A NEW APPROACH TO POWER SYSTEM STABILITY

A DISSERTATION
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requirements for the award of the degree
of
MASTER OF ENGINEERING
in
ELECTRICAL ENGINEERING
(Power System Engineering)

By

RAJENDRA PRASAD SHARMA

DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF ROORKEE
ROORKEE-247672 (INDIA)

October, 1980

DEDICATED

TO

My Bade Guru Ji

CERTIFICATE

Certified that the dissertation entitled 'A NEW APPROACH TO POWER SYSTEM STABILITY' which is being submitted by Mr. R. P. SHARMA in partial fulfilment of the requirements for the award of the degree of Master of Engineering in Electrical Engineering (Power System) of the University of Roorkee, Roorkee (U.P.) is the record of student's own work carried out by him under our supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

It is further certified that he has worked for a period of 9 months from January 1980 to September 1980 for preparing this dissertation at this University.

S. Agrawal
(S. AGRAWAL)
Lecturer in Electrical
Engineering Department,
University of Roorkee,
ROORKEE (U.P.)

Dated: October 2nd ,1980.

(R. B. MISRA)
Lecturer in Electrical
Engineering Department,
University of Roorkee,
ROORKEE (U.P.)

Dated: October 2 ,1980.

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R. P. SHARMA

ABSTRACT

Power system stability is the term applied to alternating-current electric power systems, denoting a condition in which the various synchronous machines of the system remain in synchronism or "in step" with each other. There has been continuous development of better techniques for assessing transient stability studies. Further the continuous need, for the development of additional transient stability indices which completely reflect all the factors that influence the system stability has been felt. There is bulk of literature available in this area using deterministic approaches. The transient stability is usually determined by using deterministic approaches with some predetermined perturbations. But these approaches are not the appropriate solution for the transient stability study, because these only concern with non-probabilistic variables.

Transient stability evaluation consider the effects of disturbances such as fault, loss of load, sudden switching of transmission line etc. on the system. At present the probabilistic techniques are being used extensively in other areas of system planning. The application of probabilistic approach in the analysis of transient stability is a realistic, logical and useful extension of the power system stability study.

As already pointed out the transient stability depends upon fault-types, fault location, fault clearing time, and other system parameters. In fact all the above factors are probabilistic in nature rather than deterministic. Therefore the transient stability analysis in this thesis has been done for a practical system of Uttar Pradesh Electricity Board, using the probabilistic approach.

The literature survey of the available methods for transient stability is presented in chapter-II. The probabilistic nature of the parameters which affect the stability is discussed in chapter-III.

Chapter-IV describes the calculation procedure for transient stability using probabilistic approach. Further the discussion about distribution and fault calculations is presented. The transient stability analysis for the system along with comments on the results is also presented in the chapter-IV. A computer program has been developed with the help of flow charts for the analysis. The flow charts and computer program are given in Appendix.

In chapter-V the conclusions drawn from the present work are given along with the suggestions for further work in the area of transient stability study.

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LIST OF SYMBOLS

Z_0, Z_1, Z_2 : positive, negative and zero sequence impedances of sending end section.

Z_0', Z_1', Z_2' : positive, negative and zero sequence impedances of receiving end section.

ZL_1, ZL_2, ZL_0 : positive, negative and zero sequence impedances of sending end of the line.

ZL_1', ZL_2', ZL_0' : positive, negative and zero sequence impedances of receiving end section of line.

Z_t : impedance of sending end transformer to all sequences.

Z_t' : impedance of receiving end transformer to all sequences.

Z_{g1} and Z_{g2} : positive and negative sequence impedance of sending end generator.

Z_1'', Z_2'', Z_0'' : the positive, negative and zero sequence impedances of entire circuit.

D_1, D_2, D_0 and D_1', D_0', D_0' : the positive, negative and zero sequence distribution factors for the sending and receiving end sections respectively.

I_a, I_b, I_c and I_a', I_b', I_c' : currents in phases A, B, C at sending and receiving end sections respectively.

I_a'', I_b'', I_c'' : total fault current in phase A,B and C respectively.

I_1, I_2, I_0 and

I_1', I_2', I_0' : positive, negative and zero sequence currents in sending end and receiving end sections.

I_1'', I_2'', I_0'' : positive, negative and zero sequence components of fault current.

$I_{a11}, I_{b11}, I_{c11}$: currents in phase A,B and C of 11 KV transformer winding.

I_R, I_Y, I_B and

E_R, E_Y, E_B : the currents and phase to neutral voltages under fault conditions respectively.

$E_{R-Y}, E_{Y-B}, E_{B-R}$: voltage, between phases R-Y, Y-B and B-R of the generator during fault.

Ps : mechanical power input to the machine G.

M : moment of inertia of the machine G.

δ : power angle between the machine and infinite bus.

δc : critical clearing angle for fault.

E_G : voltage behind the transient reactance of the machine G.

E_I : voltage of the infinite bus.

X_{12} : transfer reactance between the machine and the infinite bus during the fault.

Y_{12} : transfer admittance between the machine and infinite bus during the fault.

$P = d/dt$: time differential operator.

l_1 and l_2 : the distances in p.u. corresponding to transfer admittance.

X'_d : transient reactance.

X_2 : negative sequence reactance.

X_0 : zero sequence reactance.

CHAPTER-I

INTRODUCTION

In the beginning,direct current machines were used for the power generation purposes, because the electrical science and practical applications of electricity both began with direct current. Alternating current came later. Initially series wound direct current generators were used. Later the shunt wound direct current generators came in to use.

The first electric central station in the world, on Pearl street, in New York, was built by Thomas A. Edison and began operation in year 1882. Direct current generators were used for this central power station. But the initial supermacy of the direct current was completly superseded by alternating current soon. Therefore alternators (Synchronous Machines) replaced the direct current generators. These alternators were driven with the help of reciprocating steam engines. The torque and speed available at the end of engine shaft was not constant, due to the lack of fast and automatic governing control schemes, which caused severe problems and one of them was hunting. To over come this draw back the damper windings were used. But there were losses in the damper windings, because of the current induced due to relative motion. The application of hydro and steam turbines reduced the problem of hunting together with the help of fast governing and automatic control schemes. Although this problem is always associated, if the prime mover of the system are diesel engines.

Further, the purturbations are large or small upset the balance between the mechanical input and the electrical output of the alternator connected with the electrical system. But with this it is also well known that basic purpose of power system is to supply the power from generation point to the consumer place. And this should be with in the specified limitations of voltage and frequency. For the continuous electric supply it is essential to maintain the synchronism between the various machines of a power system, which is not a very easy job, as the inter-connections between the system continues to grow. The disturbances affect the output and input with the result that some machines may accelerate, while the others may decelerate. If more than one alternators are in operation, the rotor angle will go under wide variation and due to this, synchronism of the system gets influenced. Sudden loading, load rejections, severe faults, switching of lines may cause the loss of synchronism and equilibrium. The entire phenomena is known by the term 'STABILITY'. Now this term stability has become a very important aspect of electrical power system engineering. Thus power system stability may be defined as: "the tendency of a power system or its component parts to develop forces to maintain the synchronism and equilibrium". In other words the transient stability refers to the maximum power that can be transmitted with stability when the system is subjected to an 'aperiodic' disturbances. A further definition of stability is to describe it as the condition among synchronous machines in which the angular position of the rotors of machines relative to each other remain constant when no disturbance is present [19] become constant following an aperiodic disturbance. Finally the transient stability limit refers to the maximum flow of power possible through a point, without the loss of stability when a sudden disturbance occurs. If the power system has more than one alternator, during the steady operation, there must be an equilibrium between the mechanical input and the sum of the losses and electrical output of each alternator. Similarly the equilibrium should exist for each generating unit.

Purturbations may occur either as a change of mechanical input or as a change in electrical output. But synchronism and equilibrium both must be maintained by time dependent protective devices. Otherwise both of the important parameters viz. voltage and frequency, may deviate drastically from the normal specified limits. This results in 'cascading outages' of units and ultimate collapse of the power system. To over come all these problems the stability studies are carried out to enable the power system engineers to plan, co-ordinate and design the system to give efficient and reliable electric supply to the consumers

The simulation techniques [34,37] and direct and indirect methods of Lyapunov's [9,14,32,33,36,38] are available for transient stability studies. These may be applied for linearized and non-linearized models for relatively small purturbations.

In all the methods explained in Chapter-II [1,2,4,9, 12,14,21] with the deterministic models and principles, these do not consider the probabilistic nature of variables affecting the transient stability. The three phase fault is considered to be the most severe fault for a power system design and studies in deterministic approaches. The system design is based on this, erreneouses the picture, as the probality of its occurrence is very low which can be seen in Appendix.

The following are the main factors those affect the transient stability of a system.

(i) Fault type
(ii) Fault location
(iii) Fault clearing time
(iv) Loading conditions.

Although that all the above factors are probabilistic in nature in fact, but these are assumed to be the some fixed values in deterministic approaches. The probabilistic methods and principles are being used widely in other field of system planning and for its development [44,45,46]. The basic aim of the system planning is to develop a system which meets the consumer's requirements with the specified level of security and reliability with an aceptable cost.

Literature review of the different available methods for transient stability evaluation is given in Chapter-II. The description of the different factors which affect the transient stability is given in Chapter III. In addition the description of the probabilistic natures of these factors has also been given in the same chapter.

Power system stability indices are explained in Chapter-IV. All the types of distributions applicable to the transient stability study are also given in the same Chapter. The severity with location and types of fault are shown with a system example in Chapter-IV. Further the transient stability study of a (second system example) transmission system having 66 KV double circuit transmission lines from Mohamadpur to Ram Nagar (Roorkee) has been done and the results obtained are discussed.

