturbances must be taken into account in the design of the auxiliary supply so that critical motors and support systems are not tripped during the transient and thus lead to unit shutdown.

Since network disturbances cause only a temporary unbalance between total prime mover input and total electrical load on all generators in the system, the system automatic generation control is not affected. If however, the disturbance leads to the loss of a generator or of a large load or a load area the automatic generation control and the generators on control are affected. Here, only network disturbances has been incorporated in the system condition so the second kind of abnormality i.e. major load/generation unbalance (islanding)is not discussed.

2.3 SYNCHRONOUS GENERATOR MODELS

Three types of synchronous generator models has been considered here. These models have been described in great detail in this section. They are as follows

(i) The two-axis model - neglecting $\dot{\lambda}_d$ and $\dot{\lambda}_q$ for a cylindrical rotor machine

In the two axis model the transient effects are accounted for, while the substransient effects are neglected. The transient effects are dominated by the rotor circuits, which are the field circuit in the d-axis and an equivalent circuit in the q-axis formed by the solid rotor. An additional assumption made in this model is that in the stator voltage equations the terms $\dot{\lambda}_d$ and $\dot{\lambda}_q$ are negligible compared to the speed voltage terms and that $\omega \cong \omega_R =$ 1 pu .

The machine will thus have two stator circuits and two rotor circuits. However, the number of differential equations described these circuits are reduced by two since $\dot{\lambda}_d$ and $\dot{\lambda}_q$ are neglected in the stator voltage equations (the stator voltage equations are now algebraic eqns).

The stator transient flux linkages are defined by

$$\lambda_d' \triangleq \lambda_d - l_d' i_d \quad \text{and} \quad \lambda_q' \triangleq \lambda_q - l_q' i_q \qquad (2.1)$$

and the corresponding stator voltages are defined by

$$e_d' \triangleq -\omega \lambda_q' = -\omega_R \lambda_q' \quad \text{and} \quad e_q' \triangleq \omega \lambda_d' = \omega_R \lambda_d' \qquad (2.2)$$

It can be derived that

$$v_d = -ri_d - \omega_R l_q' i_q + e_d' \qquad (2.3)$$

and $$v_q = -ri_q + \omega_R l_d' i_d + e_q' \qquad (2.4)$$

or $$e_d' = v_d + ri_d + x_d' i_q + (x_q' - x_d') i_q \qquad (2.5)$$

$$e_q' = v_q + ri_q - x_q' i_d \qquad (2.6)$$

Since the term $(x_q' - x_d')\, i_q$ is usually small, we can write approximately

$$e_d' \cong v_d + ri_d + x_d' i_q \qquad (2.7)$$

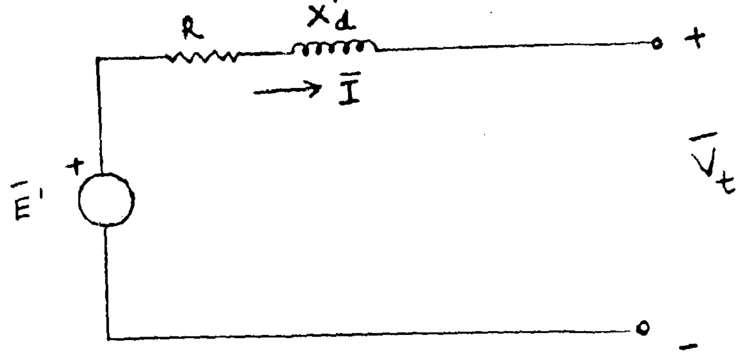


FIG. 3. TRANSIENT EQUIVALENT CIRCUIT OF A GENERATOR

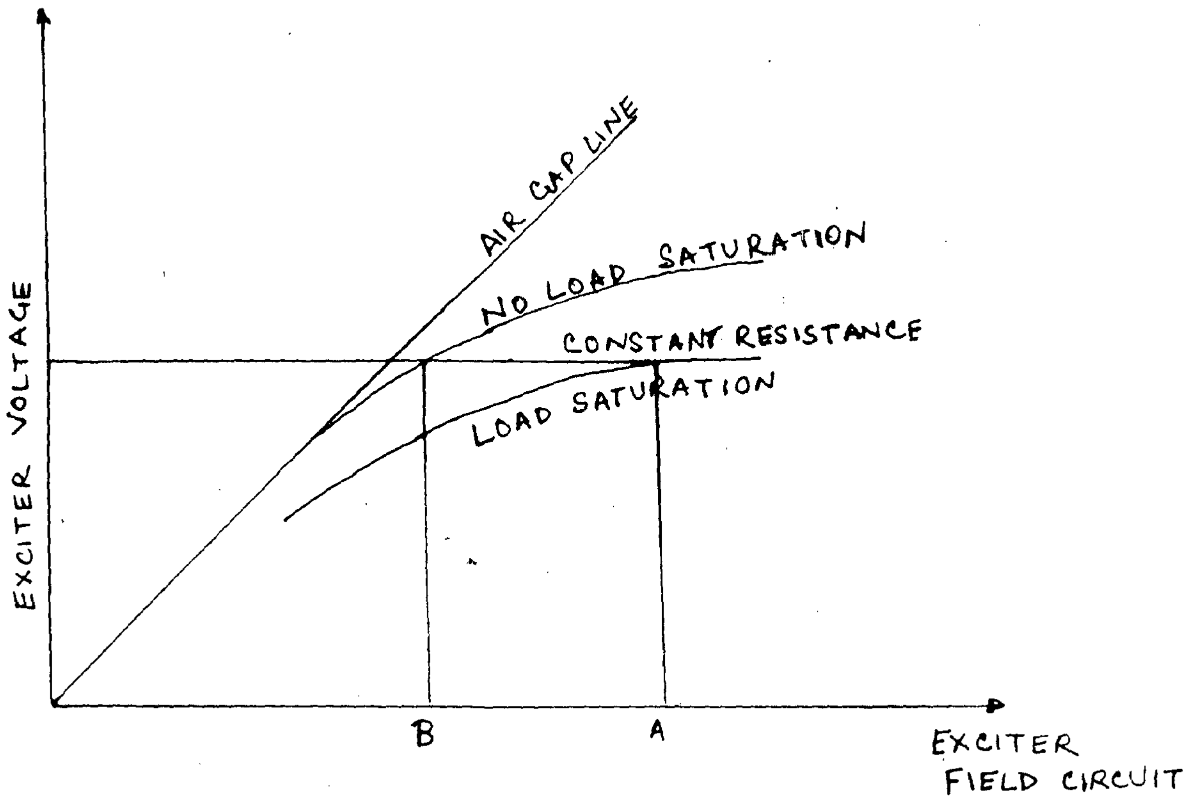


FIG. 4. EXCITER SATURATION CURVES

The voltage e_q' and e_d' are the q and d components of a voltage e' behind transient reactance. The above two equation indicate that during the transient the machine can be represented by the circuit diag shown in the Figure [3] It is interesting to note that since e_d' and e_q' are d and q axis stator voltages. They represent $\sqrt{3}$ times the equivalent stator rms voltages. It can be verified that $e_q' = \sqrt{3}E_q'$. The voltage e' is not a constant it will change with change in flux linkage in the d and q-axis rotor circuits. The differential equation for the voltages e_d' and e_q' are written below. The d-axis flux linkage equations for this model are

$$\lambda_d = L_d i_d + L_{AD} i_F \quad \text{pu} \qquad (2.8)$$

and $\lambda_F = L_{AD} i_d + L_F i_F \quad \text{pu} \qquad (2.9)$

From the above equation, if i_F is eliminated than the following equation can be derived

$$\lambda_d - \sqrt{3}E_q' = L_d' i_d \quad \text{pu} \qquad (2.10)$$

Similarly, for the q-axis

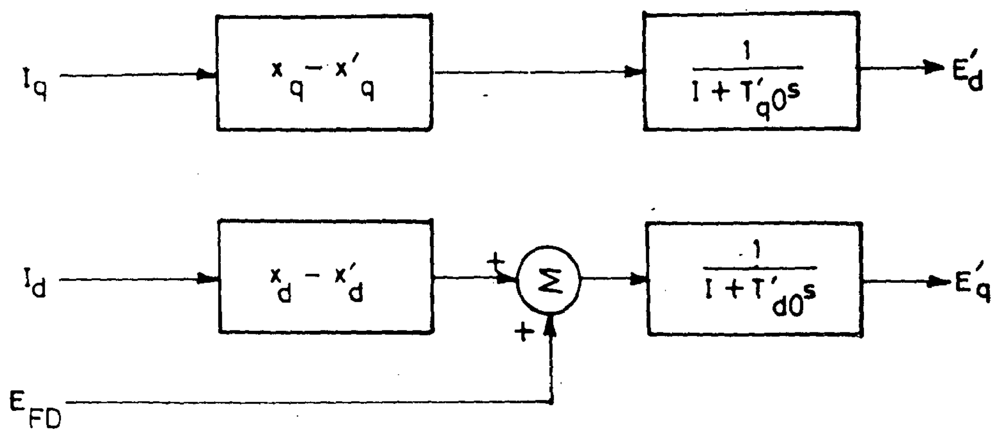
$$\lambda_q = L_q i_q + L_{AQ} i_Q \quad \text{pu} \qquad (2.11)$$

$$\lambda_Q = L_{AQ} i_q + L_Q i_Q \quad \text{pu} \qquad (2.12)$$

eliminating i_Q we compute

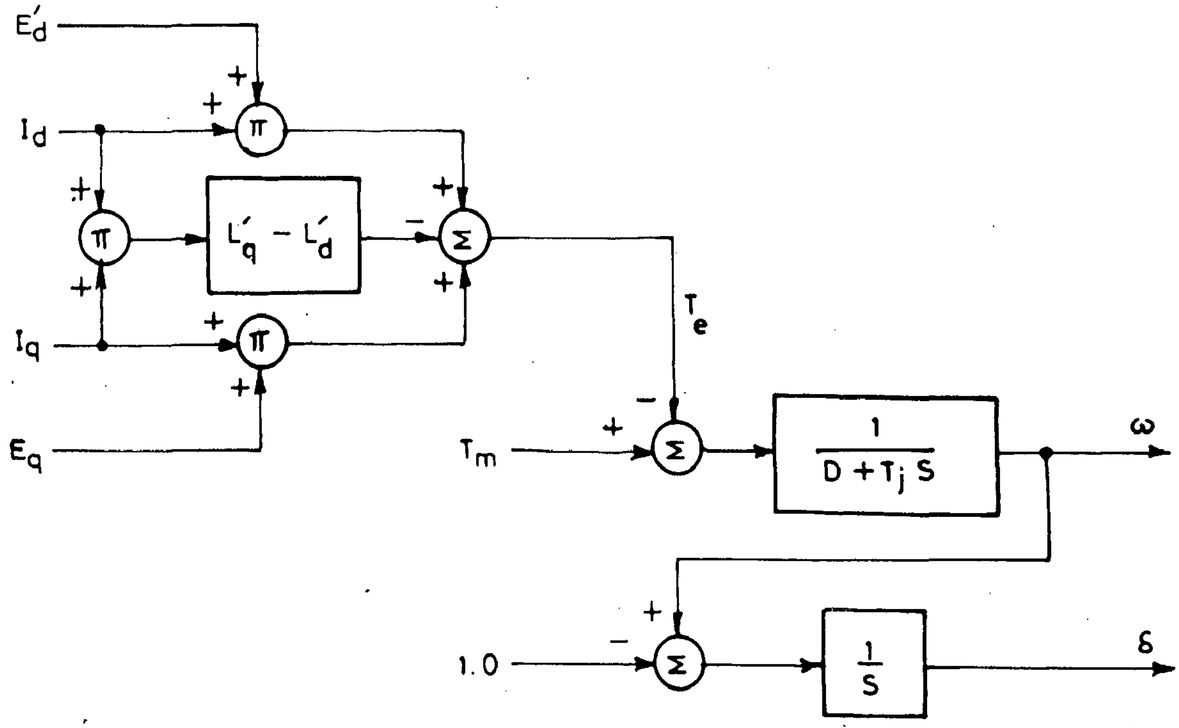
$$\lambda_q - (L_{AQ} / L_Q) \lambda_Q = (L_q - L_{AQ}^2 / L_Q) i_q \quad \text{pu} \qquad (2.13)$$

by defining



BLOCK DIAGRAM REPRESENTATION OF THE TWO AXIS MODEL

FIG.5.



BLOCK DIAGRAM REPRESENTATION OF (2.23)

FIG. 6.

$$L_q' = L_q - L_{AQ}^2 / L_Q \quad \text{pu} \tag{2.14}$$

We also define

$$\sqrt{3}E_q = e_q = L_{AD}\, i_F \quad \text{pu} \tag{2.15}$$

$$\sqrt{3}\, E_d = e_d = L_{AQ}\, i_Q \quad \text{pu} \tag{2.16}$$

We can show that

$$E + x_d\, I_d = E_q' + x_d' I_d \tag{2.17}$$

and $$E_d + x_q\, I_q = E_d' + x_q'' I_q \tag{2.18}$$

From the Q circuit voltage eqn. $r_Q\, i_Q + d\lambda Q/dt = 0$

and by using (2.8) with (2.15) we get

$$T_{qo}'\, \dot{E}_d' = -E_d' - (x_q - x_q')\, I_q \tag{2.19}$$

where for uniformity, we adopt the notation

$$\tau_{qo}' = \tau_{qo}'' = L_Q / r_Q \tag{2.20}$$

Similarly, from the field voltage equation

we get

$$\dot{E}_q' = \frac{1}{\tau_{do}'}\,(E_{FD} - E) \tag{1}$$

To complete the description of the system, the

electrical torque is obtained from $T_e = \lambda_d\, i_q - \lambda_q i_d$
which is used in two more earlier eqns. to get

$$T_e = E_d' I_d + E_q' I_q - (L_q' - L_d')\, I_d\, I_q \tag{2.22}$$

The remaining system equations are given by

$$\tau_j \dot{\omega} = T_m - D_\omega - [E_d' I_d + E_q' I_q - (l_q' - l_d') I_d I_q]$$
$$\dot{\delta} = \omega - 1 \qquad (2.23)$$

By combining the Figs. (5 & 6) the complete block diagram for the model is obtained. Again saturation can be accounted by taking

$$E = E_q' - (x_d - x_d') I_d + E_\Delta \qquad (2)$$

where E_Δ is a voltage increment that corresponds to increase in field current due to saturation. This change can be incorporated in the block diagram.

(ii) <u>The one axis model</u> - <u>neglecting amortissear effects</u>

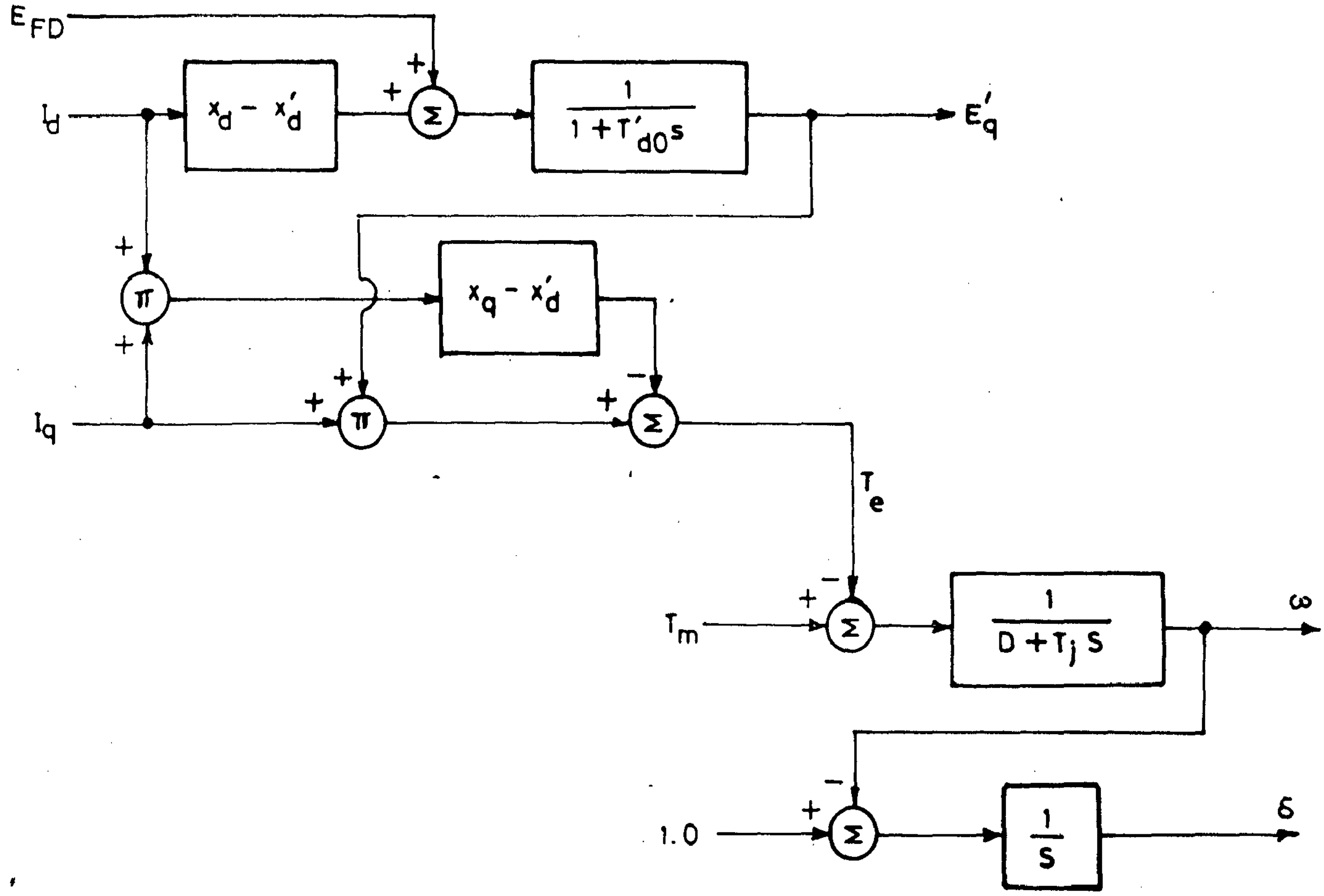
This model is similar to the model described for the two axis model. But there is one exception and that is the absence of Q circuit. This eliminates the differential equation for E_d' and e_d' (which is a function of current i_Q). The voltage behind transient reactance e' has only the component e_q' changing by field effects according to equations (2.21) and (2.24). The component e_d' is completely determined from the currents and v_d . Thus the system equations are

$$\tau_{do}' \dot{E}_q' = E_{FD} - E \quad pu$$

and $$E = E_q' - (x_d - x_d') I_d \quad pu \qquad (2.25)$$

The voltage E_d' is obtained with $\lambda_d = 0$ and we get

$$E_d' = v_d + x_q' I_q + rI_d \quad pu \qquad (2.26)$$



BLOCK DIAGRAM REPRESENTATION OF THE ONE AXIS MODEL

FIG. 7.

The torque is derived from $T_{e\phi} = \lambda_d i_q - \lambda_q i_d$. (2.27)

In the absence of the Q - circuit $\lambda_q = L_q i_q$.

$$\therefore \quad T_e = E_q' I_q - (L_q - L_d') I_d I_q \text{ pu} \qquad (2.28)$$

Thus the remaining system equations are

$$\tau_j \dot{\omega} = T_m - D\omega - [E_q' I_q - (L_q - L_d') I_d I_q] \text{ pu} \qquad (2.29)$$

and $\dot{\delta} = \omega - 1$ pu (2.30)

The block diagram representation is shown in the Fig. [7].

(iii) <u>Infinite bus model</u>

From the equation $\tau_{do}' \dot{E}_q' = E_{FD} - E$ we note that the voltage E_q' which corresponds to the d-axis field flux linkage changes at a rate that depends upon τ_{do}'. This time constant is of the order of several seconds. The voltage E_{FD} depends on the excitation system charac - teristics. If the E_{FD} does not change very fast and if the disturbance causing the transient is short, in some cases the assumption that the voltage (E_q' or e_q') remains constant during the transient can be justified. Under this assumption the voltage behind transient reactance E' or e' has a q-axis component E_q' or e_q' which is always constant. The system equation to be solved is given below -

$$T_e = E_q' I_q - (L_q - L_d') I_d I_q \text{ pu} \qquad (2.31)$$

Allis Chalmers	Regulex regulator
General Electric	Amplidyne regulator
	Altemex
	Altemex - thyristor
Westinghouse	Mag -A - stat regulator
	Brushless (1967 on)
	TRA regulator.

The Fig. [8]. shows the significant transfer functions which should be included for satisfactory representation in computer studies. Many other system types may be represented if it is assumed that the excitation system ceiling voltage is independent of the Generator terminal conditions. V_T is the terminal voltage applied to the regulator input. The first transfer function is a simple time constant T_R representating regulator input filtering. For most systems, T_R is very small and may be considered to be zero. The first summing point compares the regulator reference to the output of the input filter to determine the voltage error input to the regulator amplifier. Most computer programs do not require an input of V_{REF} but rather internally calculate the proper value by assuming V_T at t = 0 at the proper value. The second summing point combines voltage error with the excitation damping error signal. The main regulator transfer function consists of gain K_A and a time constant T_A. Following with the network constraints (to determine the currents) and the condition that E_q' is constant. The next step in simplifying the mathematical model of the machine is to assume that E_q' and E' are approximately equal in magnitude and that these angles with respect to reference voltage are approximately equal (or differ by a small angle that is constant). Under these assumptions E' is considered constant. This is the constant voltage behind transient reactance representation used in the classical model of the synchronous machine.

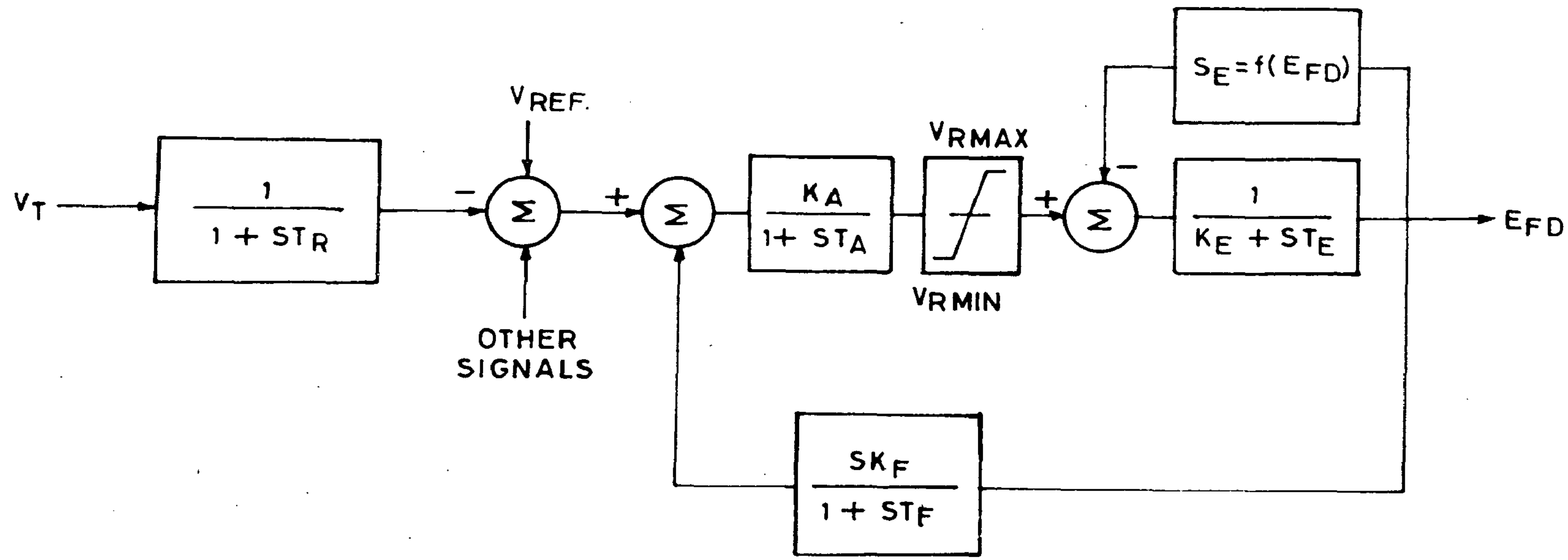
2.4 EXCITATION SYSTEM MODELS

The program allows following excitation system representations.

In the development of the excitation system block diagrams, it has been necessary to establish a per unit voltage base. One per unit generator voltage is defined as rated voltage. One p.u. exciter output voltage is that voltage required to produce rated generator voltage on the generator air gap line.

i. Type 1- Continuously acting Regulator and Exciter

The type 1 excitation system is representative of the majority of modern systems now in service and presently being supplied. This includes most continuously acting systems with rotating exciters such as



IEEE TYPE-1 EXCITATION SYSTEM
FIG. 8.

this the maximum and minimum limits of the regulator are imposed so that large input error signal cannot produce a regulator output which exceeds practical limits. The next summing point subtracts a signal which represents the saturation function $S_E = f\ (E_{FD})$ of the exciter. That is the exciter output voltage (or generator field voltage E_{FD}) is multiplied by a non-linear saturation function and subtracted from the regulator output signal. The resultant is applied to the exciter transfer function $1/(K_E + ST_E)$. When a self-excited shunt field is used, K_E represents the setting of the shunt field rheostat and provides a positive feed back of exciter output. To esta - blish initial conditions, K_E is often chosen that it is equal to the saturation function at the initial value of E_{FD}. At this value, the shunt field exactly compensates for exciter saturation and no regulator output is required to establish the initial value of E_{FD}. For those systems with a seperately excited exciter, regulator output is required to establish initial value of E_{FD}. The following expression must be satisfied during s.s. condition.

$$V_R - (K_E + S_E)\ E_{FD} = 0, \qquad (2.32)$$

$$E_{FD_{min}} \leq E_{FD} \leq E_{FD_{max}} \qquad (2.33)$$

The sign of K_E is negative for a self - excited shunt field. At ceiling, or $E_{FD} = E_{FD_{max}}$

$$V_{R_{max}} - (K_E + S_{E_{max}})\ E_{FD_{max}} = 0 \qquad (2.34)$$

K_E is always specified as input data or program logic, to permit automatic calculation. If any two of the following three constants V_{Rmax}, S_{Emax}, and $E_{FD\ max}$ are known then the third constant is also calculated. The minimum value of E_{FD} is zero and cannot be negative.

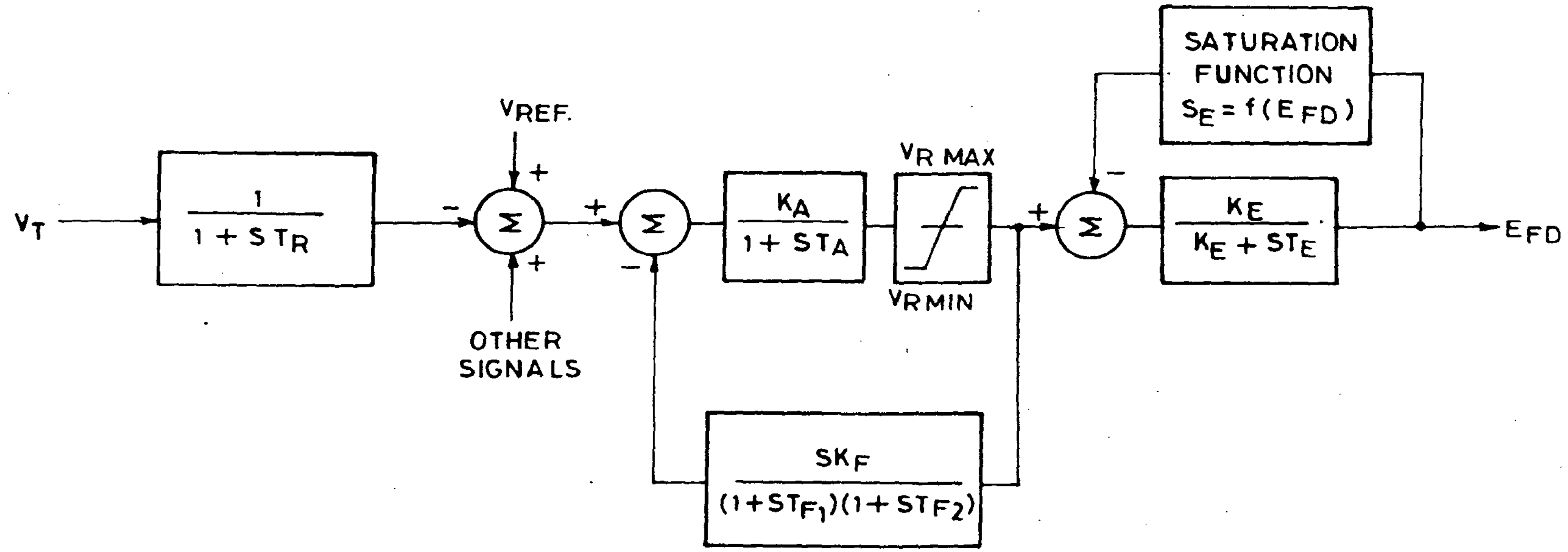
Saturation function.

The exciter saturation function S_E is defined as a multiplier of exciter output E_{FD} to represent the increase in exciter excitation requirements because of saturation. The Fig. [4]. illustrates the calculation of a particular value of S_E. At a given exciter voltage, the quantities A and B are defined as the exciter excitation to produce the output voltage on the constant resistance load saturation curve and air gap line, respectively.

$$S_E = \frac{A-B}{A} \qquad (2.35)$$

ii. IEEE Type 1S Excitation System - Controlled rectifier systems with Terminal potential supply only

The excitation source is the terminal voltage with controlled rectifiers only. If the ceiling voltage is proportional to the gen. terminal voltage than this kind of system responds quickly. Here $V_{Rmax} = K_P V_T$. In general, the constants of this type of system are such that $K_E = 1$, $T_E = 0$, and $S_E = 0$.



IEEE TYPE-2 EXCITATION SYSTEM

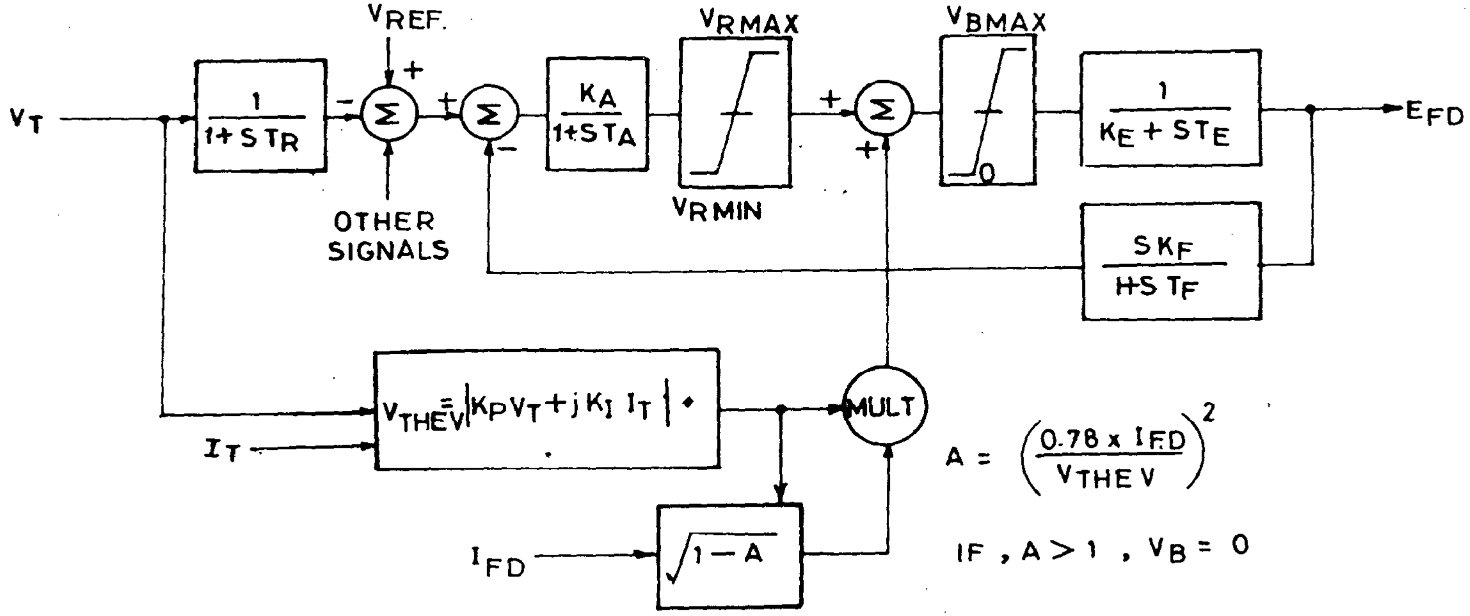
FIG. 9.

iii. IEEE type 2-Rotating rectifier system exc sys

In this kind of system the major damping loop input is from the regulator output. An example is the Westinghouse brushless system. The transfer function has one additional time constant to compensate for the exciter which is not included within the loop. Other characteristics are similar to type 1.

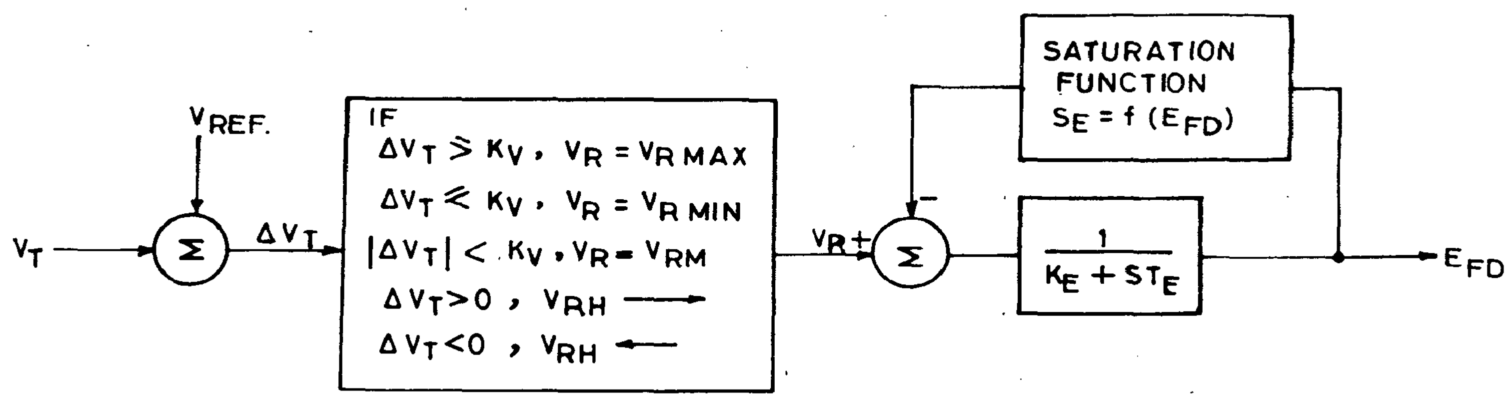
iv. IEEE Type 3 static with terminal potential and current supplies

Here gen terminal current is used with potential as the excitation source. An example of such a system is the General Electric SCPT. The type 3 system has been developed to represent this particular static system. The regulator transfer functions are similar to type 1, up to and including the regulator output limiter (V_{Rmax} - V_{Rmin}). The following summing point combines the regulator output with the signal representing the self excitation from the generator terminals. K_P is the coeff of shunt excitation supply proportional to terminal voltage. Similarly K_I is the coeff of the supply obtained from the terminal current transformers. The multiplier (MULT) accounts for the variation of self-excitation with change in the angular relation of field current I_{FD} and self excitation voltage V_{THEV}. The $V_{B\,max}$ sets the excitation system output to zero when $A > 1$ i.e. when field current exceeds the excitation output current.



IEEE TYPE-3 EXCITATION SYSTEM

FIG. 10.



IEEE TYPE-4 EXCITATION SYSTEM

FIG. 11

v. IEEE Type 4- Non continuously acting

The systems described above are representatives of modern high-gain, fast acting excitation sources. The type 4 system is used to represent other systems, in particular those that were used immediately before the development of the continuously acting excitation systems. Examples are

General Electric GFA4 regulator

Westing house BJ 30 regulator

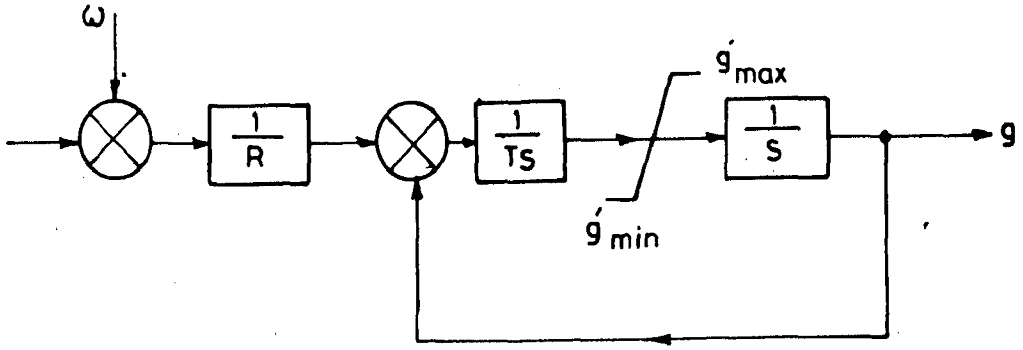
Exciter representation is similar with the exception that there is no major damping loop. Depending upon the magnitude of voltage error ΔV_T, different regulator modes are specified. If voltage error is larger than the fast raise/lower contact setting Kv (typically five percent), V_{Rmax} or V_{Rmin} is applied to the exciter depending upon the sign of the voltage error. For a voltage error less than Kv, the exciter input equals the rheostat setting V_{RH}. The rheostat setting is adjusted up or down depending upon the sign of the voltage error. The time constant representing the slow adjustment of exciter field voltage is T_{RH}.

2.5 TURBINE AND GOVERNER MODELS

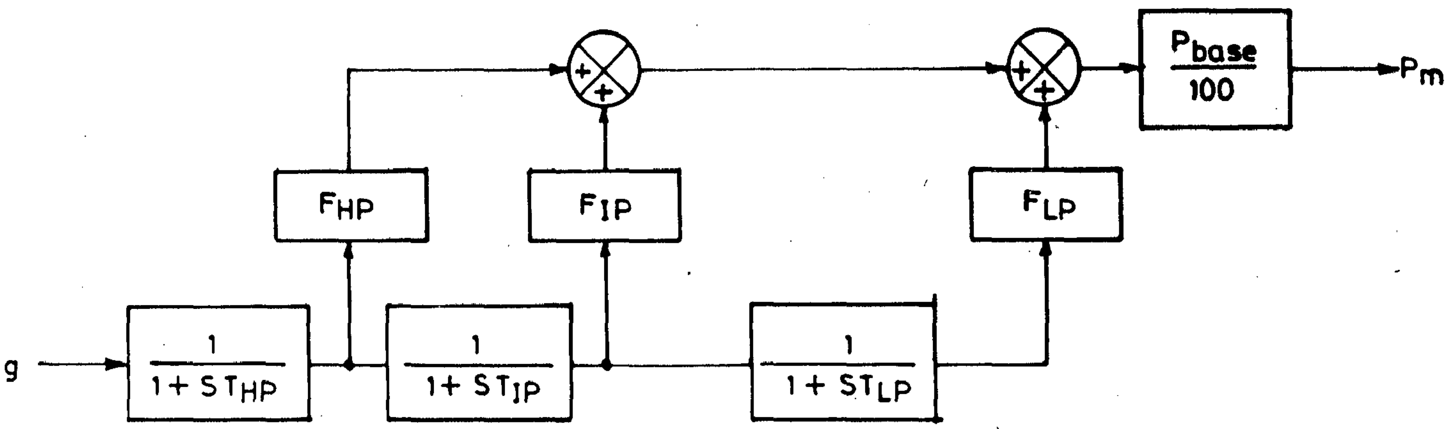
The program allows for the following turbine governor models.

(i) Steam turbines

All compound steam turbine utilize governor controlled valves at the inlet to the high pressure (or very high pressure) turbine to control steam flow. The steam



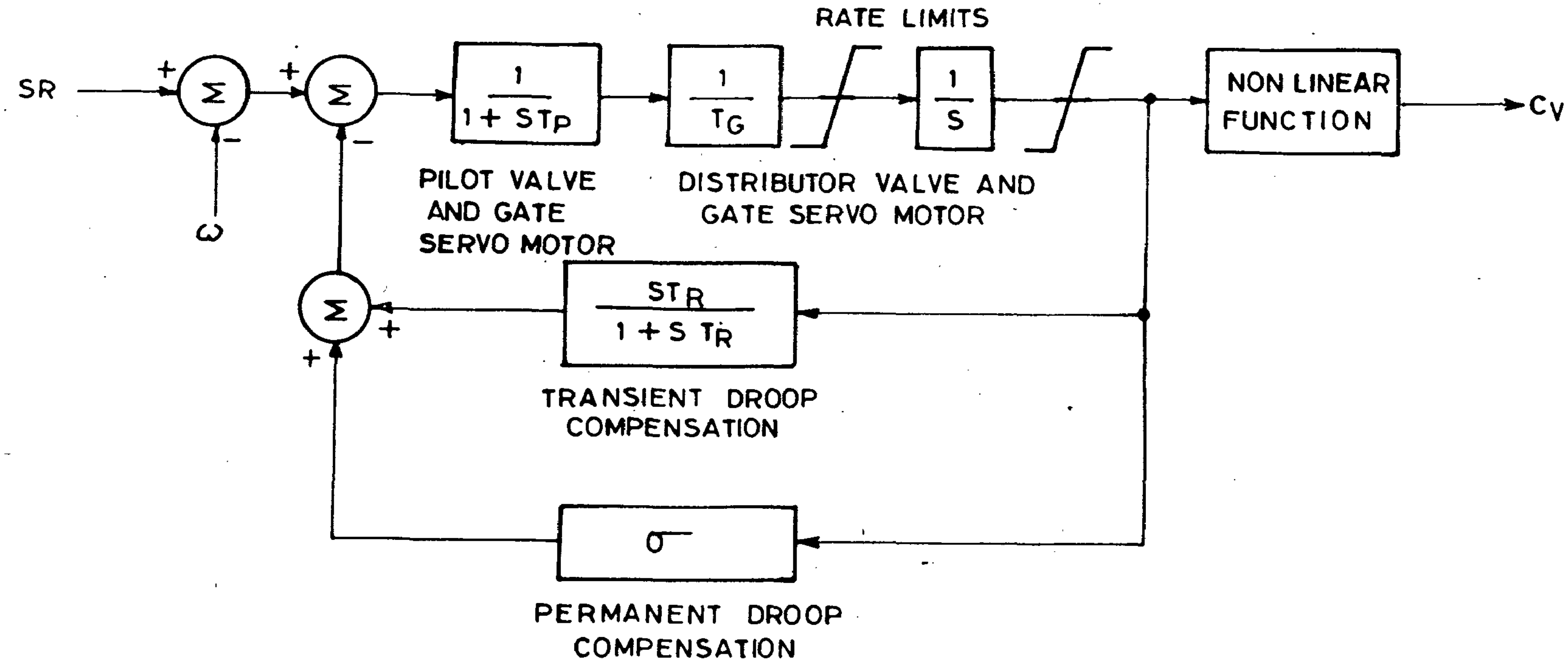
SPEED GOVERNOR



STEAM TURBINE

STEAM TURBINE AND GOVERNOR MODEL

FIG. 12.



MECH – HYDRAULIC SPEED GOVERNING SYSTEM FOR HYDRO TURBINES

FIG. 13.

chest and inlet piping to the first turbine cylinder and reheaters and cross over piping down stream all introduce delays between valve movement and change in steam flow. The principal objective in modelling the steam system for stability studies is to account for these delays. Flows into and out of any steam vessel are related by a simple time constant. Pressure changes at the entrance to the governor controlled valves may also be important in some stability studies. Boiler controls are designed to regulate valve pressure, but the controlled boiler response is not fast enough to compensate for pressure variations due to the movement of the governor-controlled valves.

Between the governor controlled valves and the high pressure turbine is a steam bowl or chest. This introduces a time delay between changes in a valve steam flow and steam flow in the high pressure turbine. let T_{CH} be this time constant. The block diagram shows a method of accounting for boiler tube drop. The pressure P_{SG} is an internal boiler pressure assumed constant over the study interval and P_T is the variable pressure at the entrance to the governor controlled valves. The parameter K_{PD} is a pipe-drop coefficient. The flow into the steam chest is

$$mCV = P_{GV}\ (P_{SG} - K_{PD}\ m\ CV^2) \qquad (2.36)$$

where appropriate per unit variables are assumed.

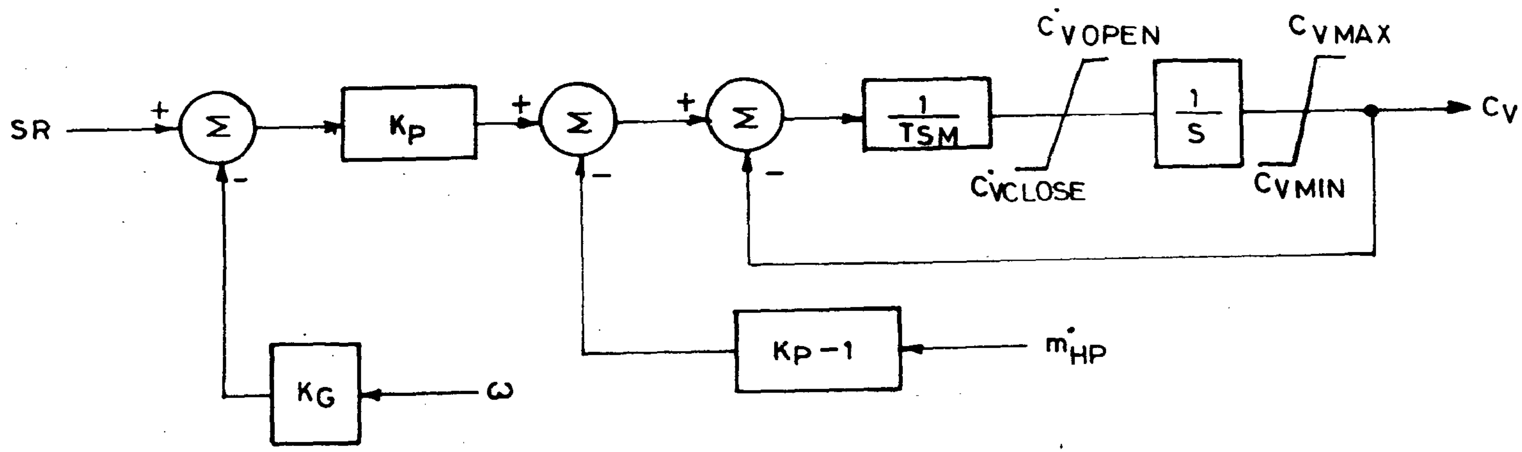
The effect of boiler tube drop can be approximated by reducing the effective gain of the governer controlled valves to the fraction F. If boiler tube drop is ignored, F is unity. Extraction steam taken at various turbine stages to heat feed water usually do not have significance for stability studies. T_{CH}, T_{RH} and T_{CO} are delays due to steam chest and inlet piping, reheaters and cross over piping respectively. The fraction F_{VHP}, F_{HP}, F_{IP} and F_{IP} represent portions of the total turbine power developed in the various cylinders.

Hydraulic Turbine

The transient characteristics of hydro turbines are determined by the dynamics of water flow in the penstock. The most precise models of water pressure and flow in the penstock are those which treat the travelling wave phenomena though the travelling wave models are not necessary for stability studies. The time constant T_W is called the water starting time or water time constant.

(ii) Mechanical hydraulic governing unit

The mech-hydro speed - governing system for a hydro-turbine consists of a speed governer, a pilot value and servometer, a distributor value and gate servometer and governer controlled gates which are functionally related. The speed governing requirements for hydroturbines are strongly influenced by the effects of water inertia and the dashpot feedback is required to achieve stable



ELECTRO-HYDRAULIC GOVERNING SYSTEM FOR HYDRO TURBINES

FIG. 14.

performance. The droop feedback reduces the likelihood rate limiting in stability analysis. Position limit exist corresponding to the extremes of gate opening.

(iii) Electric Hydro Unit

Modern speed governing systems for Hydro turbines may involve electrical apparatus to perform the low-power functions associated with speed sensing and droopcompensation. This apparatus provides greater flexibility and improved performance in both dead band and dead time. For inter - connected system operation, the dynamic performance of the electric governer is necessarily adjusted to be essentially the same as that for mechanical governer so that a seperate model is not needed.

2.6 RELAY REPRESENTATION

The three relay types considered in the program has been discussed in great detail below:

(1) Distance Relays

The impedance type distance relay has been considered here. Here the torque produced by a current element is balanced against the torque of a voltage element. The current element produces positive torque while the voltage element produces negative torque. The operating characteristic in terms of voltage and current is shown in Fig. [15].