Chapter-V concludes the observations made in the dissertation and the suggestions for further work in the area of transient stability studies.

The main objective of this dissertation thus has been to establish the procedure of probabilistic approach for transient stability.. The flow chart and computer programs for this problem has been developed according to the requirements which will be useful for further transient stability studies.

CHAPTER-II

TRANSIENT STABILITY AS APPLIED TO POWER SYSTEM ANALYSIS

The power system, stability is classified as follows:

(i) Steady state stability

(ii) Dynamic stability

(iii) Transient stability.

2.1 Transient Stability:

Transient stability refers to ability of the system to remain in synchronism when subjected to large disturbances. Transient stability as applied to single machine system and two machine system (only when it is reduced in to one machine system problem), is defined as follows.

If a synchronous machine operating in steady state equilibrium is subjected to a disturbance of any kind, which results in speed deviation. In general, transient stability limit [19] refers to the maximum flow of power possible through a point without the loss of stability when a sudden disturbance occurs.

For multi-machine system it may be defined as, if the individual machine in a multi-machine system is operating in steady state equilibrium and disturbance of any kind is imposed. The system is called transiently stable, if each machine oscillates around and ultimately comes to rest at a new stable equilibrium point.

The disturbances usually considered are most severe in transient stability studies e.g., short-circuits on transmission line near generating station, or near bus bar at sending end or sudden load rejections of large magnitude. Under the transient conditions voltage regulator, speed governor and frequency stabilizer deviate from the required operating condition.

2.2 Mathematical Description of Power System Stability:

A system description can be given by a set of first order non-linear diff.-equations of the form:

$$X_i = f_i(X_1, X_2, X_3, \ldots\ldots X_n) \qquad (2.1)$$

where $i = 1, 2, 3, \ldots\ldots\ldots n$

It can be written in the vector form as follows

$$\dot{X} = f(x) \qquad (2.2)$$

where $X, f(x)$ are n dimensional vectors, X is called as the state of the system since knowing X at time $t = t_0$.

From equations (2.1) and (2.2) uniquely define the [9,14,21] solution of $X(t)$ for $t > t_0$.

Solutions of the equation for equilibrium states becomes

$$0 = f(x) \qquad (2.3)$$

Equation (2.3) may have several solutions since, it consists of a set of non-linear, algebric equations, the solutions are represented by $Xe^1, Xe^2 \ldots\ldots\ldots Xe^n$. And in the absence of any disturbing forces, let the system be at some equilibrium state say Xe so that

$$0 = f(Xe^i) \qquad (2.4)$$

For all the small disturbances around Xe^{i} from equation (2.2) can be linearized by expanding it around Xe' by Taylor's series and higher order terms can be neglected [21].

Let the deviations around Xe' be denoted by Y-X-Xe'. Then we can write it as:

$$\dot{Y} = AY \qquad (2.5)$$

and if $A = \left.\frac{\partial f}{\partial x}\right/_{X=Xe'}$

It can be written in Matrix form

$$A = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \cdots & \frac{\partial f_1}{\partial x_n} \\ \vdots & \vdots & & \vdots \\ \frac{\partial f_n}{\partial x_1} & \frac{\partial f_n}{\partial x_2} & & \frac{\partial f_n}{\partial x_n} \end{bmatrix}_{X=Xe'} \qquad (2.6)$$

For the given values Xe', A is a (n x n) matrix with real coefficients. If A has all the eign values with negative real parts, it can be concluded, Xe' is stable for small disturbances, or, equivalently, stable. For power system analysis if Xe' represents a particular operating steady state (condition). The system can be stated as 'steady state stable' for that particular operating condition if A is stable.

In contrast to steady state stability the transient stability deals with large disturbances (due to diff. reasons) in the system. The linearization as therefore, no longer valid. Consequently, if it becomesnecessary to solve the system of non-linear differential equations, as equation (22) type corresponding to the faulted and post fault state. The transmission configuration in the faulted and post-fault states are different since either the fault shall be cleared itself or by means of switching out the faulted transmission line, the fault component has been isolated and mathematical description like in eq.(2.2) which can be again written for $f_1(x)$ and $f_2(x)$ form for the faulted and post faulted state respectively [2,14,21,33].

Assuming the fault clearing time to be t seconds and critical clearing time tc then occurrence of a fault will result in a abrupt change of the system since state at $t_0 = 0$ from $X(t_{0-}^{-})$ to $X(t_{0+})$,

$$\dot{X} = f_1(X) \qquad 0+ < t_{0-} \leq t \tag{2.7}$$

$$\dot{X} = f_2(x) \qquad \text{for } t_0 > t \tag{2.8}$$

And $t < tc$

From the above equation No.(2.7) and (2.8) we can determine the numerical solution, for the stability study. And clearing time of a device can be computed by the method given in this Chapter ahead.

2.3 Solution Procedure:

For power system, the electrical output of each generator is given by the relation:

$$Pe^{i} = \text{Re}\ [E_i I_i^{*}] \tag{2.9}$$

$$I_i = (E_i - V_i)Y \text{where } i = 1,2,\ldots n$$

(a) For $t = 0_+$, the fault conditions are in corporated in equation (2.10)

$$\left[\begin{array}{l} (Y_{11} + Y_1)\, V_1 + \dots + Y_{1N}\, V_1 = Y_1 \\ \vdots \qquad\qquad\qquad\qquad\qquad \vdots \qquad \vdots \\ Y_{N1}\, V_1 + \dots\dots\dots\dots\, Y_{NN}\, V_N = 0 \end{array}\right] \qquad (2.10)$$

Equation (2.10) can be solved for $V_1 \dots V_n$ knowing the values of $E_1 \dots E_m$.

For example if a phase to ground fault occurs at the path bus, set $p = 0$ and then Pe^i can be determined as for each generator using both (2.9) and (2.10) equations.

(b) The value of δ_i at $t = \Delta t$ is denoted by $\delta_i(\Delta t)$ value of δ_1 at $t = \Delta t$ is also calculated then

(c) At $t = \Delta t$,

$$E_i(\Delta t) = |E_i| < \delta_i\,(\Delta t) \qquad (2.11)$$

Solving again for V_i

$I_i = (i = 1, \dots n)$ at $t = \Delta t$

Putting this value in eq.(2.9)

At $t = 0^-$

$$\left.\begin{array}{l} \delta \text{ and } \delta_i \text{ at } t = \Delta t \\ \delta \text{ and } \delta_i \text{ at } t = 2\Delta t \end{array}\right]$$

All the values for given parameters under the conditions can be determined for each machine, therefore equation can be written as

$$\frac{H_i}{\pi f_0} \cdot \frac{d^2 \delta_i}{dt} + D_i \frac{\delta_i}{dt} + Pm_i = 0 \qquad (2.12)$$

where $i = 1, \ldots m$

$$\frac{d}{dt}(W_K E_i) + Pd_i = Pm_i - Pe_i \qquad (2.13)$$

where WK_i : K.E. in M.W Sec

Pd_i : damping power in MW

Pm_i : Mech Input in MW

Pe_i : Electrical output power in MW

All the values given above are for ith machine

f_0 : Synchronous frequency

The K.E α Synchronous frequency

$$WKE_i = W_0 KE_i (f_1/f_0)^2 \qquad (2.14)$$

$W^0_{KE} = i$ = KE at Synch. freq.

$f_1 = f_0 + \Delta f_i$

$$WKE_i = W^0 KE_i \frac{(f_0 + \Delta f_i)^2}{f_0^{\ 2}}$$

$$W^0 KE_i (1 + \frac{2\Delta f_i}{f_0})$$

Since Δf_i is too small during the transient swing then Diff. equations become for $WK_i n_i$ as :

$$\frac{d}{di}(WKE_i) = \frac{2w^0 KE_i}{f_0} \frac{d}{dt} \Delta f_1 \qquad (2.15)$$

Put $\delta_i = \theta_i - w_o$

$$\frac{d\delta_i}{dt} = w_o = w_i - w_o$$

$$= 2\pi(f_1 - f_o)$$

$$= 2\pi\Delta f_i$$

where θ_i is in electrical degrees Δf_i charge in frequency, with these assumptions substituting in eq.(2.2) and (2.15). The relation become

$$\frac{H_i}{\pi f_o} \frac{d^2 f_i}{dt} + D_i \frac{d\delta_i}{dt} = Pm_i - Pe_i \qquad (2.16)$$

where $i = 1, 2 \ldots\ldots m.$

$H_i = W^0 KE_i$: Inertia constant of machine i in p.u.

D_i : Damping constant in p.u.

Pm_i : Mechanical power in p.u. for the machine i

Pe_i : Electrical power in p.u. for the machine i

$$X_i = \delta_i \quad (i = 1, \ldots m) \qquad (2.17)$$

$$X_i f_m = \frac{d\theta_i}{dt}$$

$$\frac{d\theta_i}{dt} = \frac{d\delta_i}{dt} + w_o \qquad (2.18)$$

Diff. with respect to t the above equation.

$$\frac{dX_i}{dt} = X_i + m - w_o \qquad (2.19)$$

$$\frac{dX_{i+m}}{dt} = \frac{-D_i}{H_i} \pi f_o x i + \frac{\pi f_o}{H_i} (Pm_i - Pe_i) \qquad (2.20)$$

Analyse it for

$$X_i \; (i = 1,2,\ldots n)$$

$$\dot{X} = f(x)$$

where Pe_i are the solutions of a set of non-linear algebraic equation

$$Pe_i = Y_i (i = 1,2,\ldots m) \; E_i^2$$

$$\dot{X} = F(X,y) \tag{2.21}$$

$$0 = G(x,Y) \tag{2.22}$$

The above (2.21) and (2.22) equations are two sets of non-linear differential equations and algebraic equations. With different conditions, then solution can be determine [21].

2.4 Various Methods For Transient Stability Calculations:

There are two type of approacnes available for the transient stability analysis and for its detailed studies.

(i) Deterministic type approaches

(ii) Probabilitistic type approaches

The detailed explanation of these approaches is as follows:

2.5 Methods Based on Deterministic Approaches:

Various methods available for the transient stability calculations and analysis are:

(a) Transient analysis by characteristic equations [9,14, 31,35].

(b) Transient stability study from state space variable technique [9,14].

(c) Methods for determining the stability of linear control systems.
   (i) Routh-Hurwitz criterion [9,14,31]
   (ii) Nyquist criterion [9,14]
   (iii) The root locus technique [9,31]
   (iv) Phase-plane technique [9,14,26,31]

(d) Lyapunov stability criterion [9,14,31,32,33,36,39]
   (i) Lyapunov's first method for stability evaluation.
   (ii) Lyapunov's second method for stability evaluation.

OR

Lyapunov's direct method for stability evaluation.

(Lyapunov's criterion can be applied for both linear and non-linear system analysis)

(e) Equal area criterion for stability analysis [1,2,6,7,19, 22,31].

(f) Successive trial method [1,2,24,28].

(g) Method based on dynamics of the system [5,6,7,18].

(h) From swing curve and swing equations solution.
   (i) Computation of swing curve from formal solution of different swing equations [1,2,6,7,18].
   (ii) Point by point method for the transient stability calculations [1,2,6,7,21].

(i) Byrd and Pritchard's method for transient stability evaluation.

This method is only applicable when the network is purely reactive. If it is not so and line resistance or shunt loads are to be taken into account, this method can not be applied[2].

2.5.1 For the determination of clearing and critical clearing time under the transient stability analysis, following methods are available.

(i) Point by point calculations of swing equations for swing curve plotting [1,2,6,7]

(ii) By graphical integration method [1,18,26].

(iii) By selection of a curve from sets of Pre-calculated swing curves [2].

2.6 Method Based on Probabilistic Approach:

The differential equation for the single machine system is also applicable to the two-machine system,[2].

For one-machine system we can write the system equations as:

$$Mp^2(\delta) = Ps - Pu \tag{2.23}$$

Substitute $Mp^2(\delta) = 0$ in eq.(2.23)

$$0 = Ps - Pu \tag{2.24}$$

$$Ps = Pu$$

$$Ps = \frac{E_1 E_2}{X_{12}} \operatorname{Sin}\delta$$

$$Ps = E_1 E_2 Y_{12} \operatorname{Sin}\delta$$

$$\operatorname{Sin}\delta = Ps/E_1 E_2 Y_{12}$$

Substitute $\delta = \delta_0$

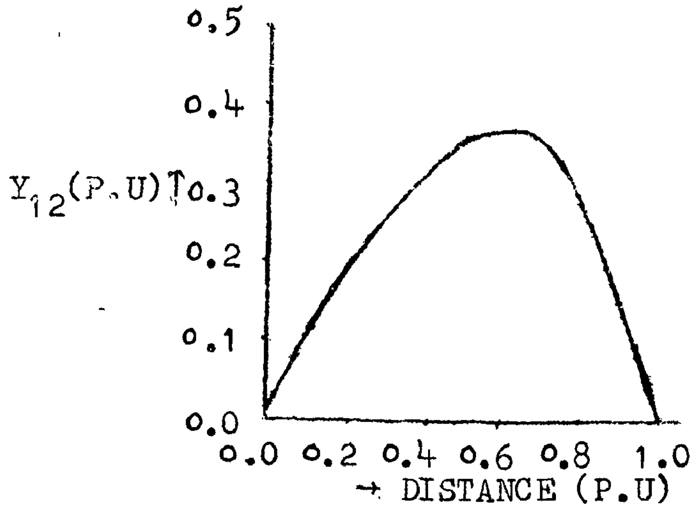


Fig.2 VARIATION IN TRANSFER ADMITTANCE WITH THE FAULT FROM SENDING END

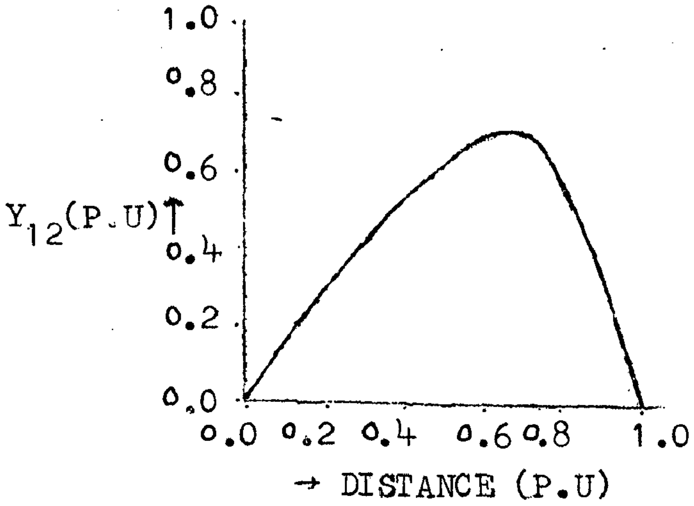


Fig.2.1 VARIATION IN TRANSFER ADMITTANCE WITH THE DISTANCE OF THE FAULT FROM SENDING END

Therefore $\text{Sin}\delta_0 = Ps/E_1E_2Y_{12}$

$$\delta_0 = \text{Sin}^{-1}(Ps/E_1E_2Y_{12}) \qquad (2.25)$$

Y_{12} for the particular type of fault can be determined by Δ - Y transformation, and curve showing variation of Y_{12} with distance is given in Fig.2-2.3 for three phase (L - L - L) fault, phase to phase to Earth (L - L - E), phase to phase (L - L - E), phase to phase (L - L) fault, phase to Earth (L - E) fault.

Where l_1 and l_2 are the distances respectively for the value of transfer admittance Y_{12} (Fig.2)

Then

$$\text{Probability } (Y \geq Y_{12}) = \text{Prob.}(l_1 < x < l_2) \qquad (2.26)$$

$$= \text{Prob.}(X \leq l_2) - \text{Prob.}(X \leq l_1) \qquad (2.27)$$

$$= F(l_2) - F(l_1) \qquad (2.28)$$

where X and Y are two random variables. Corresponding to transfer admittance and fault occurred at particular distance respectively, and both of these parameters are probabilistic in nature $F(l_2)$ and $F(l_1)$ are the values of the c.d.f. of the fault at distances l_2 and l_1 respectively δ_0, δ_m and δ_c can be computed by swing equations using equal area criterion. After determination of δ_c the values of critical clearing time (t_c) can be calculated. Therefore probability of stability is obtained from the probability distribution of clearing devices as probability $(T \leq t_c)$ which is the c.d.f. at t_c. For the given value of P_1 and transfer admittance (Y_{12}) obtained from

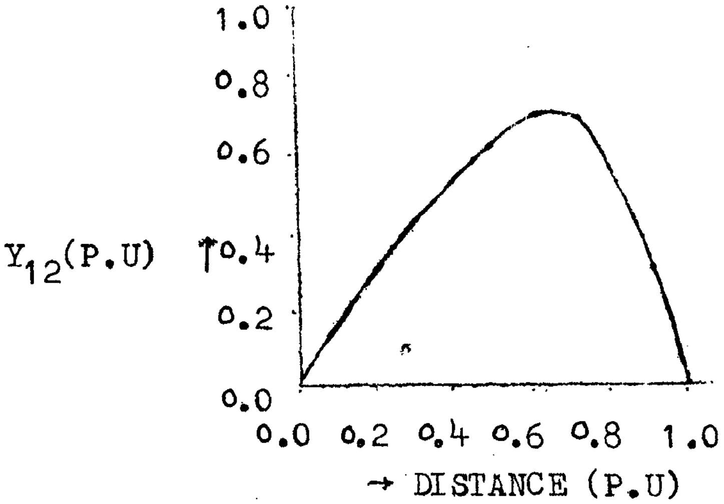


Fig.2.2 VARIATION IN TRANSFER ADMITTANCE WITH THE DISTANCE OF THE FAULT FROM THE SENDING END

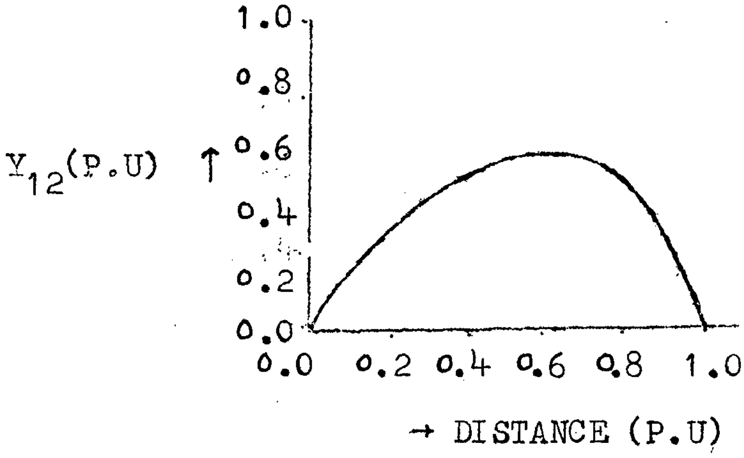


Fig.2.3 VARIATION IN TRANSFER ADMITTANCE WITH THE DISTANCE OF THE FAULT FROM THE SENDING END.