Hence from this diagram we see that the relay operates only when the value of Z(line impedance) is less than the constant value of Z. By adjustment the slope of the operating characteristic is changed, so that the relay will respond to all values of impedance less than any desired upper limit. The operating characteristic of the impedance relay on the R-X axis neglecting the control spring effect is shown in fig.[16]

The circle is defined by its radius (Z) and center (in the above case 0,0). The value to which the relay is set is taken as an input data. The user also specifies as part of input the total line tripping time (relay plus breaker time) and the dead time between the tripping point and the time when line reclosing is done. Single- shot reclosure is allowed. It is a practice to adjust the first zone of distance relay to reach 80 percent to 90 percent of the length of a two- ended line or to 80 percent to 90 percent of the distance to the nearest terminal of a multi terminal line. There is no time delay adjustment for this type of unit. The principal purpose of the second zone unit of a distance relay is to provide protection for the rest of the line beyond the reach of the first zone unit. It should be adjusted so that it will be able to operate even for arcing faults at the end of the line. To do this the unit must reach beyond the end of the line. Even if arcing is not to be

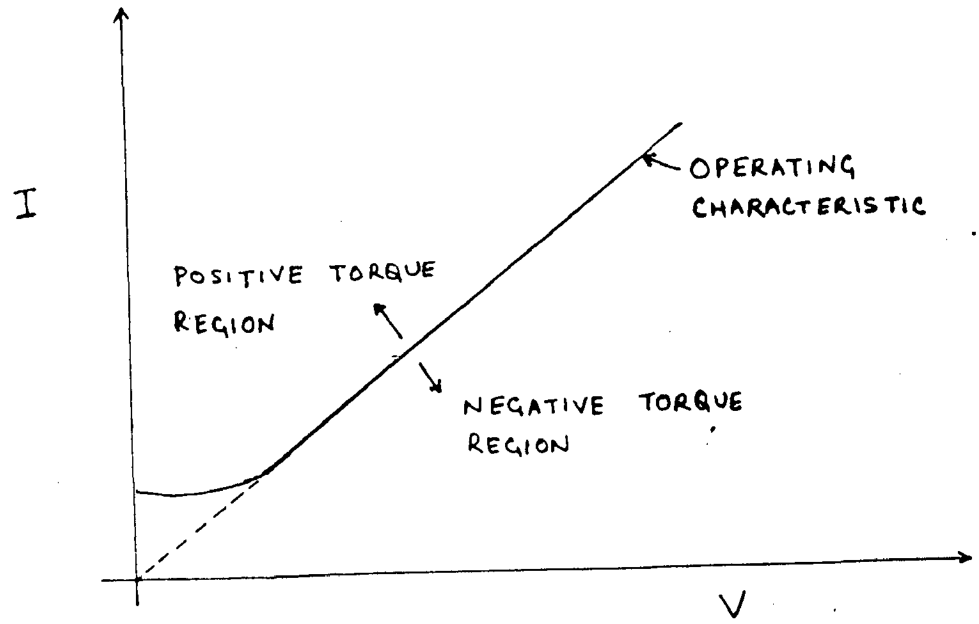


FIG. 15. OPERATING CHARACTERISTIC OF AN IMPEDANCE RELAY

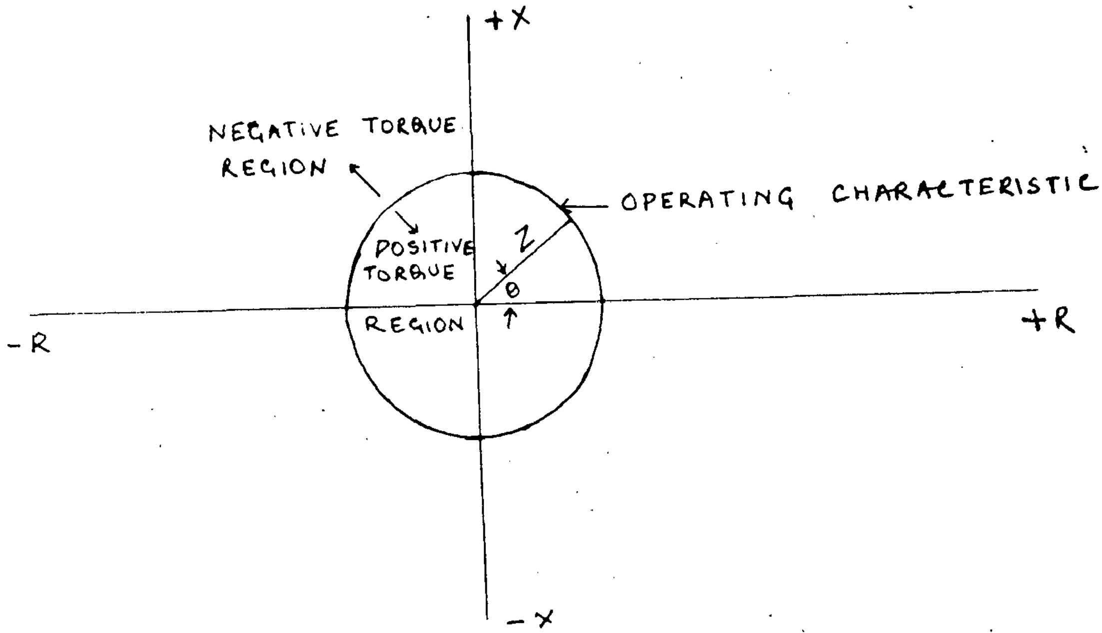


FIG. 16. OPERATING CHARACTERISTIC OF AN IMPEDANCE RELAY ON AN R-X DIAGRAM

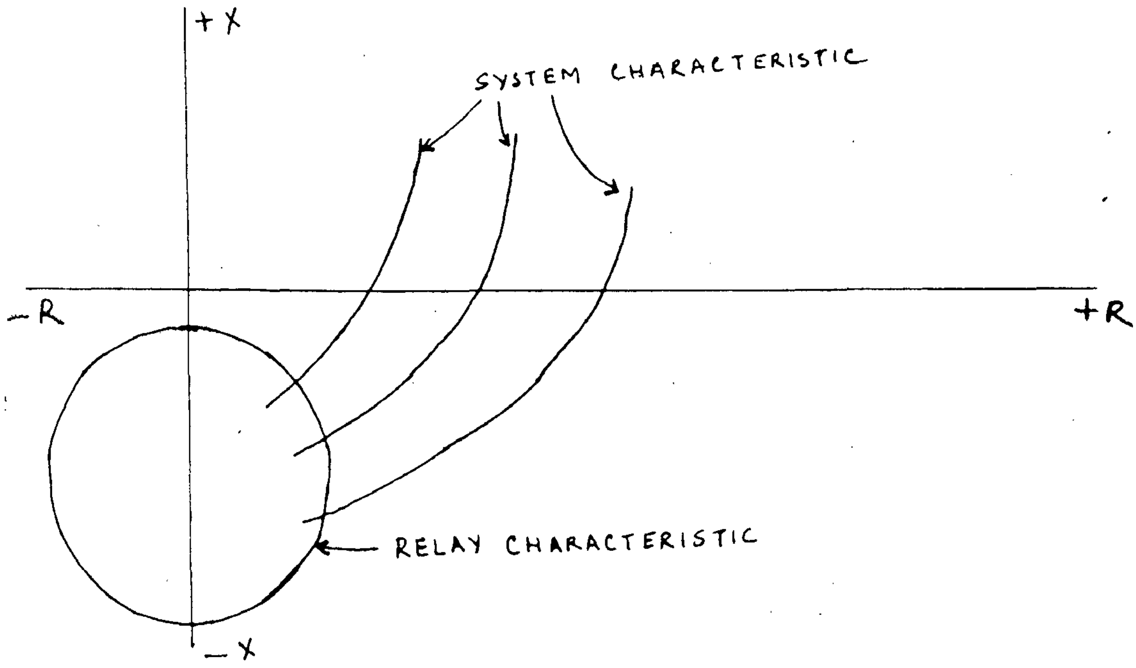


FIG. [illegible] LOSS OF EXCITATION RELAY AND SYSTEM CHARACTERISTICS considered, the underreaching tendency has to be taken into account. It is customary to have the second zone unit reach to at least 20 percent of an adjoining line section. The maximum value of the second zone reach also has a limit. The third zone unit provides back-up protection for faults in adjoining line sections. The third zone time delay is 0.4 to 1.0 sec. Its reach should extend beyond the end of the longest adjoining line section.

Under voltage relay

A voltage relay is one in which the actuating source is voltage of the circuit obtained either directly or from a voltage transformer. It is derived from the single quantity electromagnetic attraction type or induction type. In this kind of relay it closes the contacts when the actuating quantity (voltage) decreases below the reset magnitude for which the relay is operated. This relay does not have a wide range of adjustment because they are expected to operate within a limited range from the normal magnitude of the voltage.

Loss of excitation relay

Some systems cannot tolerate the continued operation of a generator without excitation. In fact if the generator is not disconnected immediately when it loses excitation wide - spread instability may very quickly develop and a major system shut down may occur. When a generator loses excitation it draws reactive power amount to as much as 2 to 4 times the generators rated load. Before it lost excitation, the generator may have been delivering reactive power to the system. Thus, this large reactive load suddenly thrown on the system, together with the loss of generators reactive power output, may cause widespread voltage reduction, which in turn will cause instability. Hence when loss-of excitation in relays occur then the generator should be tripped and removed from the system to prevent any extensive damage. For this loss of excitation relays are used. It is a directional distance type operating from the ac current and voltage at the main generator terminals. The Figure (17) shows the loss of excitation characteristics and the operating characteristics of one type of loss of excitation relay on an R-X diagram .

No matter what the initial conditions, when excitation is lost, the equivalent generator impedance traces a path from the first quadrant into a region of the fourth quadrant that is entered only when excitation is severely reduced or lost. By encompassing this region within the relay characteristic, the relay will operate when the generator starts to slip and will trip the field breaker and disconnect the generator from the system before the generator or the system can be harmed. The generator may then be returned to service immediately when the cause of excitation failure is corrected.

The tripping and reclosing times are specified as input data for all relays.

CHAPTER - 3

SOLUTION ALGORITHM

The equation which represents the dynamic behaviour of power system can be conveniently divided into two groups.

(i) Equations describing the dynamic behaviour of the machines and their controllers. These consists of a set of differential equations which may take the form.

$$\dot{y} = g\ (y, z) \qquad (3.1)$$

(ii) Equations describing the steady state behaviour of the network and generator armature circuits. These consists of algebraic equations which may take the form.

$$h(y, z) = 0 \qquad (3.2)$$

Variables y are defined as the system state variables. Variables z are referred to as auxiliary variables and are associated with the network. Cenerator speed and angular position are examples of state variables, whereas generator terminal voltages and currents are examples of auxiliary variables.

The structure of the network equations (3.2) may be altered in time due to network changes such as fault initialization, fault clearing, line switching etc. At such instants discontinuities occur in the auxiliary variables but not in the state variables.

Two fundamental approaches to the problem have been adopted;

(a) Using a low-flow technique to solve the network equations and to evaluate the nodal voltages which in turn are used in solving the network dynamic equations.
(b) Solving the network dynamic equations simultaneously and in conjunction with the network algebraic equations.

The former method is faster but it is less accurate especially if network islanding is to be considered because the load flow algorithm is not independent of the network reference node. The later method is numerically more stable, robust and inherently capable of handling islanding. In the first method the differential equations are numerically integrated explicitly with the algebraic equations solved as a sub problem. A typical algorithm of this type is the Runge -Kutta Integration technique. In the second method an implicit technique is adopted in which the differential and algebraic equations are considered together rather than successively. To facilitate this, the differential equations must be transformed into algebraic equations and appended to the existing set of algebraic equations.

3.2 NETWORK AND ARMATURE EQUATIONS

The solution of the network and armature equations forms a major step in the overall solution procedure. The state variables used in the solution comprise of the internal voltages E'_q and E'_d and rotor position θ for each generator. The auxiliary variables which are calculated are the complex voltages and currents at generator terminals. The transmission system can be represented by the matrix of driving point and transfer admittance seen from the terminals of the generators. This matrix includes the system loads which are represented as constant impedances. The network can be described by the equation.

$$[\bar{I}] = [Y_{TT}][\bar{V}] \quad (3.3)$$

where $\bar{I}$ and $\bar{V}$ are based upon the synchronous reference frame.

For each synchronous generator there are two sealar equations describing the armature circuits.

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} E'_d \\ E'_q \end{bmatrix} - \begin{bmatrix} R_a & -X'_q \\ X'_d & R_a \end{bmatrix} \begin{bmatrix} I_d \\ I_q \end{bmatrix} \quad (3.4)$$

In equation (3.4) the voltages and currents are based upon the individual d, q reference frames of each generator. In order to obtain a combined solution of equations (3.3) and (3.4) all the equations must first be transformed to a common reference frame.

Let,

$$\bar{I} = I_{real} + jI_{imag} \tag{3.5}$$

then

$$I_d + j\,I_q = \bar{I}\,e^{-j\phi} \tag{3.6}$$

where ϕ is the angle between the generator d axis and the synchronous reference frame. Similar expressions also exist for $\bar{V}$ and $\bar{E}$. If transient saliency is neglected ($X'_d = X'_q$) then the simultaneous solution of equations (3.3) and (3.4) is quite simple. In this case the two scalar equations in (3.4) can be combined into a single complex equation.

$$(V_d + jV_q) = (E'_d + jE'_q) - (R_a + jX'_d)\,(I_d + jI_q) \tag{3.7}$$

Equation (3.7) transforms to the synchronous reference to become.

$$\bar{V} = \bar{E}' - (R_a + j\,X'_d)\,\bar{I} \tag{3.8}$$

Equations (3.3) and (3.8) can be solved by adding the generator transient impedances $R_a + jX'_d$ at the network terminals. The terminal voltages $\bar{V}$ and currents $\bar{I}$ are calculated from knowing the voltages $\bar{E}' = (E'_d + jE'_q)e^{j\theta}$ behind the transient impedances.

3.2 EFFECT OF SALIENCY

On the other hand, if transient saliency is not neglected the simultaneous solution of equations (3.3) and (3.4) is considerably more difficult. In this case when (3.4) is transformed to the synchronous reference framewe obtain

$$\begin{bmatrix} V_{real} \\ V_{imag} \end{bmatrix} = \begin{bmatrix} E'_{real} \\ E'_{imag} \end{bmatrix} - \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} R_a & -X'_q \\ X'_d & R_a \end{bmatrix} \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} I_{real} \\ I_{imag} \end{bmatrix} \quad (3.9)$$

Two difficulties arise in the solution of equation (3.9).

(i) It cannot be combined into a single complex equation with the form of (3.7).

(ii) The coefficients of I_{real} and I_{imag} are functions of θ and are therefore time varying.

It is possible to combine equations (3.3) and (3.9) to obtain a set of 2N (N= no. of generators) real equations which can be solved directly. However, because the coefficients are varying, the matrix must be refactored or reinverted for every integration time step and this is very time consuming.

One effective method for overcoming these difficulties, requires iterations at each integration time step but uses a matrix which is constant as long as a certain network configuration exists. This method is based upon representing the generator by a fictitions slack voltage behind a fictitions admittance as shown in Fig. (   ). The generator fictitions admittance is defined by .

$$\bar{Y}^{fict} = \frac{R_a - j\frac{1}{2}(X'_d + X'_q)}{R_a^2 + X'_d \; X'_q} \qquad (3.10)$$

and the generator fictitious slack voltage is calculated as

$$\bar{E}^{fict} = \bar{E}' + \frac{j\frac{1}{2}(X'_q - X'_d)}{R_a - j\frac{1}{2}(X'_d + X'_q)} (\bar{E} - \bar{V}^*)e^{j2\theta} \qquad (3.11)$$

Equation (3.11) is derived by considering that the current produced by $\bar{E}^{fict}$ behind $\bar{Y}^{fict}$ should be identical to that obtained by solving equation (3.4) for given E'_d and E'_q.

When the fictitious generator admittances are added to the network, the combined equations for the network and generator armature circuits of the form.

$$\begin{bmatrix} 0 \\ \bar{I} \end{bmatrix} = \begin{bmatrix} Y_{TT} & Y_{TG} \\ Y_{GT} & Y_{GG} \end{bmatrix} \begin{bmatrix} \bar{V} \\ \bar{E}^{fict} \end{bmatrix} \qquad (3.12)$$

Eliminating $\bar{V}$ with Krons reduction we obtain.

$$[\bar{I}] = [\,\bar{Y}_{GG} - \bar{Y}_{GT}\,\bar{Y}_{TT}^{-1}\,\bar{Y}_{TG}\,]\,[\,\bar{E}^{fict}\,] \qquad (3.13)$$

The simultaneous solu tion of equation (3.11) and (3.13) is obtained by iterating the voltage $\bar{V}$. The exact details of the iterative procedure are described below. The convergence of the procedure is very reliable and usually requires two or three iterations.

(i) Set initial estimate of $\bar{V}$ to the terminal voltages obtained in the previous time step.

(ii) Transform generator internal voltages to the synchronous reference frame. For each generator calculate.

$$\bar{E} = (E_d' + j E_q') e^{j\theta} \quad \text{and } \theta$$

(iii) Calculate the fictitious internal voltage E^{fict} for each generator using equation (3.11).

(iv) Calculate the generator currents using equation (3.13).

(v) Calculate new estimates of the terminal voltages from.

$$\bar{V} = \bar{E}^{fict} - \bar{I} / \bar{Y}^{fict} \qquad (3.14)$$

(vi) Check for convergence. For each generator calculate.

$$I_d = j I_q = \bar{I} e^{-j\theta}$$

and

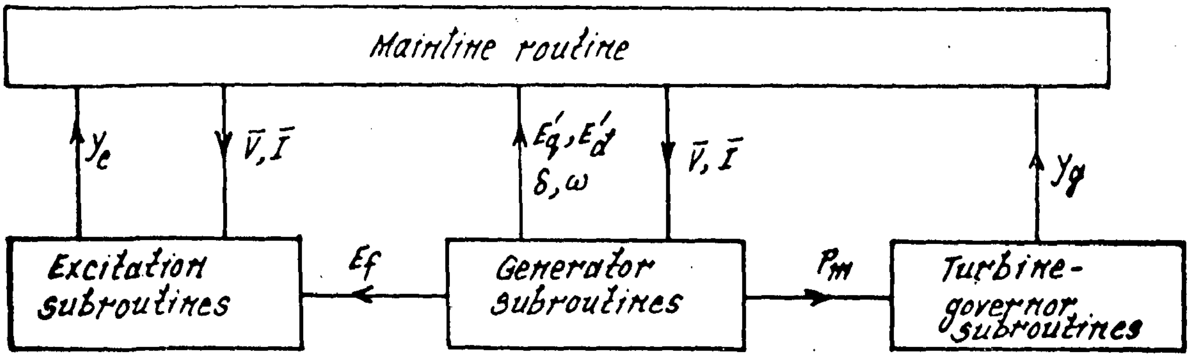
$$V_d + jV_q = \bar{V} e^{-j\theta} \quad \text{if } V_q = E_q' - X_d' I_d - R_a I_q$$

$$\text{and } V_d = E_d' + X_q' I_q - R_a I_d \qquad (3.15)$$

If the solution has not converged return to step (iii).

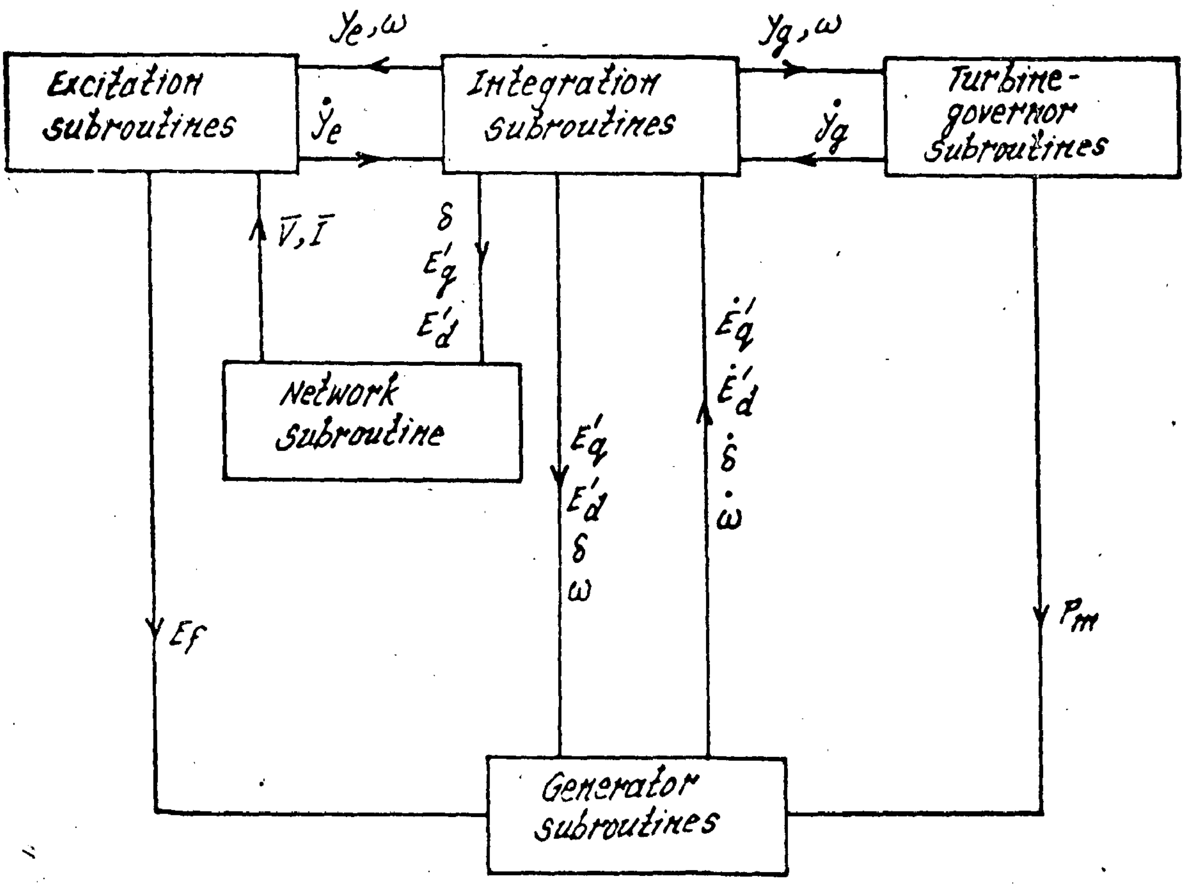
3.3 CALCULATION OF GENERATOR INITIAL CONDITIONS

The algorithm for calculating the generator initial conditions is described below.



Relationship of subroutine variables for calculating initial conditions.

Fig. 11



Relationship of subroutine variables during step by step simulation.

Fig. 12

(i) Set initial estimate of the saturation factor $k = 1$.

(ii) Calculate saturate reactances X_d and X_q.

(iii) Calculate the angle of rotor with respect to the synchronous reference.

(iv) Calculate the d and q axis components of generator current and transform them onto the generator reference.

(v) Calculate the generator transient voltages and the field voltages from

$$E_q' = \text{Mag}\ (\bar{E}_{qd}) - (X_q - X_d')\ I_d \qquad (3.16)$$

where
$$\bar{E}_{qd} = \bar{V} + (R_a + jX_q)\ \bar{I}$$

$$E_d = (X_q - X_q')\ I_q$$

$$E_f = (E_q' + (X_d - X_d')\ I_d)\ /k \qquad (3.17)$$

(vi) Calculate the air gap voltages from the following equations

$$E_{aq} = E_q' - (X_d' - X_\ell)\ I_d$$

$$E_{ad} = E_d' + (X_q' - X_\ell)\ I_q \qquad \therefore E_{at} = \sqrt{E_{aq}^2 + E_{ad}^2} \qquad (3.18)$$

(vii) Calculate a new estimate of the saturation factor k as a function of the air gap voltage.

(vii) If the saturation factor has converged continue to the next step, otherwise return to step (ii).

(ix) Calculate the initial mechanical power as the sum of the generator output and armature loss.

The algorithm to calculate the time derivatives of the state variables is described below:

(i) Define integrator inputs (generator state variables), ω, δ, E_d', and E_q' in terms of the integrator outputs.

(ii) Calculate d and q axis components of the generator current.

(iii) Calculate generator electrical output and losses.

$$P_e = V_{real}\, I_{real} + V_{imag}\, I_{imag}$$

$$P_l = (I_{real}^2 + I_{imag}^2)\, R_a \qquad (3.19)$$

(iv) Calculate saturate reactances X_d, X_q and time constants T_{do} and T_{qo}

$$X_d = k\, X_d^o + (1-k)\, X_l$$

$$X_q = k\, X_q^o + (1-k)\, X_l \qquad (3.20)$$

$$T_{do}' = T_{do}^{o\prime}\, [1-(1-k)\, (X_d^o - X_d')/\, (X_d^o - X_l)]$$

$$T_{qo}' = T_{qo}^{o\prime}\, [(1-k)\, (X_q^o - X_q')/(X_q^o - X_l)] \qquad (3.21)$$

(v) Calculate the air gap voltage and the saturation factor k.

(vi) Calculate the time derivatives of the generator state variables and store them as integrator inputs.

$$\dot{E}_q' = (k\, E_f - E_q' - (X_d - X_d')I_d)/\, T_{do}' \qquad (3.22)$$

$$\dot{E}_d' = (-E_d' + (X_q - X_q')\, I_q)/\, T_{do}' \qquad (3.23)$$

$$\dot{\omega} = (P_m - P_e - P_l - D\omega)/2H, \quad \dot{\delta} = 2\pi f_o \omega \qquad (3.24)$$

3.4 NETWORK REDUCTION

The reduction of the Y matrix is done by matrix operation if we recall that all the nodes have zero injection current except for the internal generator nodes. This property is used to obtain the network reduction as shown below.

Let $\bar{I} = \bar{Y}\,\bar{V}$

where $\bar{I} = \begin{bmatrix} I_n \\ 0 \end{bmatrix}$

Now the matrices Y and V are partitioned accordingly to get

$$\begin{bmatrix} I_n \\ \cdots \\ 0 \end{bmatrix} = \begin{bmatrix} Y_{nn} & Y_{nr} \\ \cdots & \cdots \\ Y_{rn} & Y_{rr} \end{bmatrix} \begin{bmatrix} V_n \\ \cdots \\ V_r \end{bmatrix} \qquad (3.25)$$

Here the subscript n is used to denote generator nodes and the subscript r is used for the remaining nodes. Expanding the above matrix equation we get

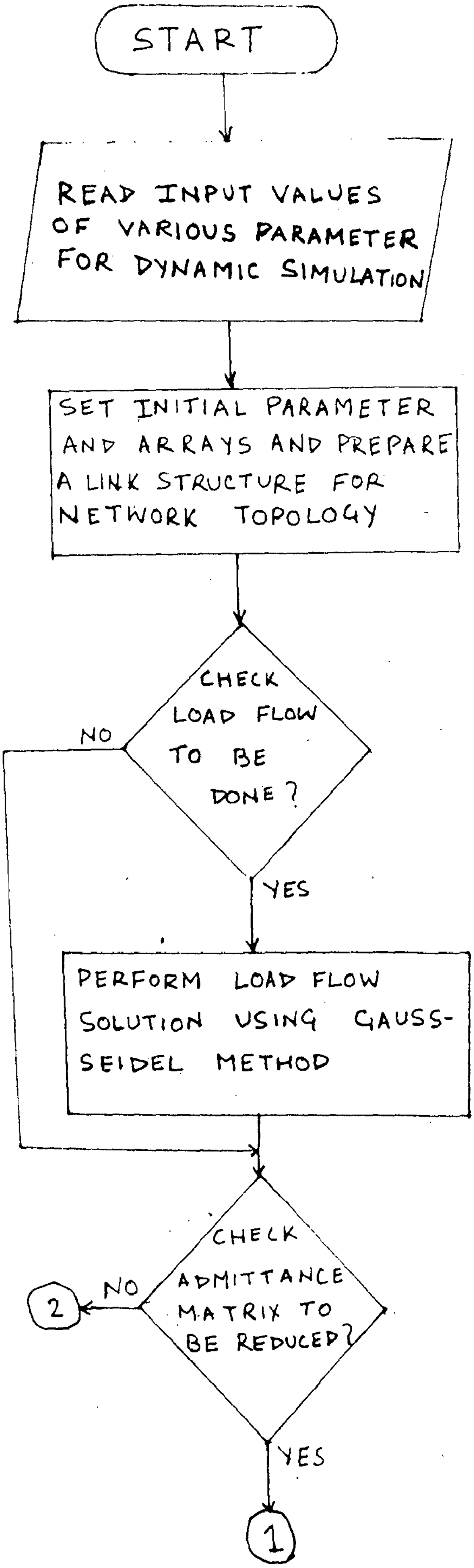
$$I_n = Y_{nn} V_n + Y_{nr} V_r,$$
$$0 = Y_{rn} V_n + Y_{rr} V_r \qquad (3.26)$$