Δ-Y transformation during the fault occurrence, the value of Y_{12} between, Y_{12} minimum and Y_{12} maximum can be determined. Then probability of stability can be evaluated by the relation given below:

$$\text{Prob.(Stability)} = \sum_{i=1}^{m} \text{Prob.(Stability given for the transfer admittance} = y_i) \times \text{Prob.(transfer admittance} = y_i) \qquad (2.29)$$

where y_i is the minimum and y_m is the maximum values of the transfer admittance for a given fault and power transferred. Probability of instability may be obtained from the following equation:

$$\text{Prob.(Instability)} = 1 - \text{Prob.(Stability)} \qquad (2.30)$$

Thus probability (stability) or Prob.(Instability) Index can be obtained for the different types of faults with the initial conditions for power system transient analysis.

CHAPTER-III

PROBABILISTIC ASPECTS FOR TRANSIENT STABILITY STUDY

Under the stability studies particularly with transient stability analysis, the main factors considered are sudden disturbances which includes:

(i) Fault due to short-circuit

(ii) Sudden loading

(iii) Load rejections

(iv) Switching operations of the transmission lines.

The probability of occurrence of fault near generating station or bus and sudden increase in load are quite different phenomenon and random in nature. The deterministic criterion does not included these probabilistic aspects of the power system variables, which should be the case for realistic results. And probabilities associated with occurrence, fault types, clearing time and fault location are important parameters may helpful in realistic assessment of transient stability. In the Chapter IV the probability of fault and location are given in system examples, by dividing the transmission line into a number of segments and applying the deterministic stability analysis for each segment calculations. And this probability of stability is obtained by using the conditional probability approach explained in Chapter II.

Other factors which affect the transient stability involve in computation are given below.

3.1 Fault Types:

Faults are basically classified as:

(i) Shunt fault
(ii) Series fault.

Later type of faults are not so severe as the previous one and only shunt faults drastically affect [46] the transient stability. These shunt faults are further subdivided into two classes:

(i) Symmetrical faults
(ii) Asymmetrical faults.

(i) Symmetrical faults e.g. three phase fault or (L-L-L) fault.

(ii) Asymmetrical faults e.g.

- (a) Two phase to ground fault or (L-L-G) fault
- (b) Phase to phase fault or (L-L) fault.
- (c) Phase to ground or (L-G) fault.

Variation in the severity of above types of faults for a system example with distance from sending end to receiving end is given in Chapter IV. From the system example 1 it is clear that the severity increases from (L-G) fault to (L-L-L) fault. A detailed explanation is given in the Chapter IV.

All the different stability evaluation approaches available till now are based on three phase fault consideration, which is assumed to be the most severe and worst possible case, but the probability of occurrence of three phase fault is small as compared with the other cases. Appendix I shows the probability of occurrence of all the types of faults, from the system data for specified period.

3.2 Fault Location:

The fault location affects the stability calculations a lot. The severity of fault decreases as the fault location changes from generating bus to the far end [45] system example given in Chapter IV supports this contest on location of fault occurrence is probabilistic and it is considered with the system example given in the same Chapter IV, depending upon the location of faults, which is further classified as:

(i) Close in fault
(ii) Mid-line fault.

(i) Close in Fault: If all the parameters measured in p.u. under the length of line either from sending end or receiving end for faults from (0-20 % and 80-100 %) are considered as close in faults.

(ii) Mid-Line Faults: Faults under the length from (20-80 %) are considered as the mid-line faults. The location of the mid line faults is taken as the middle point of the line and a probability is assigned to this location. The sum of these probabilities is unity. The actual distribution of the probabilities depends upon the line configuration and fault statistics. In the case of a long line it may be necessary to use more mutually exclusive probabilities for additional line segments. The probabilities associated with the fault clearing time depend on the protection and its schemes. It may be different for each line and type of fault. It is clear that the probability distribution of the clearing time for a particular fault is not same for close in and mid line faults. The methods applied to system example 2 and results are given in various tables for each type of fault.

3.3 Loading Conditions:

Due to the uncertainty of loading or load rejections of the system, is itself a random one in nature. Therefore, the consideration of the random variables, become more essential. The [illegible] effect of random load levels is examined with different load levels keeping the load levels [45,46] mutually exclusive.The

For the system, study it is examined with the several discrete steps of loads. The single index for the probability of stability gives the sum of the probabilities of stability as the sum of all the individual probabilities associated with each load. Thus the probability of stability for any faults is also determined by the same relation, given in Chapter-II. For different load level of P_1 it is determined and results are given in Chapter-IV for the system example 2.

3.4 Fault Clearing Phenomena:

Time for fault clearing for the system devices is an important factor among those factors, considered for the transient stability studies. Clearing time taken by the protective device for the fault clearing is denoted by t (sec) and critical clearing time for the device is denoted by t_c. The fault clearing time t should always be less than critical clearing time t_c for the safty of the system. Lesser the clearing time of the protective device for fault clearing, higher is the system stability margin. But in fact fault clearing time is also a random variable, and is probabilistic in nature. The normal distribution [44,46] is used to determine the probabilities associated with location and critical clearing time (t_c). Other type of distribution for the same type of calculations with specific and special case of distribution called Weibull distribution is used. Variation with parameters of the distribution shape is given in Fig.4.1.

3.5 System Parameters and Operating Conditions

The physical parameters of the system are non-probabilistic in nature i.e. there is only small change with the physical change and these parameters exist, with preventive maintenance. The system operating condition at sometimes in the future may be probabilistic in nature and does affect the system stability. Thus it can also be said that all the physical parameters associated with system elements affect the system stability in some particular sequence. From the previous discussion , It is clear that some parameters are random in nature, which affect the system stability. But with the both types of variables, probabilistic and nonprobabilistic in nature, the system stability is very much dependent upon the operating conditions for the system when a fault occurs. From the system example given in Chapter-IV. This fact is evident for the system stability. The stability is also dependent upon initial operating conditions, such as system loading, machine inertia, and load angle etc. The initial operating conditions for system are obtained by a conducting load flow [11] study. The assumptions used are, such as constant voltage behind transient reactance, Neglecting the resistance and shunt capacitance of transmission lines. However, it is possible to perform net work reduction e.g. (same for two machine system to one machine system) and (same for multi machine system). On the system eliminated bus bars except the generator bus bar. The location of fault is given by the reference of this generator location. Following system parameters affect the stability.

(i) Machine Inertia

(ii) Frequency

(iii) System Reactance

(iv) Machine constant (G)

(v) Effect of Random Variables.

In the system operation area of probabilistic methods can be used to identify the crediable contingencies, given above, which are helpful subsequently in detailed transient stability analysis.

CHAPTER IV

TRANSIENT STABILITY CALCULATIONS

The different calculations for transient stability [21, 46] with two system examples are carried out, before describing the system examples it is essential to explain the power system stability indices and the choice of the distribution which are the important factors for the evaluation of the probability index.

4.1 Power System Stability Indices :

The power system analysis is considered with fault type, fault clearing time [19] and along with critical clearing time (t_c) and fault location. With purturbations the system is tested under the different normal and abnormal conditions for its stability. The important random variables and other parameters [46] which affect the system stability have been explained in detailed in Chapter III. These variables are probabilistic in nature, consideration of these variables affect along with the affect of variables nonprobabilistic in nature which quantifies the system stability. And forms the probability of stability index either the probability of Instability Index. These indices posses the following properties:

(i) If the probability of stability index is tending towards unity, the system stability is not affected by the disturbances.(Occurred on the system).

(ii) If the probability of stability index is tending towards zero the system will loose synchronism i.e. system is unstable.

For calculating these indices (probability of stability or probability of instability) the distribution factors which are considered probabilistic in nature, therefore in the next section different types of distributions, of general use for this problem are discussed.

4.2 Choice of Distribution:

In general one chooses a model for a continuous distribution function on the basis of one or more of the following criterion:

(i) The physical nature of the problem fits the most of all of the underlying assumptions associated with a particular distribution.

(ii) If data is available and a plot of the data in terms of function F(x) turns the problem into one of the curve fitting out of different types of curves [10,13].

(iii) Further a convenient and simple model is chosen which satisfies both the above criterion. The type of problem must justify the approximate nature of the modelling. Long duration experience and knowledge in the area of engineering role is also important one for the selection of distribution.

4.2.1 Binomial distribution: There are some experiments based on discrete probability models, in which the application of binomial distribution is required. The binomial distribution some times called the Bernoulli's distribution, applied to such a problem in which an event can either occur or not occur, the more simple terms are success or failures, a legacy from the days when probability theory is used for the measure of chance. These terms used for reliability evaluation are also suited for the application of probability of stability evaluation. For computation of different steps the Pascal's triangle technique can also be used.

4.2.2 Normal distribution : The best known two-parameters distribution is the normal, or Gaussian distribution. "The normal distribution was discovered by De-Moivre in 1733",Nevertheless the term 'Gaussian distribution is also an accepted synonym for the normal distribution'. This distribution is very often a good fit for the size of manufactured parts, the size of a living organism and other types of problems too, when a certain parameter which is a random variable is the sum of many other random variables the parameter will have a normal distribution in most of all the cases [10,13,16].

This normal probability distribution is the most important distribution in the entire field of statistics and probability. The normal curve is symmetrical about its mean value and degree of dispersion about the mean is measured by the standard deviation. This distribution is applicable to a wide variety of quantities which vary from some mean or central value within a fixed system [8,10,13,16]. The density function for the normal distribution as

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{\frac{x^2}{2\sigma^2}} \qquad (-\ \infty < x < +\ \infty) \qquad (4.1)$$

And the normal frequency distribution curve for a continuous random variable x said to be normally distributed is expressed as:

$$f(x) = Y = \frac{n}{\sigma\sqrt{2\pi}}\, e^{\frac{(x-\mu)^2}{2\sigma^2}} \qquad (4.2)$$

where μ = mean value of x

σ = standard deviation of x

n = number of observation of x

Now dividing the equation by n gives a normalized curve.

$$Y = \frac{1}{\sigma\sqrt{2\pi}}\, e^{\frac{-(x-u)^2}{2\sigma^2}} \qquad (4.3)$$

Curve drawn for this f(x) is known as the normal probability distribution curve or the normal density function. It represents the probability of occurrence of all the possible values of the random variable X and the area under the curve is equal to 1.

The equation (4.3

can be written as: $\frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{+\infty} e^{\frac{-(X-u)^2}{2\sigma^2}}\, dx = 1 \qquad (4.4)$

This function has a peak of $\frac{1}{\sigma}\sqrt{2\pi}$ at x = 0 and falls symmetrically on either side of zero. The rate of fall off and the height of the peak at x = 0 are determined by the parameter σ. In the general one deals with random variable x which is spread about some value such that the peak of distribution is not at zero in this case one shifts the horizontal scale of the normal distribution so that the peak occurs at $x = \mu$. eq.(3.4) Fig.4.1. The integral can not be expressed in a simple functional form but it can be computed by numerical methods. For any one distribution μ and σ are constant. The value of μ is often called the location parameter as it moves the distribution along the horizontal axis. Here the standard deviation is often called scale parameter and determines the horizontal spread and changes the distribution shape [10,13]. If the mean value μ is set at zero and all the deviations are measured from the mean in terms of standard deviation, the equation for f(x) = y becomes.

$$Y = \frac{1}{\sqrt{2\pi}}\, e - \frac{z^2}{z} \qquad (4.5)$$

where $z = \frac{x - \mu}{\sigma}$

All the deviations from the mean μ are now expressed in terms of z and the standard deviation has some fixed value. The curve now has a standard form and the area under the curve are expressed in tables in terms of the number of standard deviations [8,10,13,16]. The effect of changing σ can be seen with the help of curve for different values of σ.

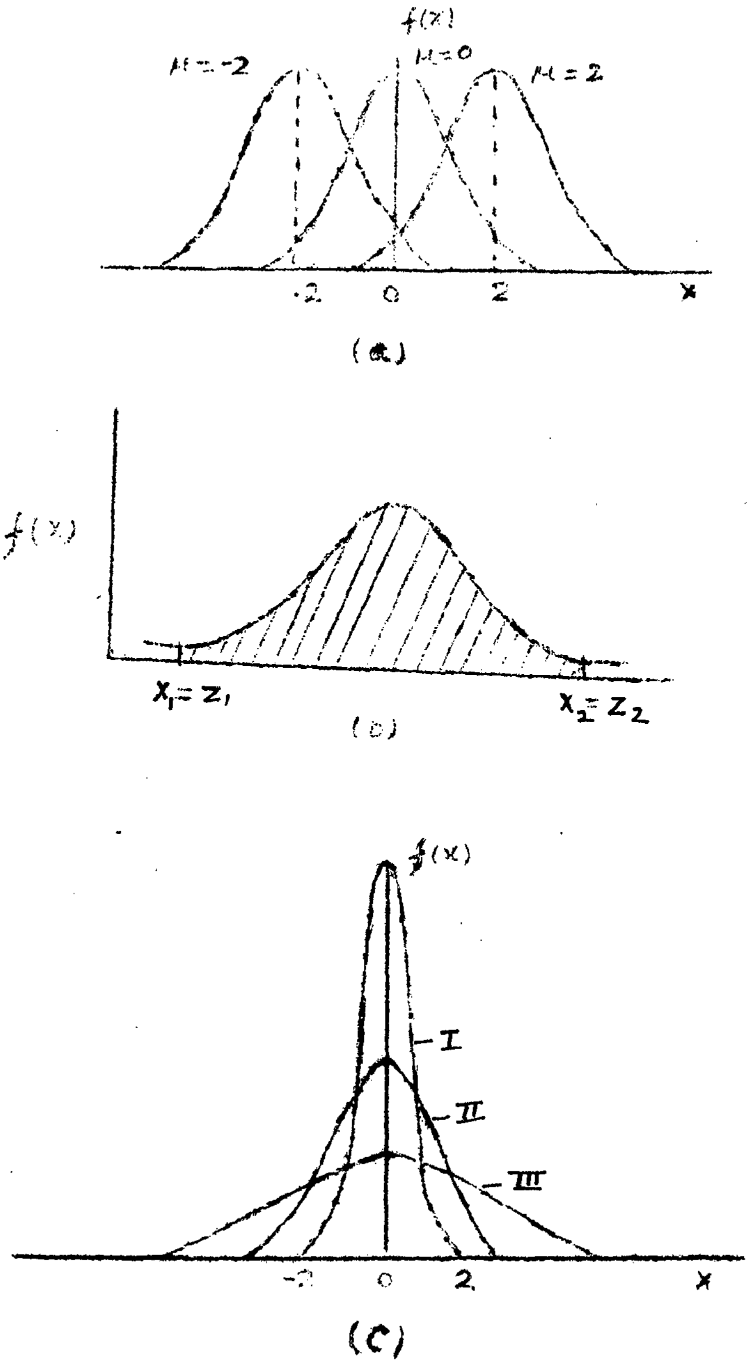


Fig.4.1 NORMAL DISTRIBUTION

For a large value of σ means a low, broad curve and for a small value of σ a thin, high curve shown in Fig.4.1 A change in μ is merely slides the curve along the x axis, then again distribution function is given by the relation.

$$F(x) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} e - \frac{(\xi - \mu)^2}{2\sigma^2} d\xi \qquad (4.6)$$

where $z = \frac{(\xi - \mu)^2}{2\sigma^2} d\xi$

same eq.(4.6) here is a dummy variable of integration for the shapes of the normal distribution see the Fig.4.1 . For the change of variable we can write the relation as

$$P_r(z_1 < x \leq z_2) = F(x = z_2) - F(x = z_1) \qquad (4.7)$$

$$F(x = z_2) = P_r(x \leq z_2) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{z_2} e - \frac{(\xi - \mu)^2}{2\sigma^2} d\xi \qquad (4.8)$$

$$F(x = z_1) = P_r(x \leq z_1) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{z_1} e - \frac{(\xi - \mu)^2}{2\sigma} d\xi \qquad (4.9)$$

We can find the probability corresponding to any value directly with the help of probability tables.

4.2.3 Weibull distribution: The density function is a special case of a more general two-parameter distribution called the Weibull distribution. The density and distribution function for the Weibull are as:(Fig.4.2)

$$f(x) = Kx^m \, e^{-Kx^{m+1}} \Big/ m+1 \qquad (4.10)$$

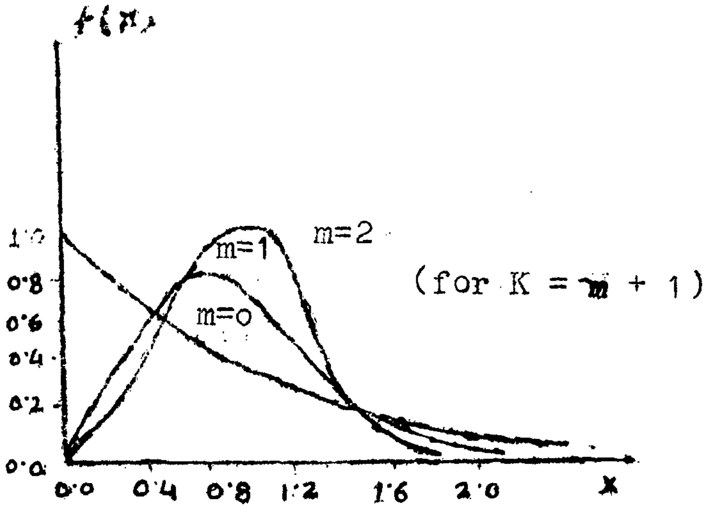


Fig. No. 2 (d)

WEIBULL DISTRIBUTION

$$F(x) = 1 - e^{-Kx^{m+1}/m+1} \qquad (4.11)$$

The parameter m determines the shape of the distribution, and parameters K is a scale-change parameter [10].

4.3 System Examples:

Two system examples are discussed. Example 1 illustrates the fault type, fault location, and severity of fault. The actual data for the systems [Mohamadpur to Ram Nagar (Roorkee)] are used in system example 2 for realistic application of this new stability evaluation approach based on probability theory.

4.3.1 Example 1:

The single line diagram for the example 1 is given in Fig.4.3 and data for this example are given in table 4.1. Both the alternators are connected by a 100 Kms long transmission line rated for 132 KV.

Table 4.1

Machine	F.L. current in Amp.	Reactance in (ohms)			KV to neutral
1. Generator 25 MVA	110	86	116	0	76.2
2. Transformer 30 MVA	131	58	58	58	76.2
3. Transformer 15 MVA	65	116	116	116	76.2
4. Generator 15 MVA	65	172	232	01	76.2

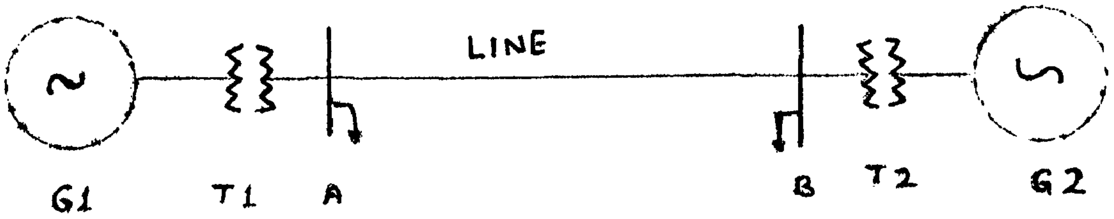


Fig.4.3 SINGLE LINE DIAGRAM FOR POWER SYSTEM EXAMPLE 1

The 25 MVA generator has a full-load reactive voltage drop of 12.5 % of the external voltage. The 30 MVA transformer has a reactive voltage drop of 10 % . The positive and negative sequence reactances of the transmission line are 0.7 ohm/Km.. The zero sequence reactance of the line (including earth wire) is 0.2 ohms/Km. The 100 Kms. lines is connected at the distance end through 15 MVA transformer to a 15 MVA generator, the reactances are 10 % and 15 % respectively.