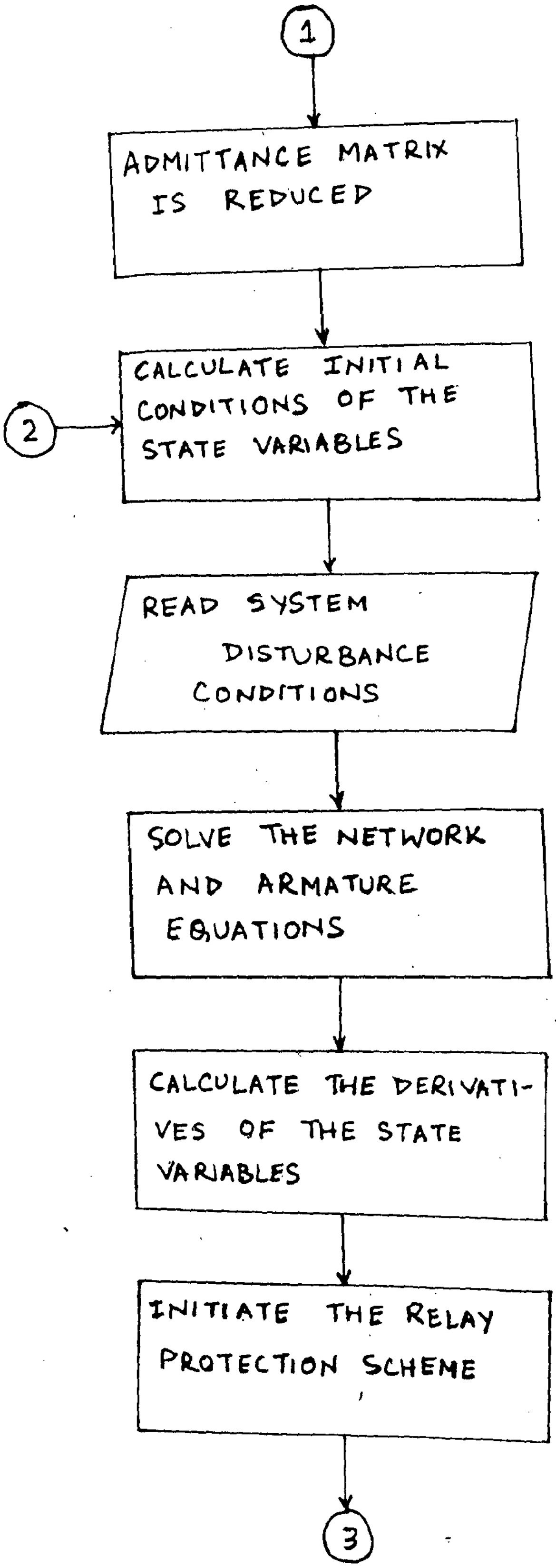
from this V_r is eliminated to find

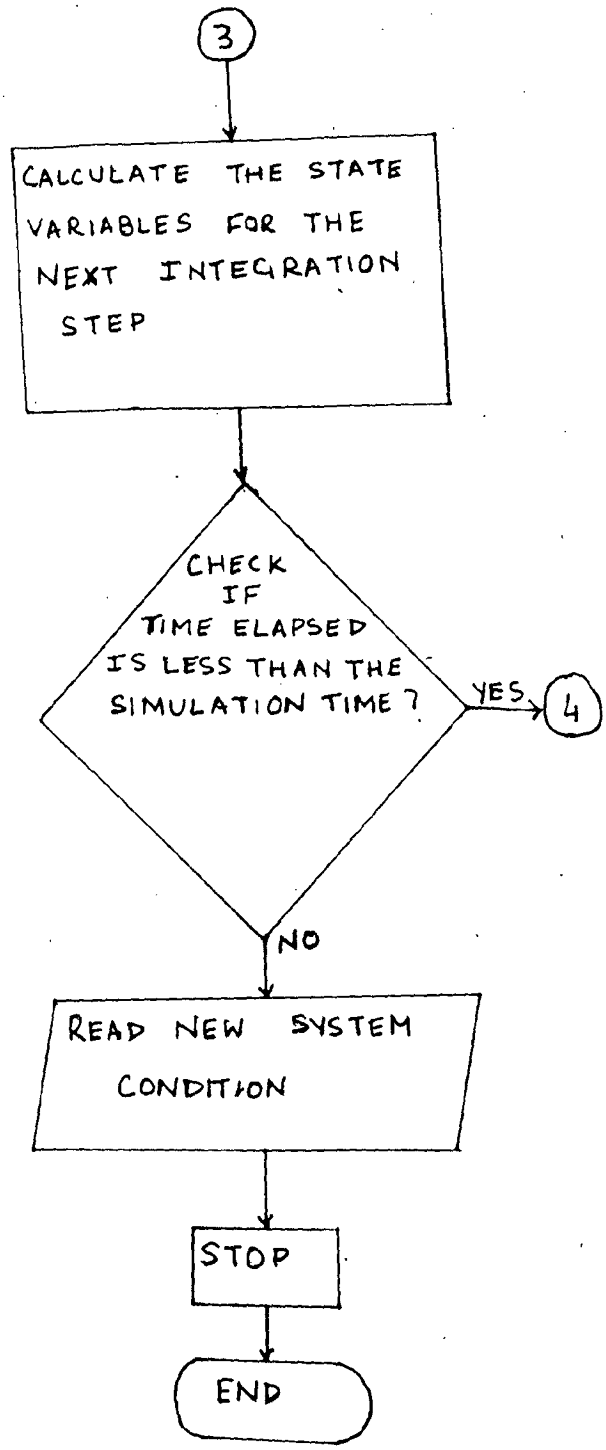
$$I_n = (Y_{nn} - Y_{nr} Y_{rr}^{-1} Y_{rn})\, V_n \qquad (3.27)$$

The matrix $(Y_{nn} - Y_{nr} Y_{rr}^{-1} Y_{rr})$ is the desired reduced Y matrix. It has dimension (nxn) where n is the number of generators. The above method can be used only when the load impedances are treated as constant otherwise the identity of the load buses must be retained.

FLOW CHART


START
READ INPUT VALUES OF VARIOUS PARAMETER FOR DYNAMIC SIMULATION
SET INITIAL PARAMETER AND ARRAYS AND PREPARE A LINK STRUCTURE FOR NETWORK TOPOLOGY
CHECK LOAD FLOW TO BE DONE ?
NO
YES
PERFORM LOAD FLOW SOLUTION USING GAUSS-SEIDEL METHOD
CHECK ADMITTANCE MATRIX TO BE REDUCED?
NO
2
YES
1


1
ADMITTANCE MATRIX IS REDUCED
CALCULATE INITIAL CONDITIONS OF THE STATE VARIABLES
2
READ SYSTEM DISTURBANCE CONDITIONS
SOLVE THE NETWORK AND ARMATURE EQUATIONS
CALCULATE THE DERIVATIVES OF THE STATE VARIABLES
INITIATE THE RELAY PROTECTION SCHEME
3


3
CALCULATE THE STATE VARIABLES FOR THE NEXT INTEGRATION STEP
CHECK IF TIME ELAPSED IS LESS THAN THE SIMULATION TIME ?
YES
4
NO
READ NEW SYSTEM CONDITION
STOP
END

3.5 SIMULATION STEPS

The simulation steps of the program are enumerated below. They will be described in more detail along with the subroutines in the next chapter.

(i) Read Input values of various parameter.

(ii) Perform link structure to store network topology.

(iii) Perform load flow using Gauss Seidel method.

(iv) Eliminate the load buses.

(v) Calculate the initial conditions of the state variables.

(vi) Read System disturbance condition.

(vii) Solve the network and armature equations.

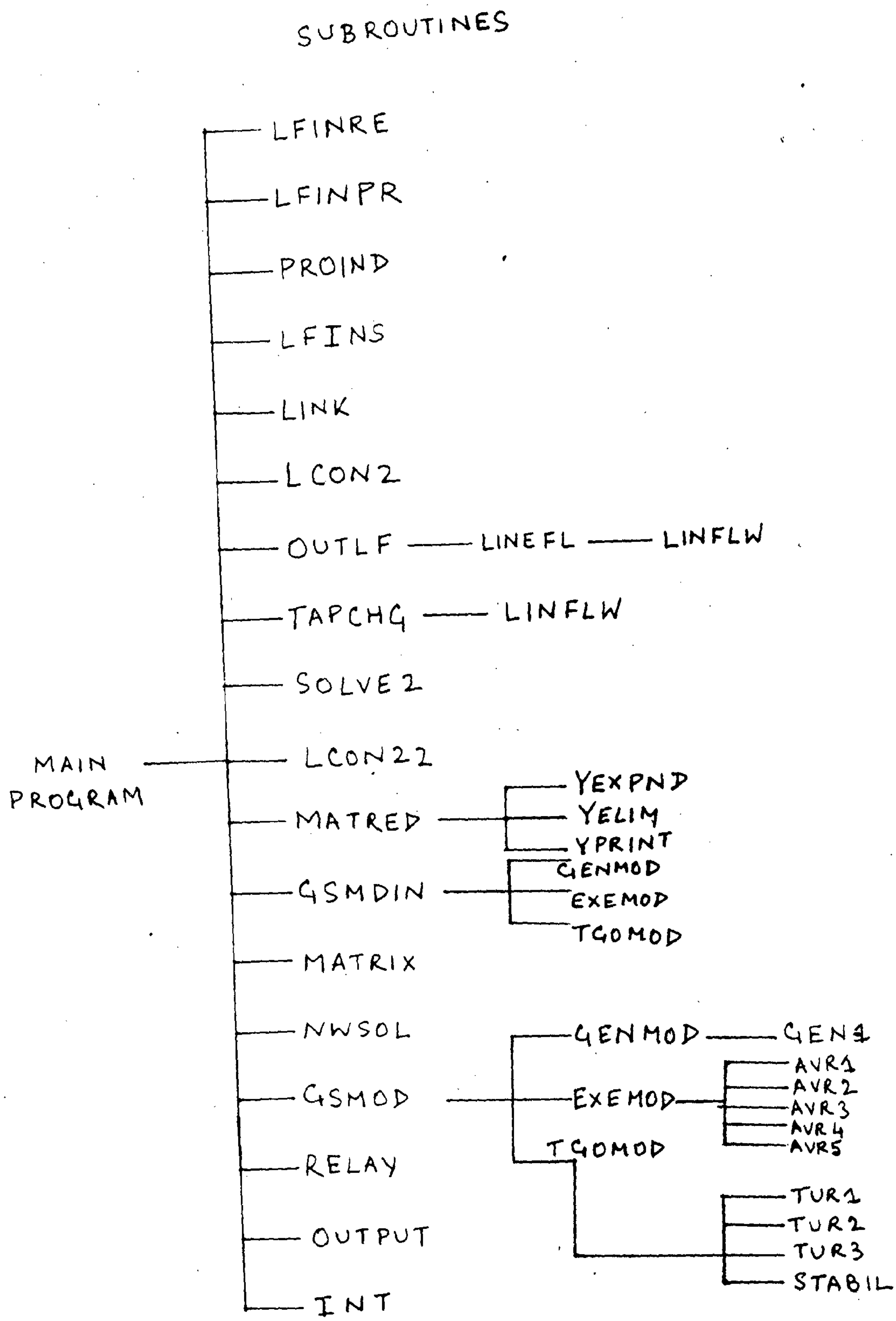
(viii) Calculate the state variable derivatives.

(ix) Activate the relay protection scheme if required.

(x) Calculate the state variables for next increment in time. Check the time elapsed. If time elapsed is less than the simulation time go back to (vii) otherwise check the new network condition by going back to (vi) and stop.

CHAPTER - 4

PROGRAM DESCRIPTION AND EXECUTION



PROGRAM ORGANISATION

245239
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FIG. 20.

There is a main program which calls number of subroutines and this on the whole completes the simul-tion of the power system problem considered. The various subroutines are being described one by one below.

(i) Initialization

The variables and the arrays are initialized in the main program. This is done before the input data is read. Some of the variables like NFAUlT, NSTEP, NPRINT and NPlOT are all set to a 0 value. A control file name is read. This file consists of the data files of bus, line, transformer, machine,relay and system condition. The different unit numbers of these data files are also read through the control file. Some of the arrays are given below.

SAVE (I,J) - value of integrator input for previous integration time step.

PlUG (I,J) - value of integrator input (state variable derivatives)

where I = no. of generating unit and

J = no. of integrators.

The variables to be printed are stored in PRTVAR (I,J) where I = no. of generator and J = no. of printout variable.

AVR PRM (I,J) and TUR PRM (I,J) are the integrator input for excitation system models and turbine governor models respectively. Where I = no of generating units and J = no of integrators.

SAVE (I, J), PLUG (I, J), PRT VAR (I, J), AVR PRM (I, J) and TUR PRM (I, J) are all set to 0 value.

(ii) Reading input data

After the initialization of the variables and Arrays input subroutines are called by the main program. The input subroutines are used to read the values of the bus data parameters, line data parameters, transformer data parameters reactor/capacitor data parameters, machine data parameters, excitation system and turbine governor model parameters. The three input subroutines of this program are described below.

(a) IFINRE - This is the first input subroutine called by the main program. It reads bus data, line data, trans - former data and reactor/capacitor data variables. All these input data for the above variables are stored in a datafile specified by the control file. The unit of this data file is identified by INDLF. The system base MVA is taken to be 100 MVA.

The bus data parameters read are Bus type, bus base kv, bus voltage magnitude, bus voltage angle, bus MW generation, bus MVAR generation, bus MW load, bus MVAR load, bus voltage desired, bus MVAR generation lower limit, bus MVAR generation upper limit and bus name. The bus data card is represented by an integer value of 20.

The line data parameters read are line resistance, line reactance, line admittance charging, line type, line to transformer data pointer, line ratings, line voltages and line status. The line data card is represented by an integer value of 40. If line to transformer data pointer is 1, then the transformer data parameters are to be read otherwise if it is 0 then the transformer data is ignored.

The transformer data parameters read are transfor - mer resistance, transformer reactance, transformer type, transformer to phase shifter data pointer, transformer to line data pointer, transformer ratio, transformer minimum ratio, transformer tap steps, transformer controlled bus upper limit of voltage, transformer controlled bus lower limit of voltage. The transformer data card is represented by an integer value of 60. If transformer type is set to an integer value 4, then a variable INPS is set to 1. In this case only,the phase shifter data parameters are read otherwise they are ignored.

The phase shifter parameters to be read are phase shifter angle, phase shifter angle steps, phase shifter (MW) maximum, phase shifter (MW) minimum,phase shifter angle maximum, phase shifter angle minimum. The data card number is 80. Thereafter the reactor/capacitor data parameters are read.

The three types of buses considered here are (i) Gen bus or voltage controlled bus (ii) load bus and (iii) swing bus or slack bus. The four types of lines considered here are (i) Normal line (ii) Tie line (iii) Transformers (iv) Phase shifters. The integer variables BBTYPE and LTYPE take different values for modelling or considering one of the above types.

MCSIND This is the second input subroutine. It reads the machine data parameters, excitation system model and turbine governor model parameters. All these parameters are read from a data file specified by the control file. The unit of this data file is identified by a variable INDMC. Total number of generators (NGEN),total simulation time (TIME) and integration time steps (TSTEPS) are read by this sub - routine from the data file.

The generator parameters to be read are generator model, number of generator bus, generator type, Inertia constant, Resistance, Reactance, d and q axis reactance and transient reactance, damping constant, open circuit time constant in the d and q axis, machine rating, IVR and ITUR. IVR takes integer values from 0 to 6 and ITUR takes values between 0 to 4. Each value of IVR and ITUR has its own significance They decide the various excitation and turbine governor models.

In the case of generator there are common set of variables for every generator model. This is not the case with the excitation systems and turbine governor systems.

PROIND - This is the third and last input subroutine called by the main program. The relay parameters are read from the third data file specified by the control file. The unit of this data file is identified by the variable INDPR. Three types of relay has been considered here. They are impedance relay, loss of excitation relay and under voltage relay. Depending on the characteristics of the relays various parameters are read. The relay parameters are to be read if and only if an integer IPROT given in the control file is equal to zero, otherwise the relay protection scheme is not taken into consideration.

(iii) Calculations

All those subroutines which do various calculations are being described here one by one as follows -

IFINS - This subroutine is called to convert the recently read bus MW and MVAR generation, bus MW and MVAR load to base MVA. The line admittances, base admittances of transformers and cap/reactor susceptances are calculated from the input values.

LINK - The next subroutine to be called is link. It prepares a link structure of the lines of the power system example considered. This is done with the help of the input variables IFROM (line from) and ITO (line to). The network topology obtained is stored in the various arrays defined in the program.

Now the question that arises is whether the load flow solution is to be carried out or not. If yes, then whether the initial load flow solution is to be read or not.

ICON2 - This is the next subroutine called. Here the self impedance of buses are calculated and line admittances are modified to take into account of tap settings of transformers. This subroutine models the transformers and phase shifters, determines the diagonal elements of the Y-matrix and stores the admittance contributions to the diagonal elements of the Y-matrix due to transformers and phase shifters, which change with the transformer ratio and angle. These are stored in the array TCHTAP.

Now for each and every bus the net active and reactive power is calculated and then the load flow is solution is performed using the Gauss- Seidel method.

SOLVE2A - This subroutine does the load flow solution using the Gauss seidel method. It solves the load flow solution of a specified block of network. The network topology must be available in the arrays BLIST,NEXT and IFAR. The solution is found iterating through all buses untill the biggest bus voltage difference between two successive iterations is less than a specified tolerance. The solution is said to be diverging if the maximum bus voltage difference between two successive iterations increases for subsequent iterations.

The solution is returned if it diverging with FLAG=2. A voltage kickoff flag KICKFG has been defined. If it is 0, then all the bus voltages are within the voltage kick off limits. If it is 1, then one of the bus voltage has crossed the upper voltage kickoff limit. If it is 2, then one of the bus voltage has crossed the lower voltage kick off limit, FLAG is the variable which defines of the status of the solution. If it is 0 then the solution converges, 1 if the full maximum iterations has been carried out and 2 if the solution is diverging. If the solution has not converged then one more try for load flow solution can be made.

TAPCHG - This is the next subroutine to be called by the main program. The taps of the transformers and phase shifters are adjusted by this subroutine. An integer variable IFLAG indicates what to control. If it is 0, then the MW and MVAR control is made and if 1 then voltage control is made. There is also a variable ITAPSW which indicates whether a change was made or not.

ICON22 - ICON 22 is the next subroutine called. Here the line admittances and the self admittances of the buses are modified depending on the changes in the tap positions and the angles of the transformers/phase shifters made by the previous subroutine. After making these alterations the load flow solution is again repeated.

OUTLF prints the load flow results in the output file specified by the control file. The unit of this output file is identified by the variable IOU. This subroutine calls a subroutine LINELW. This in turn calls LINFLW. These two subroutines are used to calculate the total active generation, total reactive generation, total active and reactive mis-matches. These values are also printed into the specified output file.

Thereafter the generator terminal voltage and current are calculated and the loads are converted to shunt admi-ttance.

(iv) Reduction of Y matrix -

Now whether the Y matrix reduction should be carried out or not is decided. If the answer is yes the following subroutine is called by the main program.

MATRED

This subroutine adds each internal generator bus to the network admittance matrix and then reduces the new matrix by eliminating the corresponding generator terminal bus. For each generator the following steps are applied to a matrix which is initialized as the equivalent admittance matrix for the terminal buses.

(i) The row and column of the generator in concern is moved to the outside of the matrix.

(ii) The generator internal bus is added to the matrix in the position of the recently vacated row and column.

(iii) The terminal bus row and column is eliminated from the matrix using krons reduction formula. This is done in the subroutine YELIM. Finally all the nodes except for the internal generator nodes are eliminated. Thus the $\bar{Y}$ matrix for the reduced network is obtained. This reduction of the network admittance matrix helps in reducing the execution time of the program considerably. The size of the reduced matrix is checked by comparing it with the maximum size specified. If it exceeds the specified value then an error signal gets printed. This reduced Y matrix is printed into a file specified by (unit = NRDE).

(v) Modelling Subroutines

These subroutines are called to calculate initial conditions of the system. They solve the dynamic equations of the generators and their controllers. The development of these subroutines are based upon the analog computer approach. The two main function of the subroutines are.

(i) They calculate the initial conditions of the machines and the controller state variables and the initial controller set points.

(ii) They calculate the time derivatives of the machine and controller state variables at each integration time step.

These subroutines are classed according to whether they model a generator, excitation system or turbine - governor model.

GSMDIN - This subroutine develops models for generator, exciter, and turbine - governor. This calls three sub - routines. One for generator modelling, the second for exciter modelling and the third for governor - turbine modelling.

GEN MOD - This is the subroutine called by the previous subroutine. This in turn calls a subroutine GEN 1. This subroutine is derived from the analog model of the various types of generators. The generator modelling subroutine gets somewhat complicated by taking into account saturation. The integrators are first defined. This is nothing but the generator terminal voltage and current in terms of the synchronous reference frame. From this the integrator inputs are calculated. That is the initial conditions of the generator state variables like ω, δ, E_q and E_d as well as the initial field voltage and the initial mechanical input power are calculated. The algorithm for calculating the generator initial conditions has been described in the previous section (3.0). During the step by step simulation the function of the generator subroutine is to calculate the time derivatives of the generator state variables. The algorithm for this is described in great detail in the section (3.0).

The excitation system subroutines are AVR1, AVR2, AVR3, AVR4 and AVR5. These subroutines are derived from the analog model of the different excitation systems. The turbine governor subroutines are TUR1, TUR2 and TUR3. These subroutines are also derived from the analog models of the various turbine governor systems. In the excitation system subroutines first the integrator outputs are defined and then the intermediate variables are calculated. In this process the integrator inputs are calculated. A check is carried out on the initial conditions calculated for every excitation system model. It is done to see whether the initial conditions are within specified limits or not. If not then an error signal gets printed into the output file. The same thing is done in the case of turbine governor. subroutines.

(vi) Read System Condition

The system conditions are read from an input file specified by the control file. SYSCON be the integer variable which indicates the system conditions. If SYSCON is 0, then a three phase bus fault is simulated, 1 then a three phase line fault is simulated, 2 if line has been kept open, 3 for simulation of load change, 4 then loss of excitation is simulated, 5 for three phase bus fault cleared and 6 for the loss of generation.

The various values of the SYSCON input data is read from the input data file with (unit = INSYC). In the case of three phase fault the bus at which the fault has occured is read. Similarly for the three phase line fault the line number, distance from the sending bus is read. For the simulation of loss of excitation generator number on which field fault has occured and the type of field fault whether open circuited or short circuited is read. When there is a change in the load then the bus number at which the load is changed and the new values of active power and reactive power of the load is read. Thereafter the load is converted to shunt admittance. After reading the system condition and obtaining the new reduced admittance matrix for the given system condition the network and armature algebraic equations are solved. Thereafter the following subroutines are called by the main program.

MATRIX - This subroutine calculates the equivalent Y matrix for internal generator buses. It augments the Y matrix with internal generator buses and eliminates the terminal buses.

NWSOI - The next subroutine after MATRIX, NWSOI is called in the main program. This subroutine solves the network and armature equations. The solution procedure has been described in the section (3.C).

Then the modelling subroutines are called to calculate the state variable derivatives at each integration time step. If the variable IPROT is not equal to zero then the relay protection schemes are called to identify the faulted portion of the system by the subroutine RELAY, till the fault is cleared. This protects the system from any damage.

The variables to be printed are stored in the array PRTVAR(I,J), where I = no. of generating units and J = no. of printout variables. The variables to be printed can be stated by inserting statements which specifies the elements of PRTVAR(I,J) in the machine and controller subroutines.

The INT subroutine is then called in the main program to calculate the state variables for next increment in time. Once the total simulation time has elapsed the new network condition is checked and the program execution comes to an end.

OUTPUT - This subroutine gives printouts of the variables calculated during the simulation.

CHAPTER -5

DESCRIPTION OF THE SYSTEM

The NORTHERN REGIONAL power system example taken for study comprises of 93 total buses. Out of which there are 63 load buses and 29 generator buses. The system base MVA is 100. The input data sheets has been provided in this section for bus, line, machine, excitation system models, transformers, capacitors and reactors and turbine governor models. Different types of system conditions have been considered in this system. The system performance for these conditions can be observed one by one. This has been discussed in the next section.

In this example three types of generator models have been included. They are (i) two axis model (ii) one-axis model and (iii) Infinite bus. All these have been described in great detail in the 2nd chapter. Five types of exciter models have been considered. They are (i) IEEE Type 1 excitation system (ii) IEEE Type 1s excitation system (iii) IEEE type 2 excitation system (iv) IEEE type 3 excitation system (iv) IEEE type 4 excitation system. Along with these five types of exciters, three types of turbine governor systems are modelled. They are (i) steam turbine (ii) hydraulic turbine with mech governing unit (iii) hydraulic turbine with electrical governing unit.