All the sequence reactances are equal to another for the respective transformers.

The negative phase sequence of the generators are 1.35 times of the positive sequence reactances.

The assumptions for the above problem are:

(i) All the resistances are neglected

(ii) All the shunt impedances are neglected

(iii) All phase to neutral voltages of both generators are equal.

4.3.1.1 Calculations for different types of fault:

(i) Three phase fault calculations: The complete short-circuit of three phases is probably the rarest of all faults which happen on power systems. The zero and negative - sequence components are absent, because.

$$Ea = E_b = Ec = 0 \qquad (4.12)$$

$$Ia'' = I_b'' = Ic'' \qquad (4.13)$$

$$Io'' = \frac{1}{3}(Ia'' + I_b'' + Ic'') \qquad (4.14)$$

$$I_b'' = a^2\ Ia \text{ and } Ic'' = a\ Ia''$$

$$Io'' = \frac{1}{3}(Ia'' + a^2\ Ia'' + a\ Ia'')$$

$$= 0 \tag{4.15}$$

$$I_1'' = \frac{1}{3}(Ia'' + a\ I_b'' + a^2\ Ic'')$$

$$= \frac{1}{3}(Ia'' + a^3\ Ia'' + a^3\ Ia^4)$$

$$= \frac{1}{3}\cdot 3\ Ia''$$

$$= Ia''$$

$$I_2'' = \frac{1}{3}(Ia'' + a\ I_b'' + a\ Ic'') \tag{4.16}$$

From the above relation put I_b'' and Ic''

$$I_2'' = \frac{1}{3}(Ia'' + a\ Ia'' + a^2\ Ia) \tag{4.17}$$

$$= \frac{1}{3}\ Ia''(1 + a + a^2)$$

$$= 0$$

Consequently the fault current is positive phase sequence and is equal in all three phase

$$Ia'' = \frac{E}{z_1''}$$

$$= \frac{76.2}{98}\ (KA) \tag{4.18}$$

$$= 778 \text{ Amp.}$$

Applying the distribution factors to find the currents

$$Ia = Ia''.D_1 = 778 \times .663$$

$$= 515$$

Similarly

$$I_b = -\ 257 - j\ 446$$

$$Ic = -\ 251 + j\ 446$$

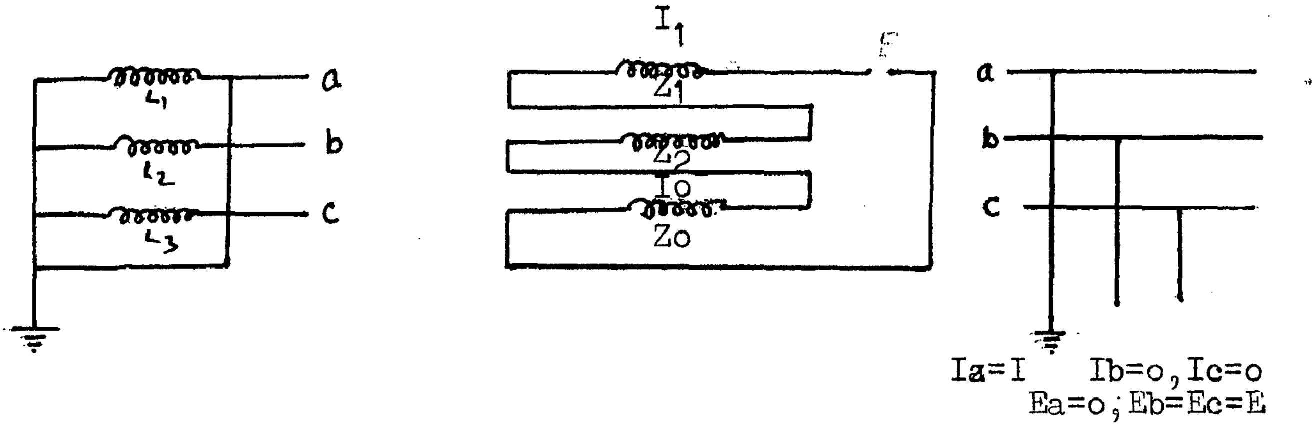


Fig.4.4 (a) LINE TO GROUND FAULT

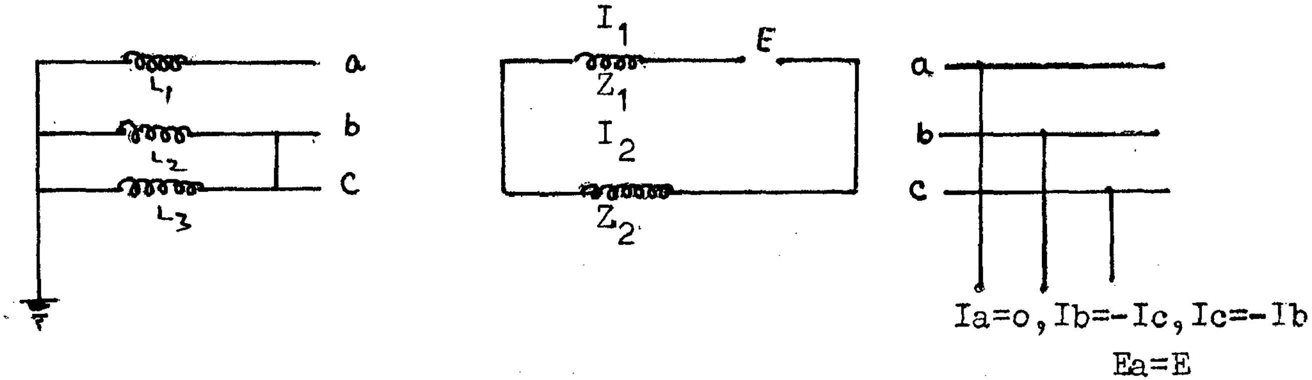


Fig.4.4 (b) LINE TO LINE FAULT

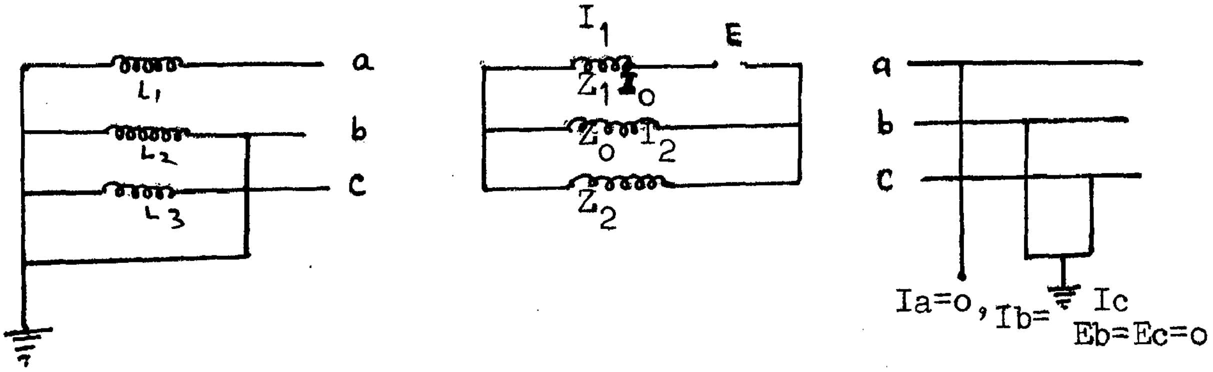


Fig.4.4 (c) LINE TO LINE TO EARTH FAULT

SEQUENCE CONNECTIONS FOR ASYMMETRICAL FAULTS

$I_a' = I_a'' D_1'$

$= 263$ Amp.

$I_b' = -132 - j228$

$I_c' = -132 + j228$

The currents in 11 KV. winding of the transformer are

$I_{a11}'' = 515 \times 6.93 = 3570$ Amp.