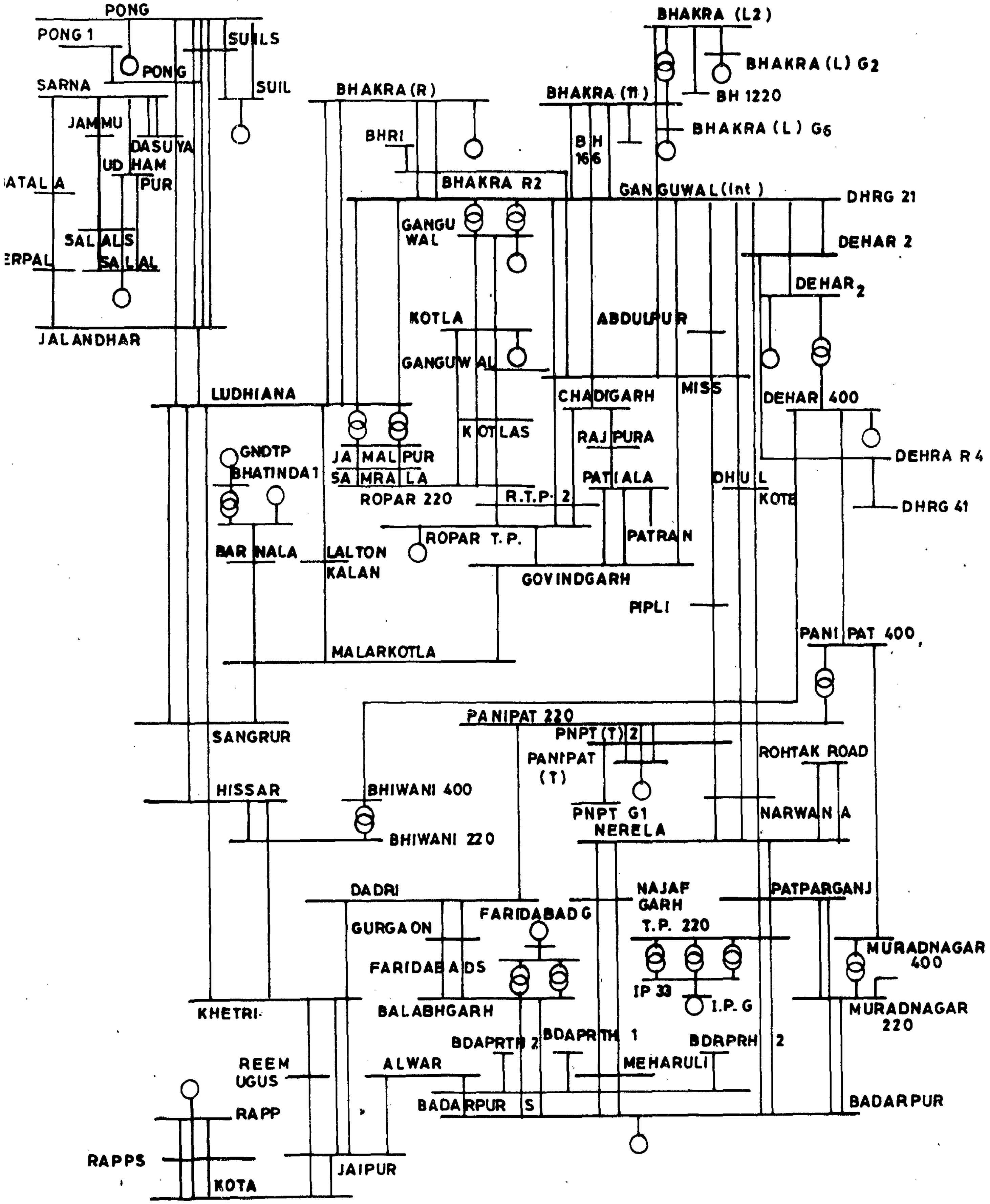

FIG. 2.1. SINGLE LINE DIAGRAM OF NORTHERN REGIONAL GRID

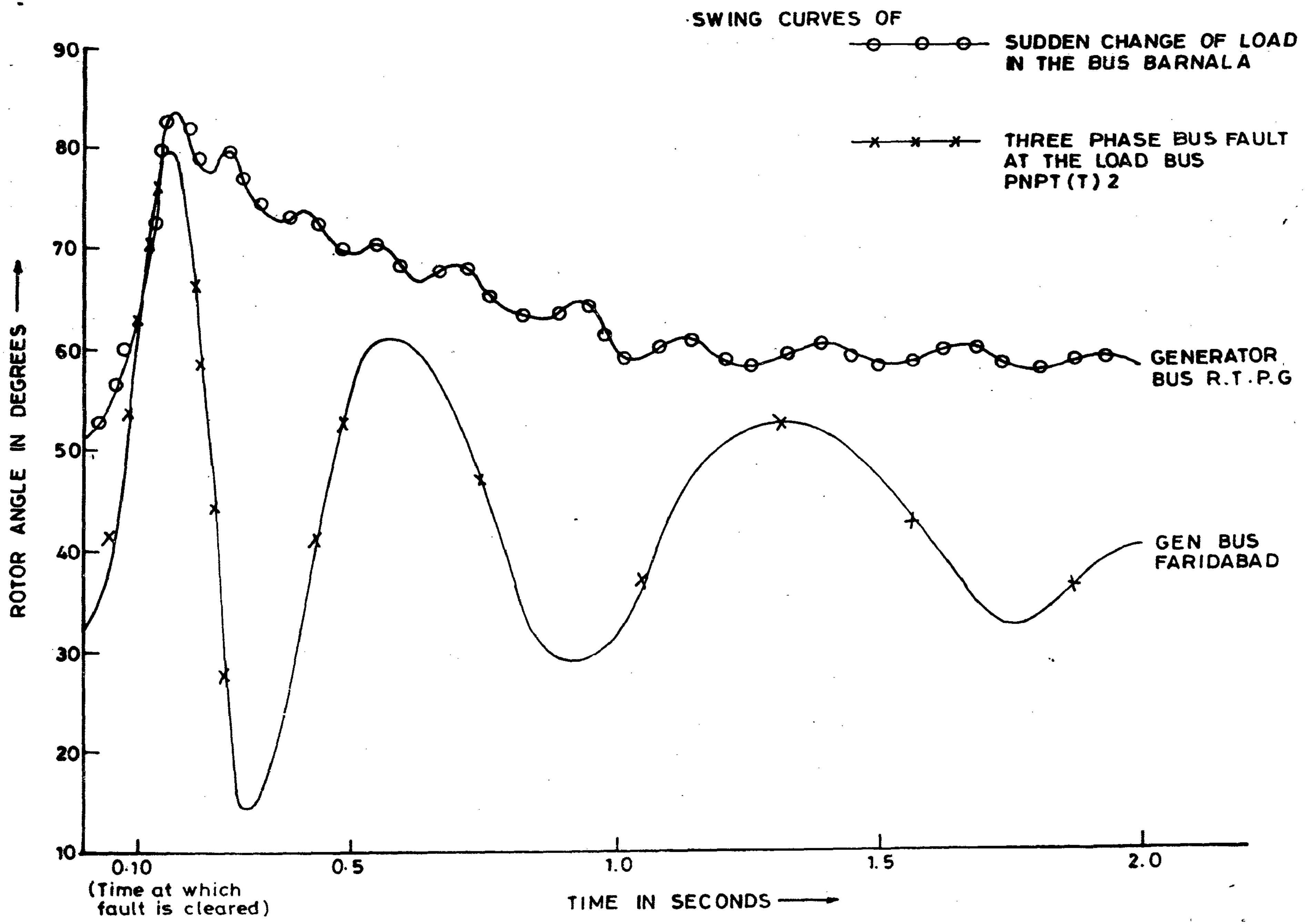
SWING CURVES OF
SUDDEN CHANGE OF LOAD IN THE BUS BARNALA
THREE PHASE BUS FAULT AT THE LOAD BUS PNPT (T) 2
GENERATOR BUS R.T.P.G
GEN BUS FARIDABAD
ROTOR ANGLE IN DEGREES
90
80
70
60
50
40
30
20
10
0.10
0.5
1.0
1.5
2.0
(Time at which fault is cleared)
TIME IN SECONDS

FIG.22.

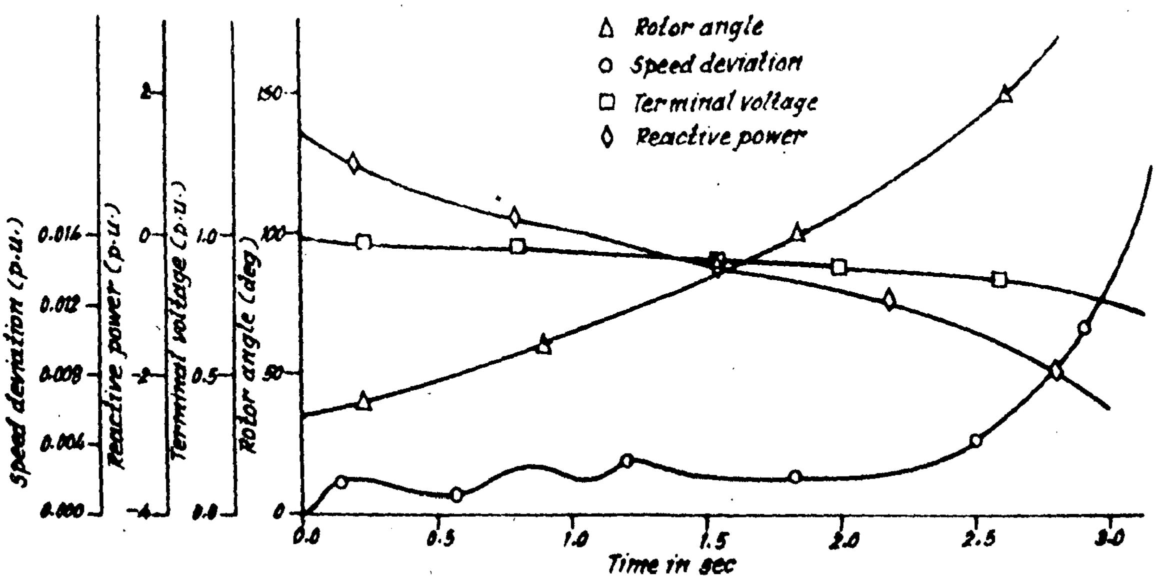

Fig.23. Response of 220 MW unit of Ropar Thermal Power Station under loss of excitation.

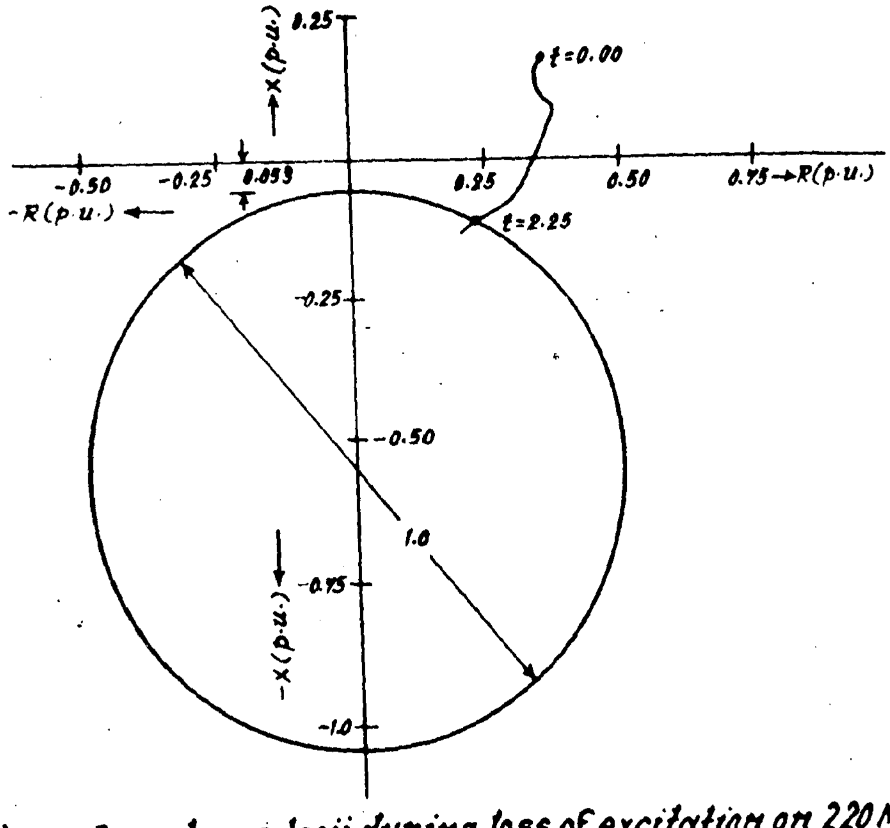

Fig 24. Impedance locii during loss of excitation on 220 MW unit of Ropar Thermal Power Station.

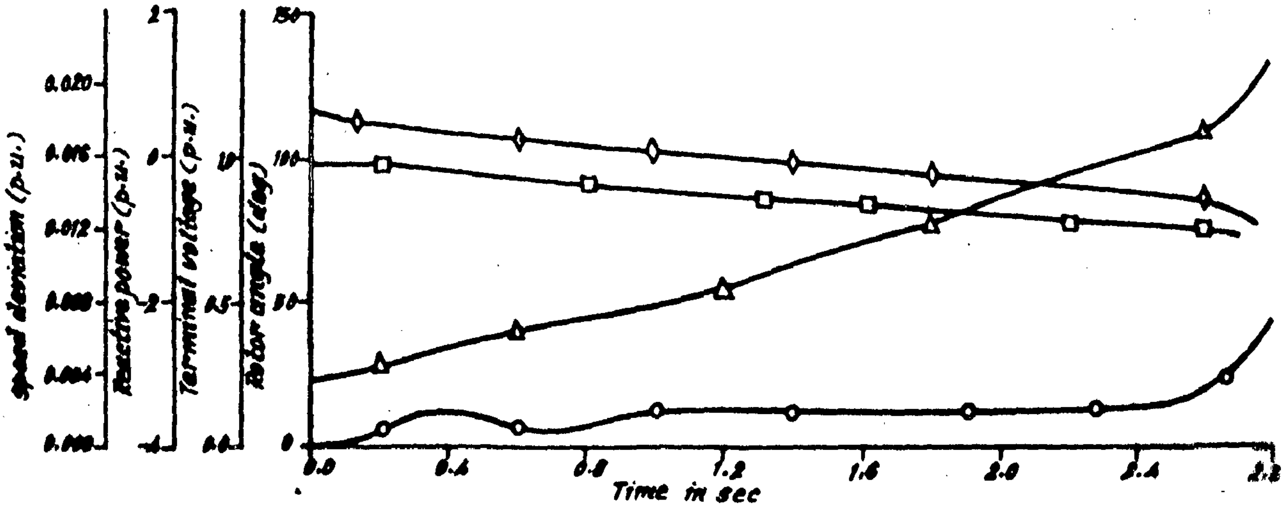

Fig. 25. **Response of 110 MW unit (133 kV bus) of Guru Nanakdev Thermal Power Station under loss of excitation.**

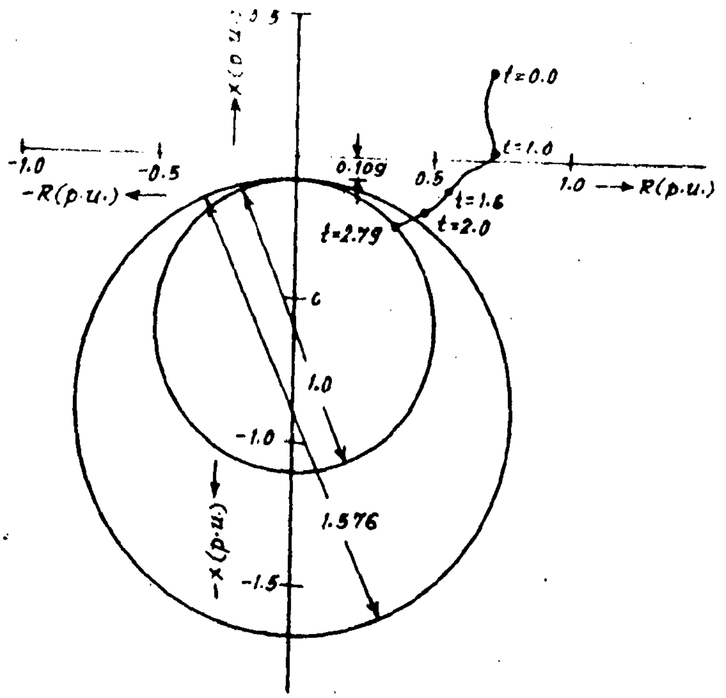

Fig. 26. *Impedance locii during loss of excitation on 110 MW unit connected to 132 kV bus of Guru Nanakdev Thermal Power Station.*

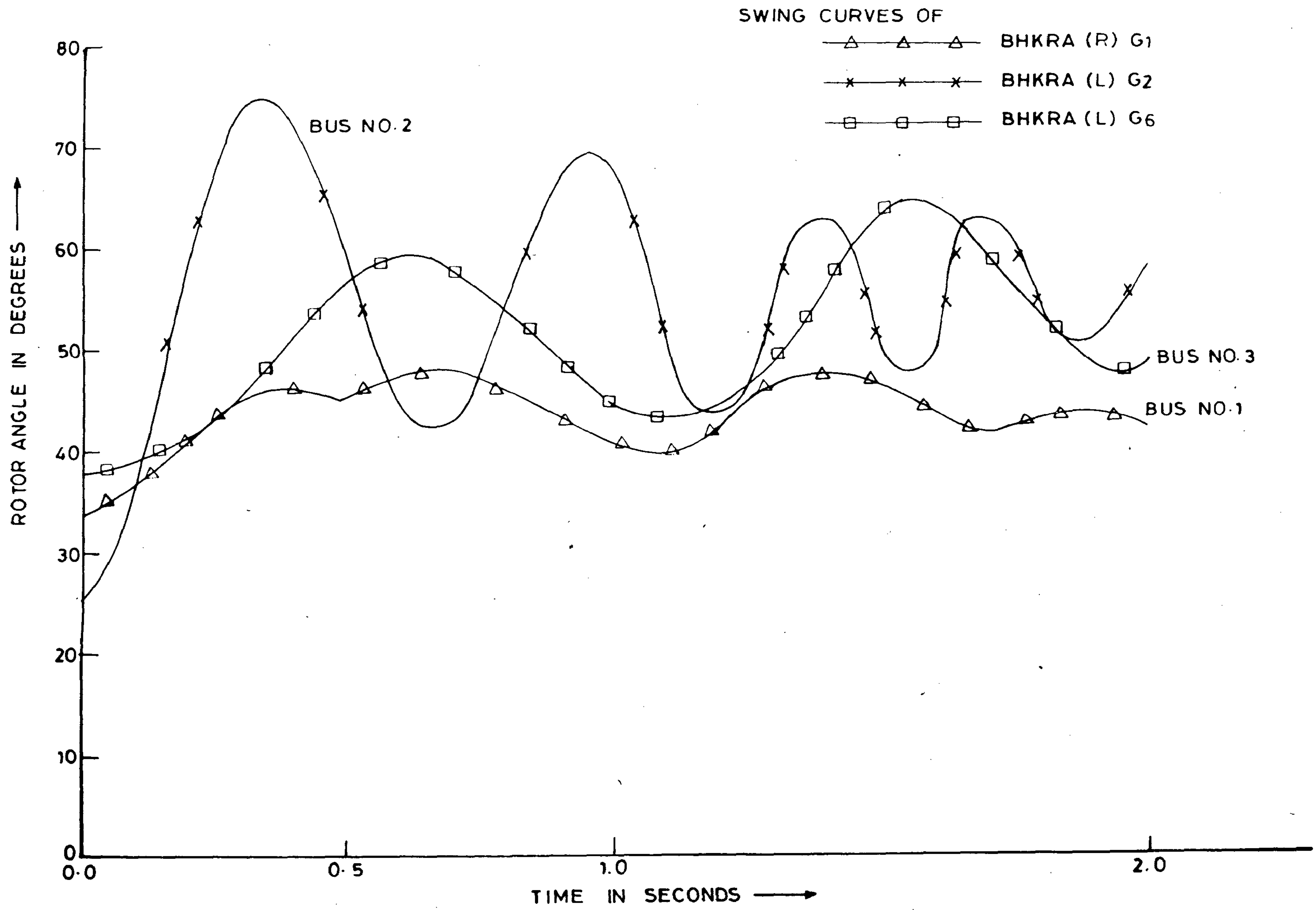
SWING CURVES OF
BHKRA (R) G1
BHKRA (L) G2
BHKRA (L) G6
BUS NO.2
BUS NO.3
BUS NO.1
ROTOR ANGLE IN DEGREES
TIME IN SECONDS
0
10
20
30
40
50
60
70
80
0.0
0.5
1.0
2.0

FIG. 27

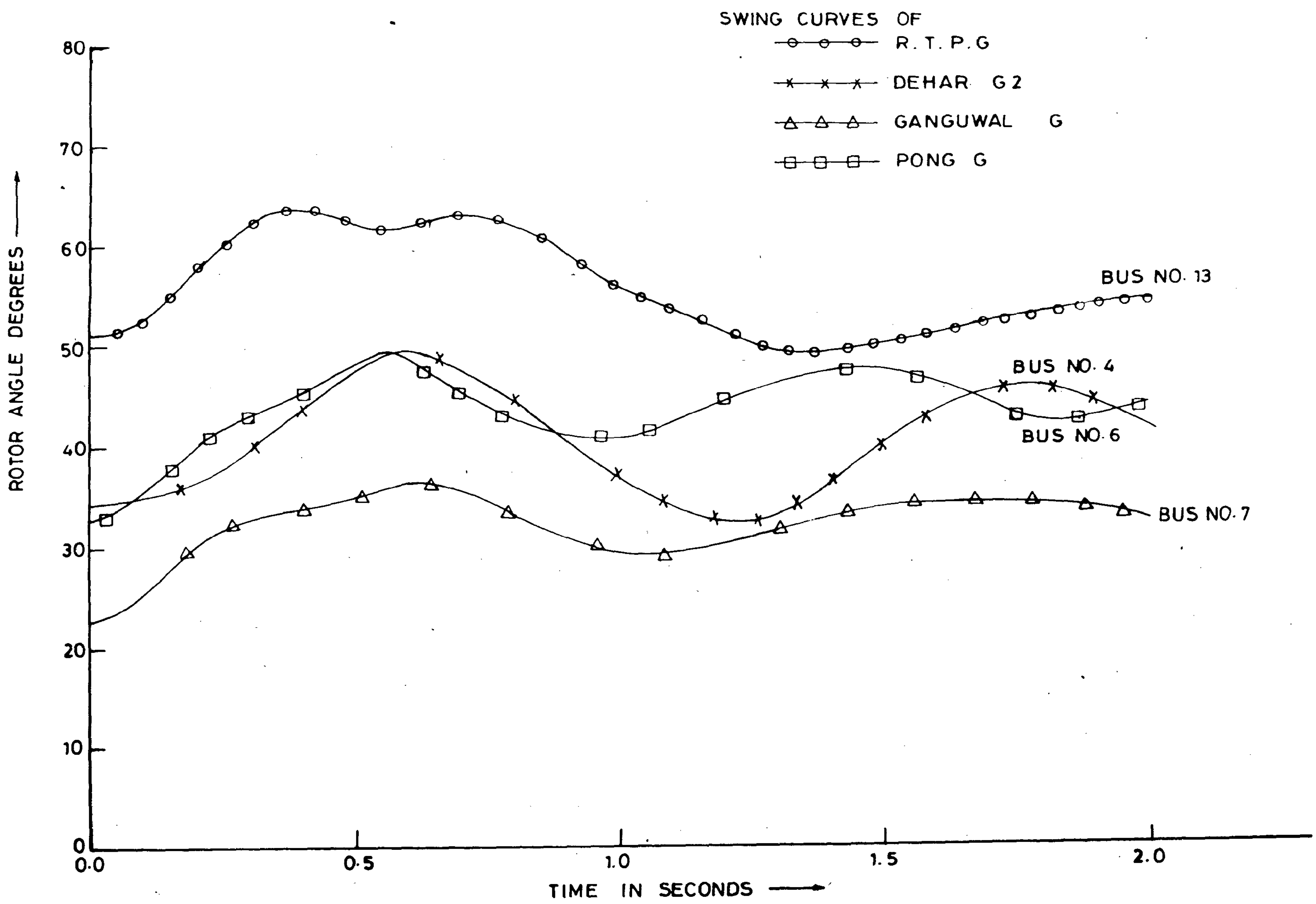
SWING CURVES OF
R. T. P. G
DEHAR G 2
GANGUWAL G
PONG G
BUS NO. 13
BUS NO. 4
BUS NO. 6
BUS NO. 7
ROTOR ANGLE DEGREES
TIME IN SECONDS
80
70
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0

FIG. 28.

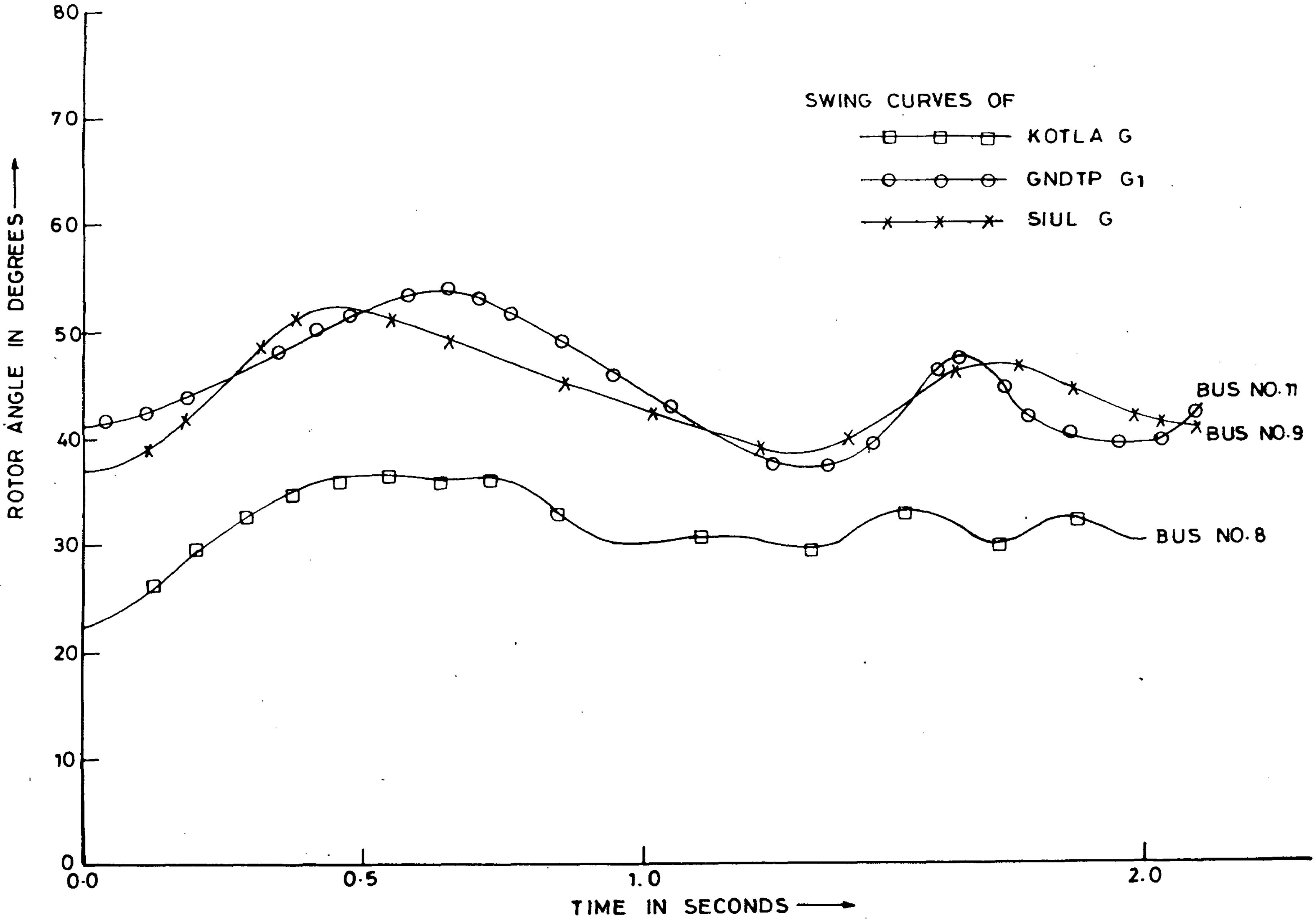
SWING CURVES OF
KOTLA G
GNDTP G1
SIUL G
BUS NO.11
BUS NO.9
BUS NO.8
ROTOR ANGLE IN DEGREES
TIME IN SECONDS
0
10
20
30
40
50
60
70
80
0.0
0.5
1.0
2.0