$I_{b11} = (-257 - j446) \times 6.93 = -1785 - j3090$

$I_{c11} = (-25) + j446) \times 6.93 = -1785 + j3090$

In the Generator windings

$I_R = I_{a11} - I_{c11} = 3570 + 1785 - j3090$

$= 5355 - j3090$

$I_Y = I_{b11} - I_{a11}$

$= - 5355 - j3090$

$I_B = I_{c11} - I_{b11}$

$= j6180$

Calculations for the voltage drops are:

$I_a ZL_1 = 515 \times 4.2$

$= 2.16$ KV

$I_b ZL_1 = (-257 - j446) \times 4.2$

$=(-1075 - j1875) \times (2.16$ KV$)$

$I_c ZL_1 = (-257 + j446) \times 4.2$

$=(- 1075 + j1875) \times (2.16$ KV$)$

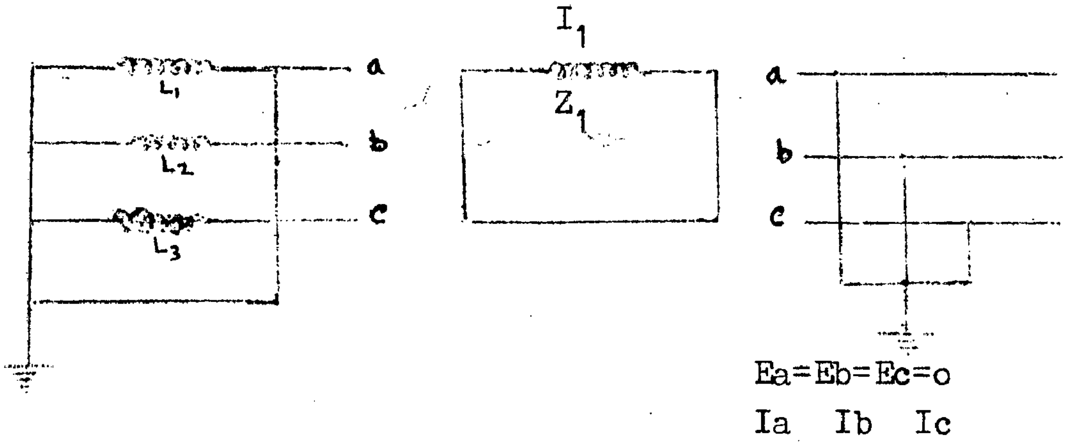


Fig.4.4 (d) LINE TO LINE TO LINE FAULT

In the sending transformer

$$I_aZt = 515 \times 58$$

$$= 29.85 \text{ KV}$$

$$I_bZt = (-257 - j446) \times 58$$

$$= -370 - j638$$

$$I_cZt = (-257 + j446) \times 58$$

$$= -14925 + j25900$$

In the receiving section of the line:

$$I_a'ZL_1' = 263 \times 2.8$$

$$= 735$$

$$I_b'ZL_1' = (-132 - j228) \times 2.8$$

$$= -370 - j638$$

$$I_c'ZL_1' = (-132 + j228) \times 2.8$$

$$= -370 + j638$$

In the sending-end generator:

$$I_RZ_{g1} = (5355 - j3090) \times 0.597$$

$$= 3200 - j1845$$

$$I_YZ_{g1} = (-5355 - j3020) \times 0.597$$

$$= -3200 - j1845$$

$$I_BZ_{g1} = j6180 \times 0.597$$

$$= j3690$$

The actual voltages across the generator phases are found from the vector differences of the phase-to-neutral voltages.

$$E_R = ja^2E - I_RZ_{g1} \qquad (4.19)$$

$$= 5550 - j3200 - 3200 + j1845$$

$$= 2350 - j1355$$

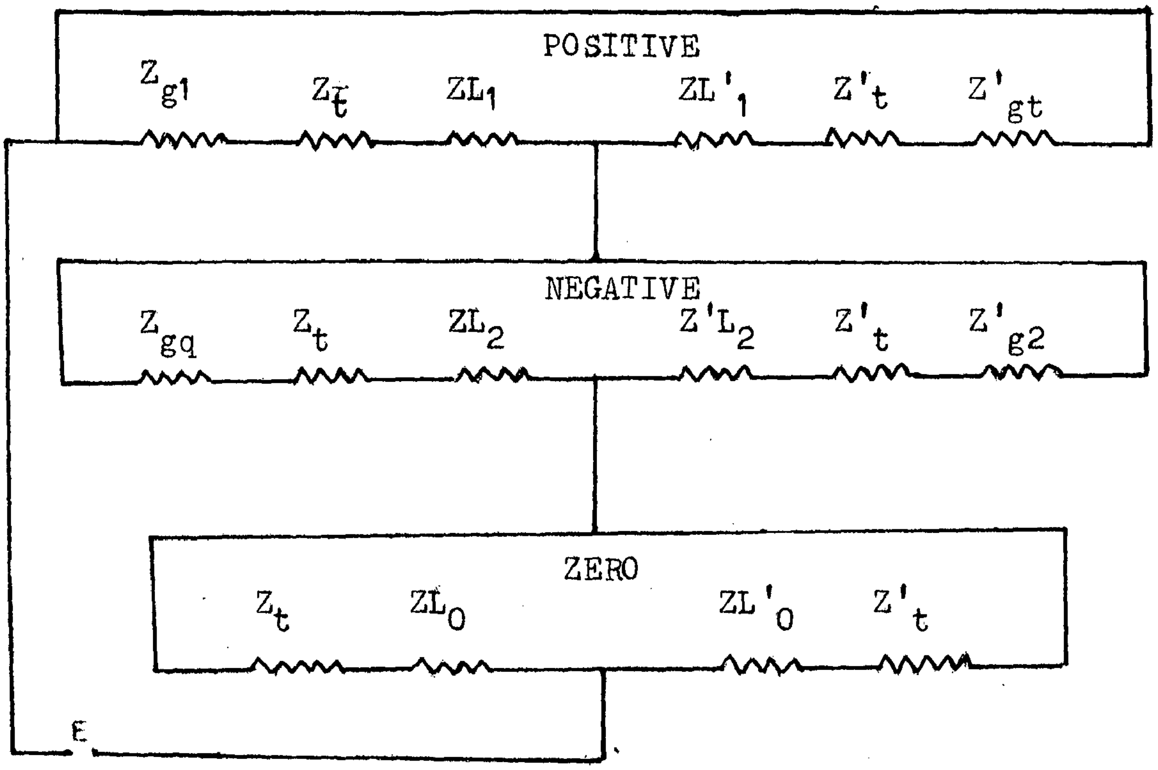


Fig.4.5 CONNECTIONS OF SEQUENCE IMPEDANCES (L-G Fault)

$$E_Y = jaE - I_Y Z_{g1} \qquad (4.20)$$

$$= -550 - j3200 + 3200 + j1845$$

$$= -2350 - j1355$$

$$E_B = jE - I_B Z_{g1} \qquad (4.21)$$

$$= j640 - j3690$$

$$= j2710$$

$$E_{R-Y} = 2350 - j1355 + 2350 + j1355$$

$$= 4.7 \text{ KV}$$

$$E_{Y-B} = -2350 - j1355 - j2710$$

$$= -2350 - j4065$$

$$E_{B-R} = j2710 - 2350 + j1355$$

$$= -2350 + j4065$$

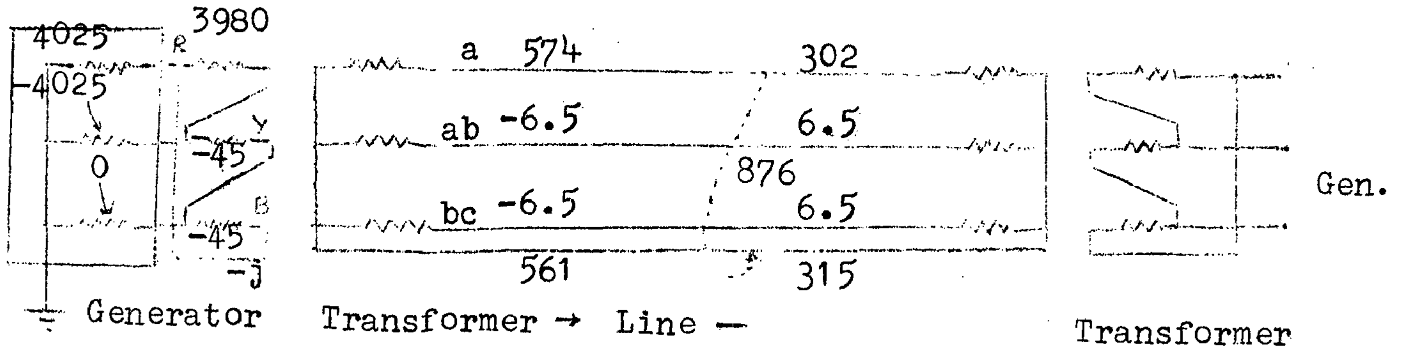
There is a balanced voltage of 4.7 KV across the phases. The marked difference between the effects of unbalanced and balanced faults on the generator voltages may be noted from the other sets of calculations. Under unbalanced conditions maintenance and even rise of voltage between the healthy phases can be expected. On the other hand, uniform fall of voltage for balanced faults [6] is invitable.

Asymmetrical fault calculations for different types of faults are carried out, and the values are given in tabular form. These values are also shown in Fig. 4.6 for the various faults.