FIG. 29

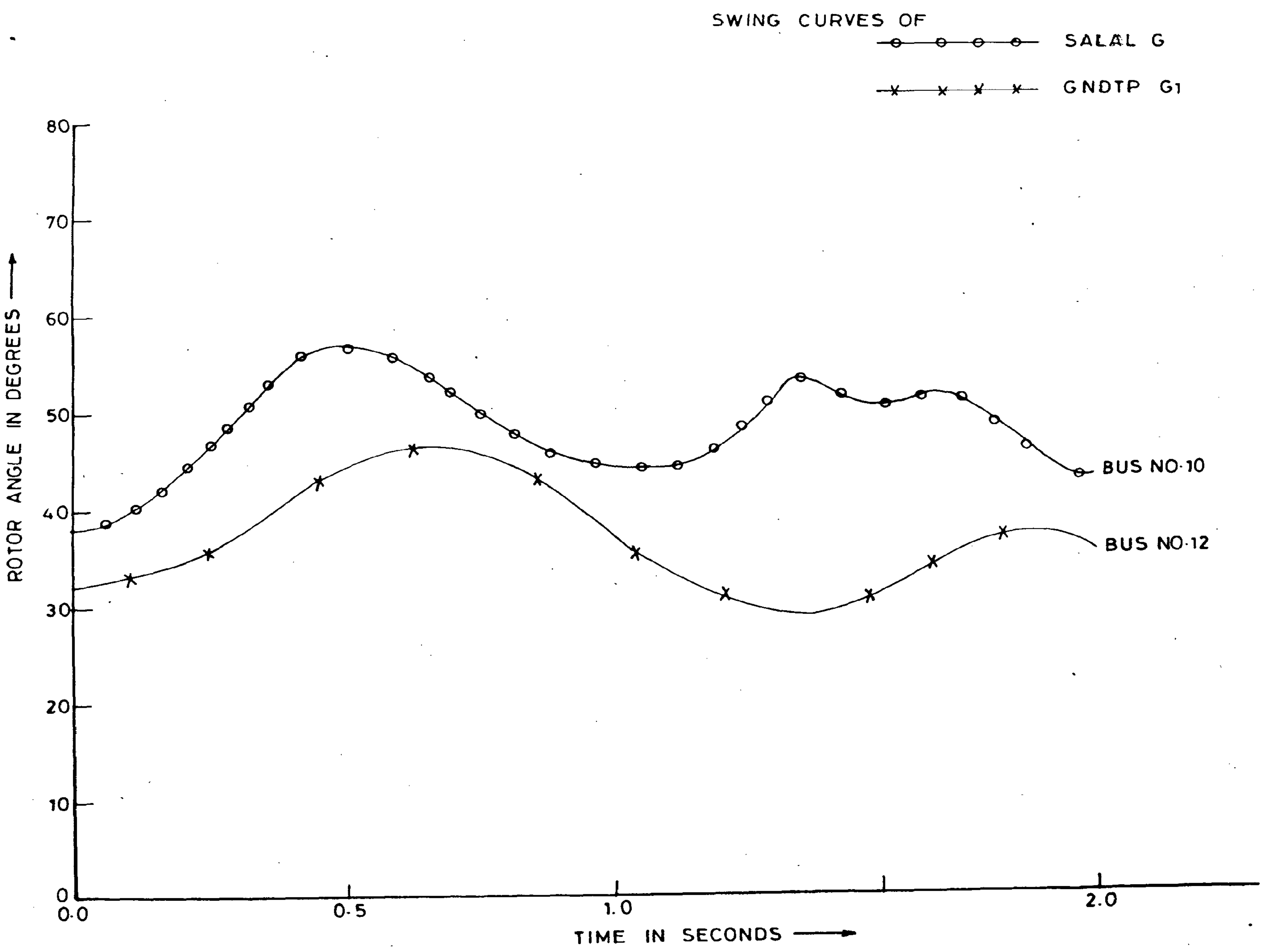
SWING CURVES OF
SALAL G
GNDTP G1
80
70
60
50
40
30
20
10
0
ROTOR ANGLE IN DEGREES
BUS NO·10
BUS NO·12
0.0
0·5
1.0
2.0
TIME IN SECONDS

FIG. 3 0.

=+==

LOAD FLOW STUDY OF NORTH-WEST POWER SYSTEM

=+==

SYSTEM DATA
SYSTEM DATA
===========

SYSTEM BASE MVA	100.
NUMBER OF BUSES	93
NUMBER OF LOAD BUSES	63
NUMBER OF GENERATOR BUSES	29
NO OF TRANSFOR MERS	40
NUMBER OF PHASESHIFTERS	0
NUMBER OF BUSES HAVING CAPACITOR/RECTOR	42
NUMBER OF SLACK BUSES	1
SLACK BUS NO AND NAME	5 DEHAR 64

17	BADARPUR 6	STEA	TWO-	100.	100.	2.670	.000	.070	1.520	.224	1.250	.300	6.500	.500	2.000	.000	.000	2	0
18	RAPP 6	NUCL	TWO-	220.	100.	5.850	.004	.125	.743	.102	.650	.510	4.610	.300	2.000	.000	.000	0	0
19	MRDNGR 4	INFI	ONE-	351.	100.	.000	.000	.000	.000	.130	.130	.000	.000	.000	.000	.000	.000	0	0
20	BH166	HYDR	TWO-	100.	100.	4.020	.003	.183	.921	.303	.560	.560	7.650	.000	2.000	.000	.000	1	2
21	BH1220	HYDR	TWO-	100.	100.	4.020	-.003	.183	.921	.303	.560	.560	7.650	.000	2.000	.000	.000	1	2
22	BHR1	HYDR	TWO-	132.	100.	6.615	.001	.250	.735	.220	.497	.497	7.500	.000	2.000	.000	.000	1	2
23	DHR621	HYDR	TWO-	165.	100.	8.220	.002	.270	.606	.135	.336	.336	8.840	.000	2.000	.000	.000	2	3
24	DHR641	HYDR	TWO-	165.	100.	8.220	.002	.270	.606	.135	.336	.336	9.840	.000	2.000	.000	.000	2	3
25	NG1	HYDR	TWO-	60.	100.	3.200	.004	.190	1.305	.330	.810	.810	5.000	.000	2.000	.000	.000	4	3
26	PN PTG1	STEA	TWO-	110.	100.	4.500	.000	.333	1.570	.210	1.491	.950	6.840	1.500	2.000	.000	.000	5	0
27	GNDG21	STEA	TWO-	110.	100.	4.500	.000	.333	1.570	.210	1.491	.950	6.840	1.500	2.000	.000	.000	2	0
28	BDRPRH2	STEA	TWO-	100.	100.	2.670	.000	.070	1.520	.224	1.250	.300	6.500	.500	2.000	.000	.000	2	0
29	BDAPRTH1	STEA	TWO-	210.	100.	5.160	.001	.204	.891	.123	.854	.460	7.000	2.500	2.000	.000	.000	2	1
30	BDAPRTH2	STEA	TWO-	210.	100.	5.160	.001	.204	.891	.123	.854	.460	7.000	2.500	2.000	.000	.000	2	1

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-- BUS DATA --
-- BUS DATA --

SEQ	TYPE	BUS VOLT KV	--GENERATION--- ACTIVE MW	REACT MVAR	----L O A D---- ACTIVE MW	REACT MVAR	BUS VOLT DESIRED P.U.	REA GEN/BUSVOLT LIM UPPER MVAR/P.U.	LOWER	UNIVERSAL BUS NO	BUS NAME
1	PV	11	410.72	.00	5.67	3.01	1.00	212.00	-212.00	1	BH KRA(R)6
2	PV	11	183.60	.00	1.62	1.33	1.00	105.50	-105.50	2	BH KRA(L)62
3	PV	11	91.80	.00	2.43	1.33	1.00	52.50	-52.50	3	BH KRA(L)66
4	PV	11	140.25	.00	2.43	1.33	1.00	54.00	-54.00	4	DE HAR 62
5	SLACK	11	123.40	.00	5.67	3.01	1.00	162.50	-162.50	5	DE HAR 64
6	PV	11	255.00	.00	5.67	3.01	1.00	150.00	-150.00	6	PO NG 6
7	PV	11	65.45	.00	.81	.42	1.00	45.00	.00	7	GA NGUWAL 6
8	PV	11	65.45	.00	.81	.42	1.00	45.00	.00	8	KOTLA 6
9	PV	11	153.00	.00	1.62	.84	1.00	87.00	.00	9	SIUL 6
10	PV	11	293.25	.00	3.24	1.75	1.00	167.00	-167.00	10	SALAL 6
11	PV	11	93.50	.00	8.91	4.76	1.00	65.00	.00	11	GN DTP 61
12	PV	11	63.75	.00	8.91	4.76	1.00	65.25	.00	12	GN DTP 62
13	PV	11	187.00	.00	17.82	9.52	1.00	136.30	.00	13	R.T.P.6
14	PV	11	164.90	.00	17.82	9.52	1.00	160.00	.00	14	PN PT(T)6
15	PV	11	114.75	.00	11.34	6.09	1.00	75.00	-75.00	15	FA RIDBAD 6
16	PV	11	232.90	.00	22.68	12.16	1.00	189.50	.00	16	I. P. 6
17	PV	11	85.00	.00	12.55	6.72	1.00	62.00	.00	17	BA DARPUR 6
18	PV	21	187.00	.00	16.20	8.68	1.00	120.52	.00	18	RA PP 6
19	LOAD	220	.00	.00	.00	.00	1.00	1.02	.70	19	BH KRA R2
20	LOAD	220	.00	.00	.00	.00	1.00	1.00	.70	20	BH KRA L2
21	LOAD	66	.00	.00	79.30	33.25	1.00	1.00	.70	21	BH KRA L6
22	LOAD	220	.00	.00	28.35	15.19	1.00	1.00	.70	22	DE HAR 2
23	LOAD	400	.00	.00	.00	.00	1.00	1.00	.70	23	DE HAR 4
24	LOAD	220	.00	.00	.00	.00	1.00	1.00	.70	24	PO NG S
25	LOAD	132	.00	.00	.00	.00	1.00	1.00	.70	25	GA NGUWAL 1
26	LOAD	132	.00	.00	.00	.00	1.00	1.00	.70	26	KOTLA S
27	LOAD	220	.00	.00	.00	.00	1.00	1.00	.70	27	SUIL S
28	LOAD	220	.00	.00	.00	.00	1.00	1.00	.70	28	SALAL S
29	LOAD	132	.00	.00	170.10	91.00	1.00	1.00	.70	29	BHATINDA 1
30	LOAD	220	.00	.00	.00	.00	1.00	1.00	.70	30	BHATINDA 2
31	LOAD	220	.00	.00	.00	.00	1.00	1.00	.70	31	R.T.P. 2
32	LOAD	220	.00	.00	.00	.00	1.00	1.00	.70	32	PNPT(T)2
33	LOAD	66	.00	.00	.00	.00	1.00	1.00	.70	33	FA RIDBAD S
34	LOAD	220	.00	.00	202.50	108.50	1.00	1.00	.70	34	BALABGARH
35	LOAD	33	.00	.00	113.40	60.69	1.00	1.00	.70	35	I. P. 3
36	LOAD	220	.00	.60	81.00	43.40	1.00	1.00	.70	36	I.P. 2.
37	LOAD	220	.00	.00	.00	.00	1.00	1.00	.70	37	BA DARPUR S
38	LOAD	220	.00	.00	81.00	43.40	1.00	1.00	.70	38	RA PP S
39	LOAD	220	.00	.00	.00	.00	1.00	1.00	.70	39	MI SS
40	LOAD	220	.00	.00	210.60	112.77	1.00	1.00	.70	40	JAMALPUR 2

41	LOAD	220	.00	.00	40.50	21.70	1.00	1.00	.78	-	[illegible]
42	LOAD	220	.00	.00	81.00	43.40	1.00	1.00	.78	41	GOVINDGARH
43	LOAD	220	.00	.00	64.80	34.72	1.00	1.00	.78	42	CHANDIGARH
44	LOAD	220	.00	.00	72.09	38.64	1.00	1.00	.78	43	ABDULAPUR
45	LOAD	220	.00	.00	40.50	21.70	1.00	1.00	.78	44	DHULKOTE
46	LOAD	220	.00	.00	36.45	19.53	1.00	1.00	.78	45	PIPLI
47	LOAD	220	.00	.00	81.00	43.40	1.00	1.00	.78	46	RAJPURA
48	LOAD	220	.00	.00	40.50	21.70	1.00	1.00	.78	47	PATIALA
49	LOAD	220	.00	.00	40.50	21.70	1.00	1.00	.78	48	PATRAN
50	LOAD	220	.00	.00	52.65	28.21	1.00	1.00	.78	49	MALERKOTLA
51	LOAD	220	.00	.00	24.30	13.02	1.00	1.00	.78	50	LALTONKLN
52	LOAD	220	.00	.00	72.90	39.06	1.00	1.00	.78	51	BARNALA
53	LOAD	220	.00	.00	283.50	151.90	1.00	1.00	.78	52	SANGRUR
54	LOAD	220	.00	.00	72.90	39.06	1.00	1.00	.78	53	JALANDHAR
55	LOAD	220	.00	.00	64.80	34.72	1.00	1.00	.78	54	VERPAL
56	LOAD	220	.00	.00	64.80	34.72	1.00	1.00	.78	55	BATALA
57	LOAD	220	.00	.00	81.00	43.40	1.00	1.00	.78	56	SARNA
58	LOAD	220	.00	.00	43.74	23.45	1.00	1.00	.78	57	JAMMU
									.78	58	UDHAMPUR
59	LOAD	220	.00	.00	.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60	LOAD	132	.00	.00	40.50	21.70	1.00	1.00	.78	60	JAMALPUR 1
61	LOAD	132	.00	.00	40.50	21.70	1.00	1.00	.78	61	SAMRALA
62	LOAD	132	.00	.00	93.15	49.91	1.00	1.00	.78	62	PAR 1
63	LOAD	400	.00	.00	.00	.00	1.00	1.00	.78	63	PNPT 4
64	LOAD	220	.00	.00	145.00	78.12	1.00	1.00	.78	64	PNPT 2
65	LOAD	220	.00	.00	52.65	28.21	1.00	1.00	.78	65	GURGAON
66	LOAD	220	.00	.00	162.00	86.80	1.00	1.00	.78	66	DADRI
67	LOAD	220	.00	.00	28.35	15.19	1.00	1.00	.78	67	BHIWANI 2
68	LOAD	220	.00	.00	89.10	47.74	1.00	1.00	.78	68	HISSAR
69	LOAD	400	.00	.00	.00	.00	1.00	1.00	.78	69	BHIWANI 4
70	LOAD	220	.00	.00	166.05	88.90	1.00	1.00	.78	70	NARWANA
71	PV	400	298.35	.00	.00	.00	1.00	.00	.00	71	MRDNGR 4
72	LOAD	220	.00	.00	.00	.00	1.00	1.00	.78	72	MRDNGR 2
73	LOAD	220	.00	.00	162.00	86.80	1.00	1.00	.78	73	NERELA
74	LOAD	220	.00	.00	93.15	49.91	1.00	1.00	.78	74	D. RH. ROAD
75	LOAD	220	.00	.00	76.95	41.23	1.00	1.00	.78	75	PATPARGANJ
76	LOAD	220	.00	.00	89.10	47.74	1.00	1.00	.78	76	NAJAFGARH
77	LOAD	220	.00	.00	174.15	93.24	1.00	1.00	.78	77	MEHRAULI
78	LOAD	220	.00	.00	76.95	41.23	1.00	1.00	.78	78	KHETRI
79	LOAD	220	.00	.00	137.70	73.78	1.00	1.00	.78	79	JAIPUR
80	LOAD	220	.00	.00	48.60	26.04	1.00	1.00	.78	80	REENUGUS
81	LOAD	220	.00	.00	140.94	75.46	1.00	1.00	.78	81	KOTA
82	LOAD	220	.00	.00	56.70	30.38	1.00	1.00	.78	82	ALWAR
83	PV	11	91.80	.00	.00	.00	1.00	52.50	-52.50	83	BHI66
84	PV	11	91.80	.00	.00	.00	1.00	52.50	-52.50	84	BHI220
85	PV	11	93.50	.00	.00	.00	1.00	53.00	-53.00	85	BHRI
86	PV	11	140.25	.00	.00	.00	1.00	54.00	-54.00	86	DHRG21
87	PV	11	140.25	.00	.00	.00	1.00	54.25	-54.25	87	DHRG41
88	PV	11	51.00	.00	.00	.00	1.00	29.00	-29.00	88	NG1
89	PV	11	82.17	.00	8.91	4.76	1.00	72.50	-72.50	89	PNPTG1
90	PV	11	63.75	.00	8.91	4.76	1.00	56.50	-56.50	90	GND621
91	PV	11	85.00	.00	12.55	6.86	1.00	62.00	-62.00	91	BDRPRH2
92	PV	11	170.00	.00	25.11	13.44	1.00	124.00	-124.00	92	BDRPRTH1
93	PV	11	170.00	.00	25.11	13.44	1.00	124.00	-124.00	93	BDRPRTH2

-- LINE DATA --

-- LINE DATA --

SEQ	FROM BUS	TO BUS	RESIS PU	REACT PU	SUSCPT PU	TYPE	T-MAP NO.	RATING MVA	FROM BUS	TO BUS
1	22	39	.002	.007	.095	1	0	.0	BHKRA L2	MISS
2	39	44	.012	.048	.289	1	0	.0	MISS	DHULKOTE
3	44	64	.013	.052	.316	1	0	.0	DHULKOTE	PNPT 2
4	64	73	.004	.018	.255	1	0	.0	PNPT 2	NERELA
5	73	74	.002	.009	.055	1	0	.0	NERELA	D, RH.ROAD
6	19	39	.002	.010	.067	1	0	.0	BHKRA R2	MISS
7	19	40	.007	.036	.231	1	0	.0	BHKRA R2	JAMALPUR 2
8	40	53	.005	.026	.166	1	0	.0	JAMALPUR 2	JALANDHAR
9	40	52	.009	.034	.206	1	0	.0	JAMALPUR 2	SANGRUR
10	52	68	.015	.060	.366	1	0	.0	SANGRUR	HISSAR
11	68	67	.006	.024	.146	1	0	.0	HISSAR	BHIWANI 2
12	67	66	.001	.006	.158	1	0	.0	BHIWANI 2	DADRI
13	66	65	.008	.033	.202	1	0	.0	DADRI	GURGAON
14	65	34	.004	.017	.105	1	0	.0	GURGAON	BALABGARH
15	22	39	.004	.026	.172	1	0	.0	DEHAR 2	MISS
16	39	43	.026	.134	.215	1	0	.0	MISS	ABDULAPUR
17	43	45	.008	.040	.064	1	0	.0	ABDULAPUR	PIPLI
18	45	64	.012	.058	.093	1	0	.0	PIPLI	PNPT 2
19	39	40	.006	.032	.208	1	0	.0	MISS	JAMALPUR 2
20	39	41	.014	.071	.113	1	0	.0	MISS	GOVINDGARH
21	39	31	.005	.026	.042	1	0	.0	MISS	R.T.P. 2
22	39	42	.013	.067	.107	1	0	.0	MISS	CHANDIGARH
23	42	31	.006	.029	.046	1	0	.0	CHANDIGARH	R.T.P. 2
24	42	46	.005	.025	.040	1	0	.0	CHANDIGARH	RAJPURA
25	31	41	.005	.024	.155	1	0	.0	R.T.P. 2	GOVINDGARH
26	41	47	.003	.017	.106	1	0	.0	GOVINDGARH	PATIALA
27	41	49	.008	.039	.062	1	0	.0	GOVINDGARH	MALERKOTLA
28	47	46	.004	.022	.035	1	0	.0	PATIALA	RAJPURA
29	47	48	.008	.041	.067	1	0	.0	PATIALA	PATRAN

30	40	50	.003	.013	.020	1	0	.0	JAMALPUR 2	LALTONKLN
31	[illegible]	[illegible]	.008	.041	.060	1	0	.0	LALTONKLN	MALERKOTLA
32	8	51	.005	.024	.154	1	0	.0	BHATINDA 2	BARNALA
33	1	52	.007	.035	.054	1	0	.0	BARNALA	SANGRUR
34	1	[illegible]	.008	.041	.060	1	0	.0	BARNALA	MALERKOTLA
35	[illegible]	52	.005	.026	.042	1	0	.0	MALERKOTLA	SANGRUR
36	27	24	.009	.044	.280	1	0	.0	SUIL S	PONG S
37	24	59	.007	.035	.056	1	0	.0	PONG S	DASUYA
38	59	53	.009	.047	.074	1	0	.0	DASUYA	JALANDHAR
39	24	53	.006	.028	.389	1	0	.0	PONG S	JALANDHAR
40	28	57	.012	.062	.100	1	0	.0	SALAL S	JAMMU
41	28	58	.003	.018	.112	1	0	.0	SALAL S	UDHAMPUR
42	57	56	.015	.075	.120	1	0	.0	JAMMU	SARNA
43	58	56	.020	.104	.166	1	0	.0	UDHAMPUR	SARNA
44	56	59	.005	.024	.154	1	0	.0	SARNA	DASUYA
45	56	55	.010	.050	.080	1	0	.0	SARNA	BATALA
46	54	53	.013	.066	.053	1	0	.0	VERPAL	JALANDHAR
47	54	55	.007	.038	.061	1	0	.0	VERPAL	BATALA
48	32	70	.008	.041	.267	1	0	.0	PNPT(T)2	NARWANA
49	32	64	.000	.004	.056	1	0	.0	PNPT(T)2	PNPT 2
50	70	68	.012	.060	.096	1	0	.0	NARWANA	HISSAR
51	64	66	.018	.091	.147	1	0	.0	PNPT 2	DADRI
52	66	78	.023	.115	.177	1	0	.0	DADRI	KHETRI
53	68	78	.019	.096	.152	1	0	.0	HISSAR	KHETRI
54	78	79	.012	.060	.304	1	0	.0	KHETRI	JAIPUR
55	78	80	.013	.067	.107	1	0	.0	KHETRI	REENUGUS
56	80	79	.011	.054	.087	1	0	.0	REENUGUS	JAIPUR
57	82	79	.021	.106	.171	1	0	.0	ALWAR	JAIPUR
58	37	82	.024	.120	.192	1	0	.0	BADARPUR S	ALWAR
59	37	34	.002	.010	.064	1	0	.0	BADARPUR S	BALABGARH
60	37	77	.001	.007	.043	1	0	.0	BADARPUR S	MEHRAULI
61	77	76	.002	.011	.066	1	0	.0	MEHRAULI	NAJAFGARH
62	76	73	.003	.014	.086	1	0	.0	NAJAFGARH	NERELA
63	73	75	.003	.014	.091	1	0	.0	NERELA	PATPARGANJ
64	75	36	.000	.002	.005	1	0	.0	PATPARGANJ	I.P. 2.
65	36	37	.001	.006	.039	1	0	.0	I.P. 2.	BADARPUR S
66	72	75	.002	.007	.156	1	0	.0	MRDNGR 2	PATPARGANJ
67	72	37	.011	.050	.087	1	0	.0	MRDNGR 2	BADARPUR S
68	67	78	.028	.142	.218	1	0	.0	BHIWANI 2	KHETRI
69	23	63	.005	.058	1.538	1	0	.0	DEHAR 4	PNPT 4

70	23	69	.006	.072	1.021	1	0	.0	DEHAR 4	BHIWANI 4
71	63	71	.002	.017	.493	1	0	.0	PNPT 4	MRDNGR 4
72	25	26	.005	.011	.009	1	0	.0	GANGUWAL 1	KOTLA S
73	26	62	.015	.032	.057	1	0	.0	KOTLA S	PAR 1
74	62	61	.026	.051	.341	1	0	.0	PAR 1	SAMRALA
75	61	60	.021	.240	.031	1	0	.0	SAMRALA	JAMALPUR 1
76	30	81	.002	.012	.172	1	0	.0	RAPP S	KOTA
77	81	79	.015	.077	.486	1	0	.0	KOTA	JAIPUR
78	19	1	.000	.052	.000	3	1	.0	BHKRA R2	BHKRA(R)6
79	20	2	.000	.014	.000	3	2	.0	BHKRA L2	BHKRA(L)62
80	21	20	.000	.083	.000	3	3	.0	BHKRA L6	BHKRA L2
81	21	3	.000	.105	.000	3	4	.0	BHKRA L6	BHKRA(L)66
82	22	4	.000	.069	.000	3	5	.0	BHHAR 2	BHHAR 62
83	23	5	.000	.075	.000	3	6	.0	BHHAR 4	BHHAR 64
84	24	6	.000	.190	.000	3	7	.0	PONG S	PONG G
85	25	7	.000	.367	.000	3	8	.0	GANGUWAL 1	GANGUWAL 6
86	26	8	.000	.316	.000	3	9	.0	KOTLA S	KOTLA 6
87	27	9	.000	.153	.000	3	10	.0	SUIL S	SIUL 6
88	28	10	.000	.062	.000	3	11	.0	SALAL S	SALAL 6
89	29	11	.000	.092	.000	3	12	.0	BHATINDA 1	GNDTP 61
90	30	12	.000	.115	.000	3	13	.0	BHATINDA 2	GNDTP 62
91	30	29	.000	.069	.000	3	14	.0	BHATINDA 2	BHATINDA 1
92	31	13	.000	.056	.000	3	15	.0	R.T.P. 2	R.T.P.6
93	32	14	.000	.115	.000	3	16	.0	PNPT(T)2	PNPT(T)6
94	33	15	.000	.010	.000	3	17	.0	FARIDBAD S	FARIDBAD 6
95	34	33	.000	.146	.000	3	18	.0	BALABGARH	FARIDBAD S
96	37	17	.000	.128	.000	3	19	.0	BADARPUR S	BADARPUR 6
97	23	22	.000	.050	.000	3	20	.0	DEHAR 4	DEHAR 2
98	72	71	.000	.052	.000	3	21	.0	MRDNGR 2	MRDNGR 4
99	35	16	.000	.061	.000	3	22	.0	I.P. 3	I.P. 6
100	36	35	.000	.107	.000	3	23	.0	I.P. 2.	I.P. 3
101	40	60	.000	.030	.000	3	24	.0	JAMALPUR 2	JAMALPUR 1
102	67	69	.000	.025	.000	3	25	.0	BHIWANI 2	BHIWANI 4
103	31	62	.000	.125	.000	3	26	.0	R.T.P. 2	PAR 1
104	25	39	.000	.030	.000	3	27	.0	GANGUWAL 1	MISS
105	64	63	.000	.031	.000	3	28	.0	PNPT 2	PNPT 4
106	30	18	.000	.060	.000	3	29	.0	RAPP S	RAPP 6
107	21	83	.000	.000	.000	3	30	.0	BHKRA L6	BH166
108	20	84	.000	.000	.000	3	31	.0	BHKRA L2	BH1220
109	19	85	.000	.000	.000	3	32	.0	BHKRA R2	BHR1
110	22	86	.000	.000	.000	3	33	.0	DEHAR 2	DHR621
111	23	87	.000	.000	.000	3	34	.0	DEHAR 4	DHR641
112	24	38	.000	.000	.000	3	35	.0	PONG S	NG1
113	32	89	.000	.000	.000	3	36	.0	PNPT(T)2	PNPTG1
114	30	90	.000	.000	.000	3	37	.0	BHATINDA 2	GND621
115	37	91	.000	.000	.000	3	38	.0	BADARPUR S	BDRPRH2
116	37	92	.000	.000	.000	3	39	.0	BADARPUR S	BDRPRTH1
117	37	93	.000	.000	.000	3	40	.0	BADARPUR S	BDRPRTH2

******************** L O A D F L O W S O L U T I O N ********************

B U S E S						L I N E S					
NO	NAME	VOLTAGE	--GEN/LOAD/REA/CAP-- MW	MVAR		NO	NAME	---L I N E F L O W S--- MW	MVAR	MVA	REMARK
1	BHKRA(R)G	1.00 PU	418.720	12.068	GEN	19	KRA R2	406.33	8.46	406.42	
		11.00 KV	5.670	3.010	LOAD						
		8.67 ANG	.000	.000	REC						
			.000	.000	CAP						
			REMARK								
		: MISMATCH	1.283 MW	-.597 MVAR :							
2	BHKRA(L)G2	1.00 PU	183.600	.376	GEN	20	KRA L2	-37.56	-1.09	37.58	
		11.00 KV	1.620	1.330	LOAD						
		.00 ANG	.000	.000	REC						
			.000	.000	CAP						
			REMARK								
		: MISMATCH	-219.544 MW	-.141 MVAR :							
3	BHKRA(L)G6	1.00 PU	91.800	26.115	GEN	21	KRA L6	89.89	24.73	93.23	
		11.00 KV	2.430	1.330	LOAD						
		13.90 ANG	.000	.000	REC						
			.000	.000	CAP						
			REMARK								
		: MISMATCH	.520 MW	-.059 MVAR :							
4	DEHAR G2	1.00 PU	140.250	-1.522	GEN	22	HAR 2	138.48	-3.05	138.52	
		11.00 KV	2.430	1.330	LOAD						
		9.60 ANG	.000	.000	REC						
			.000	.000	CAP						
			REMARK								
		: MISMATCH	.663 MW	-.197 MVAR :							
5	DEHAR G4	1.00 PU	-58.776	-5.329	GEN	23	HAR 4	-61.01	-9.44	61.73	
		11.00 KV	5.670	3.010	LOAD						
		.00 ANG	.000	.000	REC						
			.000	.000	CAP						
			REMARK								
		: MISMATCH	3.437 MW	-1.098 MVAR :							
6	PONG G	1.00 PU	255.000	18.962	GEN	24	NG S	246.73	16.02	247.25	
		11.00 KV	5.670	3.010	LOAD						
		11.42 ANG	.000	.000	REC						
			.000	.000	CAP						
			REMARK								
		: MISMATCH	-2.597 MW	.071 MVAR :							
7	GANGUWAL G	1.02 PU	65.450	.000	GEN	25	NGUWAL 1	64.87	-.53	64.87	

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              11.19 KV       .810    .420 LOAD
               6.59 ANG      .000    .000 REC
                             .000    .000 CAP
                                 REMARK   M/LL
               : MISMATCH     .232 MW      -.111 MVAR :

8 KOTLA 6      1.01 PU    65.450    .000 GEN     26    TLA S      64.86    -.53   64.87
              11.15 KV       .810    .420 LOAD
               6.31 ANG      .000    .000 REC
                             .000    .000 CAP
                                 REMARK   M/LL
               : MISMATCH     .225 MW      -.111 MVAR :

9 SIUL 6       1.01 PU   153.000    .000 GEN     27    IL S      149.46    -.80  149.46
              11.07 KV     1.620    .840 LOAD
              14.34 ANG      .000    .000 REC
                             .000    .000 CAP
                                 REMARK   M/LL
               : MISMATCH   -1.918 MW       .044 MVAR :

10 SALAL 6     1.00 PU   293.250  16.627 GEN     28    LAL S     282.75   15.10  283.15
              11.00 KV     3.240   1.750 LOAD
              15.25 ANG      .000    .000 REC
                             .000    .000 CAP
                                 REMARK
               : MISMATCH   -7.261 MW       .226 MVAR :

11 GNDTP G1    1.00 PU    93.500  13.832 GEN     29    ATINDA 1   85.01    8.98   85.48
              11.00 KV     8.910   4.760 LOAD
                .60 ANG      .000    .000 REC
                             .000    .000 CAP
                                 REMARK
               : MISMATCH     .419 MW      -.096 MVAR :

12 GNDTP G2    1.00 PU    63.750  26.000 GEN     30    ATINDA 2   55.10   22.03   59.42
              11.00 KV     8.910   4.760 LOAD
               1.41 ANG      .000    .000 REC
                             .000    .000 CAP
                                 REMARK
               : MISMATCH     .341 MW      -.094 MVAR :

13 R.T.P.G     1.00 PU   187.000  53.680 GEN     31    T.P. 2    169.70   43.86  175.28
              11.00 KV    17.820   9.520 LOAD
               6.85 ANG      .000    .000 REC
                             .000    .000 CAP
                                 REMARK
               : MISMATCH     .523 MW      -.295 MVAR :

14 PNPT(T)G    1.00 PU   164.900  21.687 GEN     32    PT(T)2    150.15   10.81  150.53
              11.00 KV    17.820   9.520 LOAD
               1.63 ANG      .000    .000 REC
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                     .000  .000 CAP
                         REMARK
      : MISMATCH    3.866 MW     -1.361 MVAR :


15 FARIDBAD 6    1.00 PU    114.750  36.154 GEN     33   RIDBAD S  106.87   29.39  110.84
                11.00 KV     11.340   6.090 LOAD
                 4.92 ANG      .000    .000 REC
                               .000    .000 CAP
                                 REMARK
      : MISMATCH    3.462 MW      -.675 MVAR :


16 I.P. 6        1.00 PU    232.900 110.624 GEN     35   P. 3      217.93   97.46  238.73
                11.00 KV     22.680  12.180 LOAD
                 6.33 ANG      .000    .000 REC
                               .000    .000 CAP
                                 REMARK
      : MISMATCH    7.712 MW      -.986 MVAR :


17 BADARPUR 6    1.00 PU     85.000   7.239 GEN     37   DARPUR S   74.16    -.20   74.16
                11.00 KV     12.550   6.720 LOAD
                 2.11 ANG      .000    .000 REC
                               .000    .000 CAP
                                 REMARK
      : MISMATCH    1.713 MW      -.718 MVAR :


18 RAPP 6        1.00 PU    187.000  94.489 GEN     38   PP S      178.70   85.44  198.07
                21.00 KV     16.200   8.680 LOAD
                -8.92 ANG      .000    .000 REC
                               .000    .000 CAP
                                 REMARK
      : MISMATCH    7.900 MW      -.372 MVAR :


19 BHKRA R2      1.03 PU       .000    .000 GEN     85   R1        -93.40    5.65   93.50
               225.88 KV       .000    .000 LOAD     1   KRA(R)6  -406.33   25.20  407.11
                 3.93 ANG      .000    .000 REC     40   MALPUR 2  222.47   27.71  224.19
                               .000    .000 CAP     39   SS                 280.44  -60.77  286.95
                                 REMARK   V/VL
      : MISMATCH    3.176 MW     -2.211 MVAR :


20 BHKRA L2      1.03 PU       .000    .000 GEN     84   1220      -91.73    7.74   92.06
               226.12 KV       .000    .000 LOAD    21   KRA L6   -102.28   50.75  114.18
                 2.90 ANG      .000    .000 REC      2   KRA(L)G2   37.56    3.00   37.68
                               .000    .000 CAP     39   SS                 161.31  -35.45  165.16
                                 REMARK   V/VL
      : MISMATCH    4.862 MW     -5.619 MVAR :


21 BHKRA L6       .99 PU       .000    .000 GEN     83   166       -91.73   -6.67   91.97
                65.22 KV     79.380  33.250 LOAD     3   KRA(L)G6  -89.89  -20.16   92.12
                11.17 ANG      .000    .000 REC     20   KRA L2    102.28  -33.48  107.62
                               .000    .000 CAP
                                 REMARK
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: MISMATCH     .042 MW    -27.063 MVAR :


22 DEHAR 2      1.03 PU       .000     .000 GEN     86    RG21      -140.05   16.52  141.02
               227.01 KV    28.350  15.190 LOAD     23    HAR 4      124.09  -39.67  130.27
                 4.12 ANG      .000     .000 REC      4    HAR G2    -138.40   16.36  139.45
                               .000     .000 CAP     39    SS                  129.28   -9.49  129.63
                                   REMARK   V/VL
   : MISMATCH    3.100 MW     -1.089 MVAR :


23 DEHAR 4      1.05 PU       .000     .000 GEN     87    RG41      -139.90   10.70  140.39
               421.05 KV       .000     .000 LOAD     22    HAR 2     -124.09   47.56  132.89
                  .00 ANG      .000     .000 REC      5    HAR G4      61.01   10.40   61.89
                               .000     .000 CAP     69    IWANI 4    156.13   12.70  156.65
                                   REMARK   V/VL     63    PT 4        52.67  -83.22   98.48
   : MISMATCH    5.743 MW     -1.856 MVAR :


24 PONG S       1.00 PU       .000     .000 GEN     88    NG1        -51.15    1.36   51.17
               219.60 KV       .000     .000 LOAD      6    NG G      -246.73    5.99  246.81
                 6.31 ANG      .000     .000 REC     53    LANDHAR    317.23   -8.48  317.34
                               .000     .000 CAP     59    SUYA       122.86    8.82  123.17
                                   REMARK            27    IL S      -148.78   -6.37  148.91
   : MISMATCH   -6.573 MW      1.320 MVAR :


25 GANGUWAL 1   1.02 PU       .000     .000 GEN     39    SS                    7.29  -17.02   18.52
               134.75 KV       .000     .000 LOAD      7    NGUWAL G   -64.87    5.25   65.08
                 2.44 ANG      .000     .000 REC     26    TLA S       59.74    9.56   60.50
                               .000     .000 CAP
                                   REMARK   V/VL
   : MISMATCH    2.162 MW     -2.212 MVAR :


26 KOTLA S      1.02 PU       .000     .000 GEN      8    TLA G      -64.86    5.29   65.08
               134.19 KV       .000     .000 LOAD     62    PAR 1      124.38    4.81  124.47
                 2.11 ANG      .000     .000 REC     25    NGUWAL 1   -59.55  -10.08   60.39
                               .000     .000 CAP
                                   REMARK   V/VL
   : MISMATCH    -.034 MW       .024 MVAR :


27 SUIL S       1.01 PU       .000     .000 GEN      9    UL G      -149.46   12.04  149.95
               222.19 KV       .000     .000 LOAD     24    NG S       150.72  -12.19  151.21
                10.04 ANG      .000     .000 REC
                               .000     .000 CAP
                                   REMARK   V/VL
   : MISMATCH    1.253 MW      -.152 MVAR :


28 SALAL S      1.00 PU       .000     .000 GEN     10    LAL G     -282.75    6.68  282.83
               219.75 KV       .000     .000 LOAD     58    HAMPUR     137.49   -6.94  137.67
                10.84 ANG      .000     .000 REC     57    MMU        135.05    2.40  135.07
                               .000     .000 CAP
                                   REMARK
   : MISMATCH  -10.202 MW      2.139 MVAR :
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29 BHATINDA 1	1.02 PU	.000	.000 GEN	30	ATINDA 2	-84.10	-16.10	85.64
	134.60 KV	170.100	91.000 LOAD	11	DTP G1	-85.01	-2.25	85.04
	-3.91 ANG	.000	.000 REC					
		.000	70.000 CAP					
		REMARK	V/VL					
	: MISMATCH	.993 MW	-.218 MVAR :					

30 BHATINDA 2	1.03 PU	.000	.000 GEN	90	DG21	-54.75	-18.00	57.63
	225.62 KV	.000	.000 LOAD	29	ATINDA 1	84.10	18.61	86.13
	-2.32 ANG	.000	.000 REC	12	DTP G2	-55.10	-17.97	58.03
		.000	.000 CAP	51	RNALA	27.30	16.56	31.93
		REMARK	V/VL					
	: MISMATCH	1.469 MW	-.807 MVAR :					

31 R.T.P. 2	1.03 PU	.000	.000 GEN	62	PAR 1	18.67	26.87	32.72
	226.30 KV	.000	.000 LOAD	13	T.P.G	-169.70	-26.59	171.77
	1.27 ANG	.000	.000 REC	41	VINDGARH	135.97	-11.02	136.41
		.000	.000 CAP	42	ANDIGARH	85.01	-9.87	85.58
		REMARK	V/VL	39	SS	-66.70	18.24	69.15
	: MISMATCH	3.238 MW	-2.361 MVAR :					

32 PNPT(T)2	1.05 PU	.000	.000 GEN	89	PTG1	-72.81	.92	72.82
	230.43 KV	.000	.000 LOAD	14	PT(T)G	-150.15	2.22	150.16
	-3.34 ANG	.000	.000 REC	64	PT 2	88.92	-21.17	91.41
		.000	.000 CAP	70	RWANA	181.65	-9.44	181.89
		REMARK	V/VL					
	: MISMATCH	6.450 MW	-9.04 MVAR :					

33 FARIDBAD S	1.01 PU	.000	.000 GEN	34	LABGARH	108.47	20.62	110.41
	66.82 KV	.000	.000 LOAD	15	RIDBAD G	-126.87	-21.16	108.95
	.74 ANG	.000	.000 REC					
		.000	.000 CAP					
		REMARK	V/VL					
	: MISMATCH	1.596 MW	-.547 MVAR :					

34 BALABGARH	1.05 PU	.000	.000 GEN	33	RIDBAD S	-108.47	-10.69	108.99
	230.87 KV	202.500	108.500 LOAD	37	DARPUR S	-211.40	-18.43	212.20
	-4.39 ANG	.000	.000 REC	65	RGAON	148.77	-20.91	150.23
		.000	70.000 CAP					
		REMARK	V/VL					
	: MISMATCH	31.398 MW	-.901 MVAR :					

35 I.P. 3	1.02 PU	.000	.000 GEN	36	P. 2.	104.52	18.97	106.23
	33.69 KV	113.400	60.690 LOAD	16	P. G	-217.93	-79.92	232.13
	2.37 ANG	.000	.000 REC					
		.000	.000 CAP					
		REMARK	V/VL					
	: MISMATCH	-.013 MW	-.260 MVAR :					

36 I.P. 2.	1.06 PU	.000	.000 GEN	35	P. 3	-104.52	-8.85	104.89

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              232.88 KV      81.000  43.400 LOAD    37    DARPUR S    83.04    41.60    92.88
               -3.07 ANG       .000    .000 REC     75    TPARGANJ    99.78   -50.89   112.01
                               .000 185.900 CAP
                                  REMARK   V/VL
              : MISMATCH   5.950 MW    8.650 MVAR :


39 BADARPUR S   1.05 PU        .000    .000 GEN     93    RPRTH2    -143.79    14.15   144.49
              232.10 KV        .000    .000 LOAD    92    RPRTH1    -143.79    14.15   144.49
               -3.32 ANG       .000    .000 REC     91    RPRH2      -71.94     7.04    72.28
                               .000    .000 CAP     17    DARPUR G   -74.16     7.24    74.52
                                  REMARK   V/VL     72    DNGR 2     -34.50   -14.59    37.46
              : MISMATCH   29.311 MW    -11.649 MVAR :


38 RAPP S       1.01 PU        .000    .000 GEN     18    PP G      -178.70   -63.78   189.74
              221.29 KV      81.000  43.400 LOAD    81    TA         128.01    13.65   128.73
              -14.83 ANG       .000    .000 REC
                               .000    .000 CAP
                                  REMARK   V/VL
              : MISMATCH   30.309 MW     -6.736 MVAR :


39 MISS            1.03 PU       .000    .000 GEN     25    NGUNAL 1    -7.29    17.15    18.64
              225.99 KV        .000    .000 LOAD    42    ANDIGARH    63.38   -16.06    65.38
                2.28 ANG       .000    .000 REC     31    T.P. 2      66.94   -21.49    70.31
                               .000    .000 CAP     41    VINDGARH    71.76   -13.30    72.98
                                  REMARK   V/VL     40    MALPUR 2   158.65    46.89   165.43
              : MISMATCH     .992 MW      -.641 MVAR :


40 JAMALPUR 2   1.00 PU        .000    .000 GEN     60    MALPUR 1    34.06     8.12    35.02
              220.05 KV     210.600 112.770 LOAD    50    LTONKLN     90.89   -31.75    96.27
                -.37 ANG       .000    .000 REC     39    SS                -156.92   -59.50   167.82
                               .000  10.000 CAP     52    NGRUR      120.56   -77.84   143.50
                                  REMARK   V/VL     53    LANDHAR    -80.42    90.99   121.43
              : MISMATCH    -.258 MW     -1.267 MVAR :


41 GOVINDGARH   1.02 PU        .000    .000 GEN     49    LERKOTLA    76.62     9.57    77.21
              225.26 KV      40.500  21.700 LOAD    47    TIALA       91.04    -5.08    91.18
                -.53 ANG       .000    .000 REC     31    T.P. 2    -135.14    -1.06   135.14
                               .000  30.000 CAP     39    SS                 -71.08     4.94    71.25
                                  REMARK   V/VL
              : MISMATCH    1.940 MW     -1.382 MVAR :


42 CHANDIGARH   1.03 PU        .000    .000 GEN     46    JPURA       67.08    -5.56    67.31
              225.88 KV      81.000  43.400 LOAD    31    T.P. 2     -84.62     6.99    84.91
                -.09 ANG       .000    .000 REC     39    SS                 -62.86     7.39    63.30
                               .000  50.000 CAP
                                  REMARK   V/VL
              : MISMATCH     .597 MW      -.495 MVAR :


43 ABDULAPUR    1.03 PU        .000    .000 GEN     45    PLI         16.23   -19.57    25.43
              226.27 KV      64.800  34.720 LOAD    39    SS                 -77.95     9.33    78.50
               -3.67 ANG       .000    .000 REC
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                          .000  25.000 CAP
                             REMARK   V/VL
             : MISMATCH   3.086 MW    -1.960 MVAR :


44 DHULKOTE     1.04 PU     .000    .000 GEN    64    PT 2       64.56  -44.96   78.67
              229.03 KV   72.090  38.640 LOAD   39    SS              -133.77   53.36  144.02
               -1.50 ANG    .000    .000 REC
                            .000  45.000 CAP
                               REMARK   V/VL
             : MISMATCH   2.876 MW    -1.731 MVAR :


45 PIPLI        1.03 PU     .000    .000 GEN    64    PT 2      -22.36  -25.06   33.58
              227.38 KV   40.500  21.700 LOAD   43    DULAPUR   -16.19   12.91   20.71
               -4.09 ANG    .000    .000 REC
                            .000  10.000 CAP
                               REMARK   V/VL
             : MISMATCH   1.947 MW    -1.127 MVAR :


46 RAJPURA      1.02 PU     .000    .000 GEN    47    TIALA      31.31    8.03   32.54
              225.41 KV   36.450  19.530 LOAD   42    ANDIGARH  -66.88    2.44   66.92
               -1.02 ANG    .000    .000 REC
                            .000  30.000 CAP
                               REMARK   V/VL
             : MISMATCH    .804 MW     -.692 MVAR :


47 PATIALA      1.02 PU     .000    .000 GEN    48    TRAN       40.83    5.04   41.14
              224.64 KV   81.000  43.400 LOAD   46    JPURA     -31.27  -12.25   33.58
               -1.36 ANG    .000    .000 REC    41    VINDGARH  -90.79   -4.73   90.91
                            .000  30.000 CAP
                               REMARK   V/VL
             : MISMATCH   -.226 MW      .189 MVAR :


48 PATRAN       1.01 PU     .000    .000 GEN    47    TIALA     -40.69  -11.25   42.22
              223.18 KV   40.500  21.700 LOAD
               -2.26 ANG    .000    .000 REC
                            .000  10.000 CAP
                               REMARK   V/VL
             : MISMATCH   -.194 MW      .159 MVAR :


49 MALERKOTLA   1.01 PU     .000    .000 GEN    52    NGRUR      57.54  -14.12   59.25
              223.00 KV   40.500  21.700 LOAD   51    RNALA      18.29  -18.79   26.22
               -2.13 ANG    .000    .000 REC    50    LTONKLN   -37.43   33.66   50.34
                            .000  10.000 CAP    41    VINDGARH  -76.17  -13.78   77.41
                               REMARK   V/VL
             : MISMATCH   2.730 MW    -1.596 MVAR :


50 LALTONKLN    1.00 PU     .000    .000 GEN    49    LERKOTLA   37.64  -38.63   53.94
              220.45 KV   52.650  20.210 LOAD   40    MALPUR 2  -90.65   30.93   95.78
               -1.11 ANG    .000    .000 REC
                            .000  20.000 CAP
                               REMARK   V/VL
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                  : MISMATCH    -.360 MW       .425 MVAR :


51 BARNALA         1.02 PU       .000     .000 GEN     49    LERKOTLA  -18.25   12.87   22.33
                 224.00 KV     24.300   13.020 LOAD    52    NGRUR      21.75    6.11   22.59
                  -2.61 ANG      .000     .000 REC     30    ATINDA 2  -27.24  -32.33   42.28
                                 .000     .000 CAP
                                     REMARK   V/VL
                  : MISMATCH     .566 MW      -.333 MVAR :


52 SANGRUR         1.01 PU       .000     .000 GEN     49    LERKOTLA  -57.37   10.68   58.35
                 223.07 KV     72.900   39.060 LOAD    51    RNALA     -21.71  -11.54   24.59
                  -3.00 ANG      .000     .000 REC     68    SSAR      126.85  -76.49  148.12
                                 .000   25.000 CAP     40    MALPUR 2 -118.93   63.42  134.79
                                     REMARK   V/VL
                  : MISMATCH    1.731 MW      -.573 MVAR :


53 JALANDHAR        .98 PU       .000     .000 GEN     54    RPAL       40.26    9.06   41.27
                 215.33 KV    283.500  151.900 LOAD    24    NG S     -310.76   -1.29  310.76
                   1.15 ANG      .000     .000 REC     59    SUYA      -96.67    1.26   96.68
                                 .000   60.000 CAP     40    MALPUR 2   81.25 -102.98  131.17
                                     REMARK
                  : MISMATCH   -2.425 MW       .464 MVAR :


54 VERPAL           .97 PU       .000     .000 GEN     55    TALA      -35.29    2.35   35.37
                 212.49 KV     72.900   39.060 LOAD    53    LANDHAR   -40.02  -12.87   42.04
                   -.37 ANG      .000     .000 REC
                                 .000   30.000 CAP
                                     REMARK
                  : MISMATCH   -2.410 MW       .552 MVAR :


55 BATALA           .97 PU       .000     .000 GEN     54    RPAL       35.39   -7.54   36.19
                 212.66 KV     64.800   34.720 LOAD    56    RNA      -101.77   -8.03  102.09
                    .48 ANG      .000     .000 REC
                                 .000   20.000 CAP
                                     REMARK
                  : MISMATCH   -1.580 MW       .471 MVAR :


56 SARNA            .98 PU       .000     .000 GEN     55    TALA      102.86    6.00  103.03
                 215.72 KV     64.800   34.720 LOAD    59    SUYA      -26.82  -26.94   38.01
                   3.53 ANG      .000     .000 REC     58    HAMPUR    -94.79    2.28   94.82
                                 .000   20.000 CAP     57    MMU       -52.79    4.96   53.02
                                     REMARK
                  : MISMATCH   -6.732 MW      1.784 MVAR :


57 JAMMU            .98 PU       .000     .000 GEN     56    RNA        53.23  -14.27   55.11
                 215.86 KV     81.000   43.400 LOAD    28    LAL S    -132.80    -.74  132.80
                   5.97 ANG      .000     .000 REC
                                 .000   30.000 CAP
                                     REMARK
                  : MISMATCH    1.434 MW      -.490 MVAR :
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58 UDHAMPUR	.99 PU	.000	.000	GEN	56	RNA	96.72	-8.62	97.10
	218.84 KV	43.740	23.450	LOAD	28	LAL S	-136.85	-.87	136.85
	9.45 ANG	.000	.000	REC					
		.000	15.000	CAP					
			REMARK						
	: MISMATCH	3.607 MW	-.885 MVAR :						

59 DASUYA	.99 PU	.000	.000	GEN	56	RNA	26.07	12.28	29.54
	217.06 KV	.000	.000	LOAD	53	LANDHAR	97.57	-3.88	97.65
	3.85 ANG	.000	.000	REC	24	NG S	-121.82	-8.99	122.15
		.000	.000	CAP					
			REMARK						
	: MISMATCH	2.625 MW	-.592 MVAR :						

60 JAMALPUR 1	.97 PU	.000	.000	GEN	40	MALPUR 2	-34.06	-7.62	34.91
	127.77 KV	40.500	21.700	LOAD	61	MRALA	-6.36	-14.38	15.73
	-1.17 ANG	.000	.000	REC					
		.000	.000	CAP					
			REMARK						
	: MISMATCH	.076 MW	-.301 MVAR :						

61 SAMRALA	.97 PU	.000	.000	GEN	60	MALPUR 1	6.41	11.55	13.20
	128.66 KV	40.500	21.700	LOAD	62	PAR 1	-46.71	-19.26	50.52
	-1.18 ANG	.000	.000	REC					
		.000	15.000	CAP					
			REMARK						
	: MISMATCH	.194 MW	-.260 MVAR :						

62 PAR 1	1.00 PU	.000	.000	GEN	31	T.P. 2	-18.67	-25.61	31.69
	131.55 KV	93.150	49.910	LOAD	61	MRALA	47.40	16.65	50.24
	-.04 ANG	.000	.000	REC	26	TLA S	-122.14	-5.86	122.28
		.000	35.000	CAP					
			REMARK						
	: MISMATCH	-.259 MW	.331 MVAR :						

63 PNPT 4	1.05 PU	.000	.000	GEN	64	PT 2	174.45	10.97	174.79
	419.77 KV	.000	.000	LOAD	71	DNGR 4	-104.64	-4.70	104.75
	-.70 ANG	.000	65.000	REC	23	HAR 4	-52.54	-85.23	100.12
		.000	.000	CAP					
			REMARK	V/VL					
	: MISMATCH	17.260 MW	-7.377 MVAR :						

64 PNPT 2	1.05 PU	.000	.000	GEN	63	PT 4	-174.45	-2.34	174.46
	230.44 KV	145.800	78.120	LOAD	66	DRI	80.98	-16.54	82.65
	-3.52 ANG	.000	.000	REC	32	PT(T)2	-88.87	15.31	90.17
		.000	50.0[illegible]	CAP	45	PLI	22.46	15.46	27.26
			REMARK	V/VL	73	RELA	74.33	-46.65	87.75
	: MISMATCH	-3.720 MW	1.358 MVAR :						

65 GURGAON	1.05 PU	.000	.000	GEN	34	LABGARH	-147.92	12.79	148.47

	230.15 KV	52.650	28.210	LOAD	66	DRI	96.99	-25.12	100.19
	-5.73 ANG	.000	.000	REC					
		.000	15.000	CAP					
			REMARK	V/VL					

: MISMATCH 1.722 MW -.534 MVAR :

66 DADRI	1.04 PU	.000	.000	GEN	78	ETRI	73.58	.72	73.58
	229.55 KV	162.000	86.800	LOAD	64	PT 2	-79.89	5.99	80.11
	-7.48 ANG	.000	.000	REC	65	RGAON	-96.26	5.96	96.44
		.000	70.000	CAP	67	IWANI 2	-33.28	-36.87	49.61
			REMARK	V/VL					

: MISMATCH 26.229 MW -7.01 MVAR :

67 BHIWANI 2	1.05 PU	.000	.000	GEN	69	IWANI 4	-151.79	-73.69	168.74
	230.03 KV	28.350	15.190	LOAD	78	ETRI	61.35	-2.07	61.39
	-7.39 ANG	.000	.000	REC	66	DRI	33.23	19.70	38.63
		.000	.000	CAP	68	SSAR	33.57	40.16	52.34
			REMARK	V/VL					

: MISMATCH 4.709 MW -.718 MVAR :

68 HISSAR	1.03 PU	.000	.000	GEN	78	ETRI	81.83	-6.40	82.08
	227.20 KV	89.100	47.740	LOAD	70	RWANA	-10.98	-4.47	11.85
	-7.66 ANG	.000	.000	REC	67	IWANI 2	-33.38	-55.12	64.44
		.000	30.000	CAP	52	NGRUR	-123.99	49.52	133.52
			REMARK	V/VL					

: MISMATCH 2.576 MW -.726 MVAR :

69 BHIWANI 4	.97 PU	.000	.000	GEN	67	IWANI 2	151.79	81.57	172.32
	388.29 KV	.000	.000	LOAD	23	HAR 4	-154.01	-175.18	233.25
	-5.04 ANG	.000	100.000	REC					
		.000	.000	CAP					
			REMARK						

: MISMATCH -2.216 MW .619 MVAR :

70 NARWANA	1.03 PU	.000	.000	GEN	68	SSAR	10.99	-5.75	12.40
	227.39 KV	166.050	88.980	LOAD	32	PT(T)2	-179.18	-7.00	179.32
	-7.31 ANG	.000	.000	REC					
		.000	70.000	CAP					
			REMARK	V/VL					

: MISMATCH -2.142 MW 1.366 MVAR :

71 MRDNGR 4	1.05 PU	298.350	.000	GEN	72	DNGR 2	199.51	45.63	204.66
	418.97 KV	.000	.000	LOAD	63	PT 4	104.80	-47.72	115.15
	.25 ANG	.000	.000	REC					
		.000	.000	CAP					
			REMARK	M/LL					

: MISMATCH 5.957 MW -2.086 MVAR :

72 MRDNGR 2	1.06 PU	.000	.000	GEN	71	DNGR 4	-199.51	-35.70	202.68
	233.91 KV	.000	.000	LOAD	37	DARPUR S	34.62	5.46	35.05
	-2.49 ANG	.000	.000	REC	75	TPARGANJ	190.63	13.72	191.13

		.000	.000	CAP				
		REMARK	V/VL					

: MISMATCH 25.746 MW -16.527 MVAR :

73 NERELA	1.05 PU	.000	.000	GEN	75	TPARGANJ	-161.05	-36.97	165.24
	231.05 KV	162.000	86.800	LOAD	76	JAFGARH	20.08	-8.54	21.82
	-4.30 ANG	.000	.000	REC	74	RH.ROAD	99.64	-3.97	99.72
		.000	80.000	CAP	64	PT 2	-74.07	19.75	76.66
		REMARK	V/VL						

: MISMATCH 7.560 MW - 8.650 MVAR :

74 D.RH.ROAD	1.05 PU	.000	.000	GEN	73	RELA	-99.44	-1.27	99.45
	230.61 KV	93.150	49.910	LOAD					
	-4.77 ANG	.000	.000	REC					
		.000	40.000	CAP					
		REMARK	V/VL						

: MISMATCH -6.288 MW 4.685 MVAR :

75 PATPARGANJ	1.06 PU	.000	.000	GEN	72	DNGR 2	-190.14	-28.94	192.33
	232.99 KV	76.950	41.230	LOAD	36	P. 2.	-99.75	50.49	111.80
	-3.17 ANG	.000	.000	REC	73	RELA	161.74	30.33	164.56
		.000	55.000	CAP					
		REMARK	V/VL						

: MISMATCH -10.051 MW 9.856 MVAR :

76 NAJAFGARH	1.05 PU	.000	.000	GEN	73	RELA	-20.07	-1.11	20.10
	231.05 KV	89.100	47.740	LOAD	77	HRAULI	-54.05	-11.02	55.17
	-4.45 ANG	.000	.000	REC					
		.000	40.000	CAP					
		REMARK	V/VL						

: MISMATCH 14.979 MW -8.511 MVAR :

77 MEHRAULI	1.05 PU	.000	.000	GEN	76	JAFGARH	54.11	4.01	54.26
	231.45 KV	174.150	93.240	LOAD	37	DARPUR S	-243.75	.54	243.75
	-4.16 ANG	.000	.000	REC					
		.000	80.000	CAP					
		REMARK	V/VL						

: MISMATCH -15.494 MW 9.246 MVAR :

78 KHETRI	1.02 PU	.000	.000	GEN	67	IWANI 2	-60.36	-16.11	62.47
	224.16 KV	76.950	41.230	LOAD	80	ENUGUS	62.91	8.45	63.47
	-11.93 ANG	.000	.000	REC	79	IPUR	80.61	-7.49	80.96
		.000	10.000	CAP	68	SSAR	-80.64	-3.56	80.72
		REMARK	V/VL		66	DRI	-72.42	-13.68	73.70

: MISMATCH 7.053 MW -1.546 MVAR :

79 JAIPUR	1.00 PU	.000	.000	GEN	81	TA	25.27	-25.33	35.78
	220.73 KV	137.700	73.780	LOAD	82	WAR	-61.59	-23.11	65.78
	-14.55 ANG	.000	.000	REC	80	ENUGUS	-11.20	-.34	11.21
		.000	.000	CAP	78	ETRI	-79.85	-27.93	84.60
		REMARK	V/VL						

```
                : MISMATCH   10.331 MW     -2.923 MVAR :

 80 REENUGUS      1.00 PU       .000     .000 GEN     79    IPUR        11.22   -8.31   13.96
                220.52 KV     48.600   26.040 LOAD    78    ETRI       -62.38  -16.71   64.58
                -14.10 ANG      .000     .000 REC
                                .000     .000 CAP
                                     REMARK    V/VL
                : MISMATCH   -2.560 MW      1.021 MVAR :

 81 KOTA          1.00 PU       .000     .000 GEN     79    IPUR       -25.18  -22.96   34.08
                220.08 KV    140.940   75.460 LOAD    38    PP S      -127.62  -28.99  130.88
                -15.67 ANG      .000     .000 REC
                                .000   20.000 CAP
                                     REMARK    V/VL
                : MISMATCH  -11.864 MW      3.494 MVAR :

 82 ALWAR         1.03 PU       .000     .000 GEN     37    DARPUR S -120.51    3.44  120.56
                227.38 KV     56.700   30.380 LOAD    79    IPUR        62.43    9.60   63.16
                -11.10 ANG      .000     .000 REC
                                .000   40.000 CAP
                                     REMARK    V/VL
                : MISMATCH   -1.385 MW       .698 MVAR :

 83 BH166         1.00 PU     91.800   15.803 GEN     21    KRA L6      91.73   15.77   93.07
                 11.00 KV       .000     .000 LOAD
                 16.76 ANG      .000     .000 REC
                                .000     .000 CAP
                                     REMARK
                : MISMATCH    -.073 MW      -.033 MVAR :

 84 BH220         1.00 PU     91.800    3.670 GEN     20    KRA L2      91.73    3.64   91.80
                 11.00 KV       .000     .000 LOAD
                  9.99 ANG      .000     .000 REC
                                .000     .000 CAP
                                     REMARK
                : MISMATCH    -.069 MW      -.030 MVAR :

 85 BHR1          1.00 PU     93.500    1.496 GEN     19    KRA R2      93.40    1.46   93.42
                 11.00 KV       .000     .000 LOAD
                  8.29 ANG      .000     .000 REC
                                .000     .000 CAP
                                     REMARK
                : MISMATCH    -.095 MW      -.032 MVAR :

 86 DHRG21        1.00 PU    140.250   -2.814 GEN     22    HAR 2      140.05   -2.90  140.08
                 11.00 KV       .000     .000 LOAD
                  9.66 ANG      .000     .000 REC
                                .000     .000 CAP
                                     REMARK
                : MISMATCH    -.201 MW      -.084 MVAR :
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87 DHRG41      1.00 PU   140.250   4.212 GEN    23   HAR 4      139.98    4.09  140.04
               11.00 KV      .000    .000 LOAD
               6.92 ANG      .000    .000 REC
                             .000    .000 CAP
                                 REMARK
               : MISMATCH   -.269 MW     -.125 MVAR :


88   NG1       1.00 PU    51.000   3.307 GEN    24   NG S        51.15    3.37   51.26
               11.00 KV      .000    .000 LOAD
               11.60 ANG     .000    .000 REC
                             .000    .000 CAP
                                 REMARK
               : MISMATCH    .152 MW      .062 MVAR :


89 PNPTG1      1.00 PU    82.170  10.137 GEN    32   PT(T)2      72.81   -5.21   73.00
               11.00 KV     8.910   4.760 LOAD
               1.48 ANG      .000    .000 REC
                             .000    .000 CAP
                                 REMARK
               : MISMATCH   -.447 MW     -.167 MVAR :


90 GND621      1.00 PU    63.750  26.794 GEN    30   ATINDA 2    54.75   22.01   59.01
               11.00 KV     8.910   4.760 LOAD
               1.30 ANG      .000    .000 REC
                             .000    .000 CAP
                                 REMARK
               : MISMATCH   -.091 MW     -.028 MVAR :


91 BDARPRH2    1.00 PU    85.000   6.659 GEN    37   DARPUR S    71.94    -.41   71.94
               11.00 KV    12.550   6.860 LOAD
               1.95 ANG      .000    .000 REC
                             .000    .000 CAP
                                 REMARK
               : MISMATCH   -.514 MW     -.206 MVAR :


92 BDRPRTH1    1.00 PU   170.000  12.110 GEN    37   DARPUR S   143.79   -1.74  143.80
               11.00 KV    25.110  13.440 LOAD
               1.61 ANG      .000    .000 REC
                             .000    .000 CAP
                                 REMARK
               : MISMATCH  -1.099 MW     -.411 MVAR :


93 BDRPRTH2    1.00 PU   170.000  12.110 GEN    37   DARPUR S   143.79   -1.74  143.80
               11.00 KV    25.110  13.440 LOAD
               1.61 ANG      .000    .000 REC
                             .000    .000 CAP
                                 REMARK
               : MISMATCH  -1.099 MW     -.411 MVAR :
```

Distance, under voltage and loss of excitation relays have been modeled in the simulator. If required then they can be very easily put to use. The total simulation time of the system is specified in an input data file (SYSCON. DAT). The equivalent admittance matrix for the faulted and unfaulted transmission networks are obtained using a network reduction program and are stored in a file identified by (unit = NRDE).

5.1 RESULTS AND DISCUSSIONS

The power system simulator is developed for the dynamic simulation of power system and its behaviour under various system disturbance conditions are observed and recorded. Different system conditions can be applied on the power system for varying period of time. All this can be specified through an input data file. The various system conditions considered here are as follows - (i) Three phase bus fault (ii) Three phase line fault (iii) Loss of excitation (iv) Load change (v) Three phase bus fault cleared. In this section behaviour under (i), (iii),(iv) and (v) system conditions have been included.

RESULT 1 - In this case a three phase bus fault has been applied on the load bus no. 33. The name of this buses is FARIDABADS. The time for which this fault is applied is 0.10 seconds. That is, after 0.10 secs the system condition

(v) is applied. Thus the three phase fault is cleared at 0.10 seconds after it has occurred at 0.0 seconds. The swing curve for the generator of the bus connected to the above load bus where the fault was applied is recorded. The bus name and no are FARIDABADG and 15 respectively. It has been provided in this section. From this curve we observe that the rotor angle increases sharply for the time during which the fault was applied but after it is cleared, it starts oscillating about the equilibrium state. The frequency and the amplitude of the oscillations are decreasing with increasing time. This suggests that the generator is slowly reaching the stable state. The simulation was carried out for 2.0 seconds. Increasing the total simulation time of the power system increases the execution time of the program. Therefore a trade-off is necessary between the two. For a five seconds simulation time the execution time was observed to be 40 minutes. For the system to be stable it is important that the fault is cleared before the critical clearing time. The swing curve of some of the Generators havebeen drawn for this case. A time scale of 2.0 seconds is taken for these curves. All these curves suggest that the system is stable.

RESULT 2 - In this case a field fault is applied on the generator of the bus no 13. The name of this generator bus is R.T.P.G. In order to identify the fault a loss of excitation relay is provided in this bus. The field circuit fault can be of two types. It can either be open circuited or short circuited. The short circuited case is provided here. The fault is applied at 0.0 seconds. The time delay of the relay is fixed at 0.40 seconds. The total time for which the fault is observed is 3.0 seconds. From the swing curve drawn for this generator bus it can be observed that the loss of excitation of the generator for 3.0 seconds makes the system unstable. This can be identified by the constantly increasing rotor angle with time. A plot for the apparant impedance characteristic for the field fault generator bus is also provided. The equivalent generator impedances follows a path from the first quadrant to the fourth quadrant as can be observed in the graph. When the excitation is severely reduced it enters a region of the fourth quadrant which is encompassed within the characteristic of the loss of excitation relay. The impedance characteristic enters the region after 2.25 seconds as can be observed from the graph. By this time the system has become unstable. Speed deviation, terminal voltage and reactive power curves have also been provided.

Another example has been taken for the loss of excitation system condition. This time the field fault is applied on the bus GN DTP (bus no.11). The short circuited case has been taken here too. The rotor angle, reactive power, terminal voltage and speed deviation curves are drawn. In this case also the relay fails to trip before the system becomes unstable.

The impedance and relay characteristics are also included in this section. From this curve it is observed that the impedance characteristic enters the outer circle of the relay characteristic after 2.0 seconds. A time delay of 0.80 seconds is provided. The impedance characteristic enters the inner circle at 2.79 seconds.

RESULT 3- When a large load of 202.50 MW and 180.50 MVAR is suddenly removed from the system, large oscillations are observed in the rotor of the generator bus connected to it, and the system becomes unstable after some time. But when a small load of 24.30 MW and 13.02 MVAR is removed from the system, itssynchronism gets restored after a time of 2.0 seconds. This can be shown by the swing curve of the generator bus connected to the load bus. The name of this load bus is BARNALA (bus no51) and the name of the generator bus is R.T.P.G.(bus no.13).

Load flow results have also been included here. Active and Reactive mismatches for each and every bus has been calculated. These mismatches for every bus should be kept as much low as possible.

CHAPTER - 6

CONCLUSIONS

6.1 SUMMARY

The power system simulator meets the need of a good tool for proper study of any power system. Detailed generator, exciter and turbine governor models have been considered. The Analog computer representation is used to write effecient subroutines of these models. The various Generator models, exciter models and turbine governor models have been described in previous chapters. A relay protection scheme is included in the simulator. It can be activated when required. Distance, under voltage and loss of excitation are the three types of relay schemes provided in this simulator. Load flow study is carried out for the power system example considered. Gauss Seidel method is used for this purpose. An efficient numerical solution technique is used for solving the network and algebraic equations and the differential equations of the machine and controller units. Different system disturbance conditions can be simulated and the behaviour of the power system under emergency conditions is observed and recorded. Thus the stability of the power system can be studied properly.

6.2 SUGGESTIONS FOR FUTURE WORK

In power system modelling much attention has been paid to generator modelling, although the impact of load models on the system is of equal importance. It has been a common practice to model a load as (a) constant power (b) constant current and (c) constant impedance. Here the third form of load modelling has been done. Though this form of modelling is satisfactory under specific conditions but in general the load cannot be satisfactorily modelled by this form. This simplifies the study but does not make it accurate. The load power varies generally with respect to voltage and frequency. Thus a load model should take this into consideration. Hence a more general form of load modelling can be done to make the study more complete and accurate. The system disturbance has been categorised into two classes. They are (i) Network disturbances (ii) Islanding. These have been discussed in chapter-2. Here,in this simulator only the first class of system disturbance has been considered. The second class can also be incorporated and its effect on the power system model can be studied.

REFERENCES

[1] IEEE Committee report - 'Computer representation of Excitation Systems', IEEE Trans. on Power Apparatus and Systems, June 1968, pp. 50-54.

[2] IEEE Committee report - 'Dynamic models for steam and hydroturbines in power systems', IEEE Trans on Power Apparatus and Systems, Dec.1972, p.1904-1911.

[3] D.Gelopulos, 'Major Simulation errors of on line Simulations', IEEE Trans. on Power Apparatus and Systems, June 1974, p. 137-140.

[4] D.Gelopulos, 'Study of large power system after severe disturbances'- SIMULATION 1978, p. 145-153.

[5] M.Rafian 'Real time power system simulation' - IEEE Proceedings,May 1987, p. 206-224.

[6] G.Z.Ben Yaacov, 'Data base approach to system analysis studied', IEEE Trans on Power Apparatus and Systems, May 1981, p.2643-2649.

[7] R.Dunlop and D.N.Ewart - 'Long time dynamic response assessment of power system using digital simulation, IEEE Trans. on Power Apparatus and Systems,May 1975, p.850-857.

[8] A.Keyhani, 'Interactive simulator for power system research,IEEE Trans on power Apparatus and Systems, Mar. 1984, p.516-521.

[9] R.Podmore and J.P.Britton -'An Advanced Dispatcher training simulator', IEEE Trans on Power Apparatus and Systems, Jan. 1982, p. 17-24.

[10] L.Elder 'An efficient method for real time simulation of large power system disturbances',IEEE Trans. on Power Apparatus and Systems, Feb. 1982, p.334-338.

[11] M.Pai Computer techniques in power system analysis, Tata Mc Graw Hill, New Delhi, 1979.

[12] D.Celopulas and G.Iddings, 'Selection of Integration algorithms for power system simulation', Proceedings of control of power systems, 1976, p.114.

[13] W.D.Stevenson Elements of power system Analysis, Mc Graw Hill, New York, 1975.

[14] F.W.Kimbark, Power system stability, Vol. 1,2,3, Wiley, New York 1948.

[15] G.W.STAGG and AHEL-ABAID, Computer methods in power system Analysis, Mc Graw Hill, New York, 1975.

[16] R.D.Dunlop and D. Ewart 'System requirements for dynamic performance and response of generating units', IEEE trans on Power Apparatus and Systems, May/June 1975, p. 835-845.

[17] F.P.De Mello, and I.H.Hannett "Validation of synchronous machine models and derivation of model parameters from tests, IEEE trans. on Power Apparatus and systems, Feb. 1981, p.662-668.

[18] P.Demello and A.Concordia 'Concepts of Machine stability as affected by Excitation Control, IEEE Trans. on Power Apparatus and Systems, April, 1969, p.316.

[19] D.N.Ewart and P.Demells, 'FACE-A Digital Analysis Program', Proc. 1967 PICA Conference, pp. 83-94.

[20] Anderson and Faovd, Power System stability and control, IOWA State Press Ames, IOWA 1977.

NOMENCLATURE

The following notation is generally used unless a specific alternative definition is made within the text.

y	State variables
z	auxiliary variables
E	generator internal voltage
I	generator current
V	generator terminal voltage
θ	angle of generator d axis to synchronous reference
	angle of generator q axis to synchronous reference
X	reactance
L	inductance
Y	admittance
R	resistance
T	time constant
D	damping factor
A, B	coefficients of generator saturation function
S	saturation function
k	saturation factor
H	inertia constant
f	frequency
E_{FD}	exciter output voltage (applied to generator field)
I_{FD}	generator field current
I_T	generator terminal current
K_A	regulator gain

K_E	exciter constant related to self-excited field
K_F	regulator stabilizing circuit gain
K_I	current circuit gain of type 3 system
K_P	potential circuit gain of type IS or type 3 system
K_V	fast raise/lower contact setting, type 4 system
S_E	exciter saturation function
T_A	regulator amplifier time constant
T_E	exciter time constant
T_F	regulator stabilizing circuit time constant
T_{F1}, T_{F2}	regulator stabilizing circuit time constant (rotating rectifier system)
T_R	regulator input filter time constant
T_{RH}	rheostat time constant, type 4 system
V_R	regulator output voltage
$V_{R\ max}$	maximum value of V_R
$V_{R\ min}$	minimum value of V_R
V_{REF}	regulator reference voltage setting
V_{RH}	field rheostat setting
V_T	generator terminal voltage
V_{THEV}	voltage obtained by vector sum of potential current signals, type 3 system
ΔV_T	generator terminal voltage error.

F_{VHP}	Very High Pressure Turbine Power Fraction	1
F_{HP}	High Pressure Turbine Power Fraction	1
F_{IP}	Intermediate Pressure Turbine(s) Power Fraction	1
F_{LP}	Low Pressure Turbine(s) Power Fraction	1
F	Gain Constant. See Fig. 5 (C)	
K_G	100./(% Steady State Speed Regulation)	
K_P	Gain Associated With Steam Flow Feedback on General Electric EHC Systems	
K_{PR}	Gain Associated With Steam Flow Feedback on Westinghouse EH System	
K_{PD}	Steam Lead Pressure Drop Coefficient	
$\dot{m}_{CV}$	Governor-Controlled Valve Steam Flow	
$\dot{m}_{HP}$	High Pressure Turbine Steam Flow	
$\dot{m}_{TO}$	Initial (time = 0^-) Throttle Valve Steam Flow	
P_{M1}	Mechanical Power, Shaft 1	
P_{M2}	Mechanical Power, Shaft 2	
P_{SG}	Internal Boiler Steam Pressure, Assumed Constant	
P_T	Throttle Pressure	
P_{TO}	Initial (time = 0^-) Throttle Pressure	
T_{SM}	Valve Positioning Servomotor Time Constant	
T_{SR}	Speed Relay Time Constant	
T_I	Time Constant Associated With Steam Flow Feedback on Westinghouse EH System	
T_{CH}	Steam Chest Time Constant (Control Valves to HP (VHP)) Exhaust	4
T_{RH} T_{RH1}	Reheat Time Constant (HP VHP Exhaust to IP HP) Exhaust	4
T_{RH2}	Second Reheat Time Constant (HP Exhaust to IP Exhaust)	4
T_{CO}	Crossover Time Constant (IP Exhaust to LP Exhaust)	4
	Hydraulic System Symbols	
a_{11}, a_{13}, a_{21}, a_{23}	Hydro Turbine Parameters	2
T_G	Gate Servomotor Time Constant	

T_P	Pilot Valve Time Constant
T_R	Dashpot Time Constant
T_W	Water Starting Time. See Appendix II
δ	Transient Speed Droop Coefficient
σ	Permanent Speed Droop Coefficient
	Common System Symbols
C_V	Effective Governor-Controlled Valve or Gate Position
ΔC_V	Effective Governor-Controlled Valve or Gat Incremental Position
C_{VMAX}, C_{VMIN}	Valve or Gate Position Limits
$\dot{C}_{VOPEN}$, $\dot{C}_{VCLOSE}$	Valve or Gate Servo Rate Limits
$K_1 - K_7$	General Model Parameters See Figure 8 and Table III
K	Total Effective Speed-Governing System G See Figure 5
P_M	Mechanical Power
P_O	Initial (time = 0^-) Mechanical Power
ΔP	Incremental Power Due to Valve or Gate M
ΔP_{MAX}, ΔP_{MIN}	Incremental Power Limits Imposed by Gate or Valve Travel
$\dot{P}_{UP}$, $\dot{P}_{DOWN}$	Limits on Rate of Change of Power Impose by Control Valve Rate Limits
P_{GV}	Power at Gate or Valve Outlet
P_{MAX}, P_{MIN}	Power Limits Imposed by Valve or Gate Tr
SR	Speed Reference
T_1, T_2, T_3	See Figure 4 and Tables I and IV
$T_4 - T_7$	General Model Time Constants See Figure 8 and Table III
ω	Speed
$\Delta\omega$	Speed Deviation
s	Differential Operator

Superscripts

-	complex
.	time derivative
'	transient
o	unsaturated
fict	fictitious

Subscripts

d	direct axis
q	quadrature axis
real	real axis of synchronous reference
imag	imaginary axis of synchronous reference
a	armature or air gap
O	open circuit or base value
k	damper winding
f	field winding
ℓ	leakage or losses
e	electrical or exciter
m	mechanical
G	Generator internal bus
T	Generator terminal bus

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