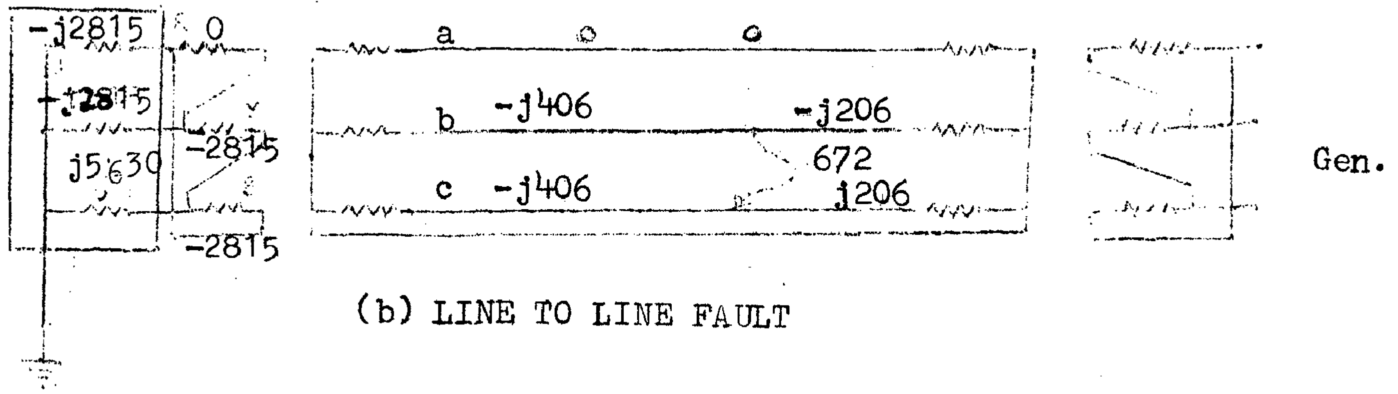
Table - 4.2

Fault currents for different types of fault

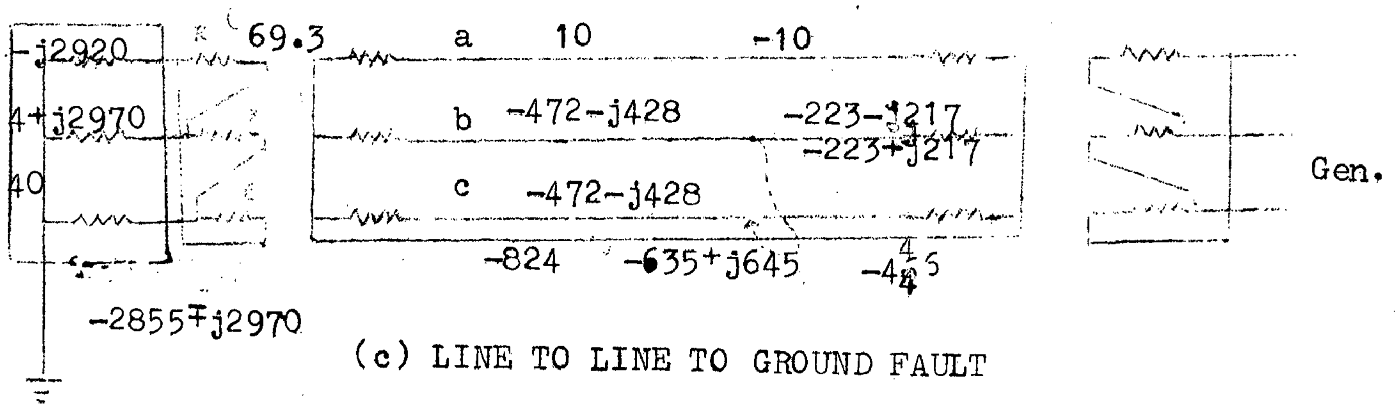
Part of the	Fault Type			
	L-G	L-L	L-L-G	L-L-L
Generator phase				
R	4025	-j2815	2924-j2970	5355-j3090
Y	-4025	-j2815	-2924-j2970	-5355-j3090
B	0	j5630	j5940	j6180
Transformer 11KV				
a_{11}	3980	0	69	3570
b_{11}	45	-j2815	-2855-j2970	-1785-j3090
c_{11}	- 45	j2815	-2855+j2970	-1785+j3090
Transformer 132KV				
a	574	0	10	515
b	-6.5	-j406	-412-j428	-257-j446
c	-6.5	j406	-412+j428	257+j446
Line (Receiving Section)				
a	302	0	10	263
b	6.5	-j206	-223-j217	-132-j228
c	6.5	j206	-223+j217	-132+j228
Line (sending Section				
a	574	0	10	515
b	-6.5	-j406	-412-j428	-257-j446
c	-6.5	j406	-412+j428	-257+j446



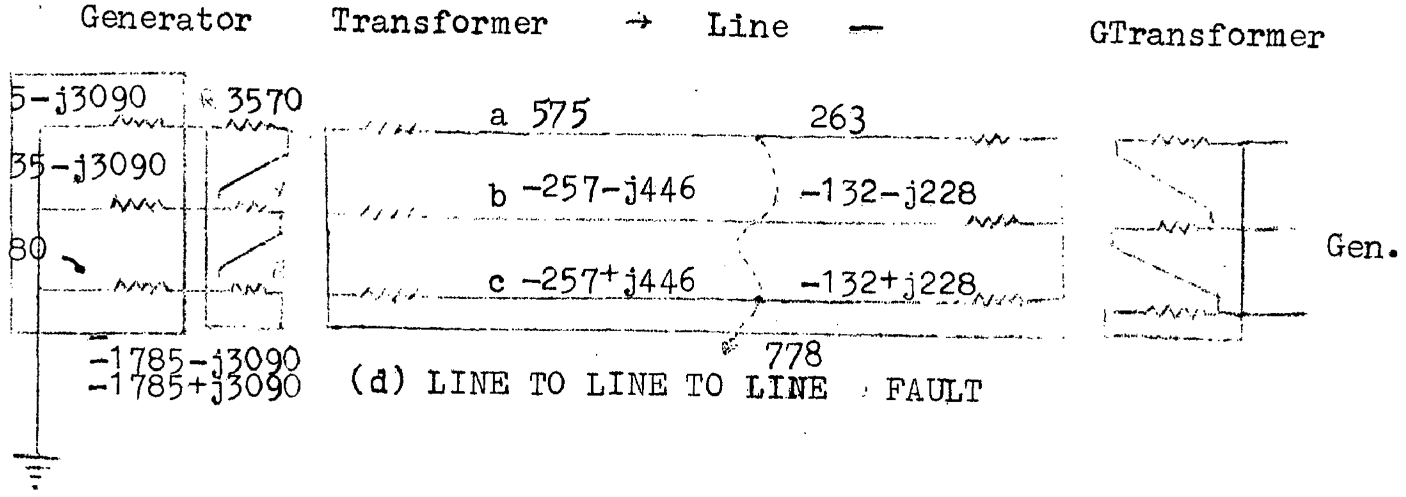
(a) LINE TO GROUND FAULT



(b) LINE TO LINE FAULT



(c) LINE TO LINE TO GROUND FAULT



(d) LINE TO LINE TO LINE FAULT

Fig.4.6 CURRENT VALUES IN SYSTEM NETWORK WITH FAULT TYPE

4.3.2 Example 2:

In this system example we are considering the probabilistic aspects for developing the stability index. The system is consisting of a single machine and an infinite bus, the machine and infinite bus both are connected through a double circuit transmission line. The simple system from Mohamadpur to Ram Nagar (Roorkee) has been selected as to illustrate the stability problem for realization of the probabilistic approach. The conclusions obtained are also applicable to multi-machine system successfully. System is shown in Fig. 4.7 consist of hydrogenerators represented by a single equivalent machine G. The system is 20 Kms far from the Ram Nagar (Roorkee Campus) and feeding power through a double circuit 66 KV transmission line. T_1 and T_2 are two transformers. Other parameters are given in Appendix I. Data for different faults for four years (1976-1979) for this system are given in Appendix I. For finding the admittance during the fault for all cases the computer program has been developed. The flow charts are given in Appendix-II.

The transfer admittance increases from zero to 0.3870969, .7365622, 0.8558143, 0.1057864 (per unit) as the faults move from zero to 0.599, 0.599, 0.599, 0.6199 (per unit) lengths of the line and after the peak value decreases towards 1.0 (per unit) length, during the (L-L-L) fault, (L-L-G) fault, (L-L) fault, (L-G) fault, respectively.

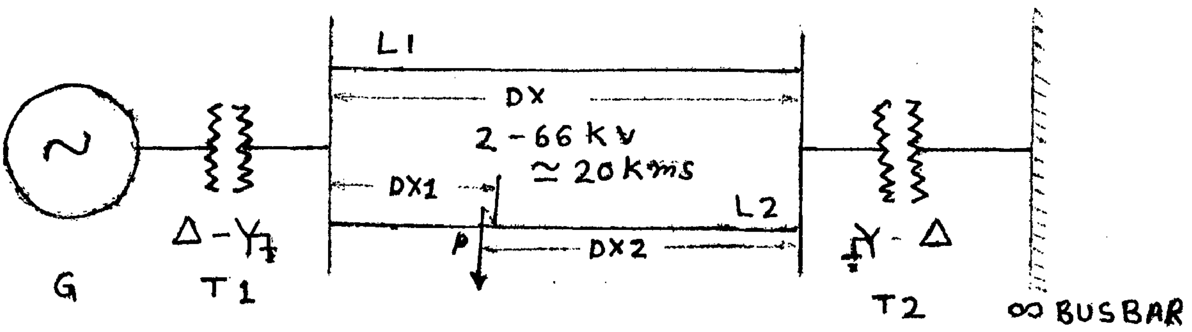


Fig.4.7 SINGLE LINE DIAGRAM FOR THE POWER SYSTEM EXAMPLE 2 [MOHAMADPUR TO RAM NAGAR (ROORKEE)]

The variation of transfer admittance Y_{12} with respect to distance are shown in figures 2 - 2.3 for all types of faults. The equal area criterion is applied to determine the critical clearing angle. The critical clearing time for fault is calculated by using the point by point calculation method, corresponding to critical clearing angle. The effect of various system parameters are studied with this problem. Three phase short circuit, double line to ground, line to line short circuit and line to ground short circuit faults calculations are given in tables 4.3 - 4.32. For different system conditions the probability of stability is evaluated. And for different values corresponding to the Ps characteristics are shown in figures 4.10 - 4.15 with different system operating conditions.

The calculations for the evaluation of the effect of different variables on probability of stability are carried out which are given in tables 4.27 - 4.32. The corresponding to these values graphs are show in the figures 4.10 - 4.15.

Table 4.27 and 4.28 provide the informations regarding the variation of probability. Fig.4.10 is corresponding to transfer admittance ($y_{10} \geq y_{12}$). For the calculations of probability distribution the fault is assumed to be the normally distributed with a mean of 0.5 p.u. and standard deviation is .2 P.U. of the maximum P.U. value of length. For the fault clearing time of the breaker the probability of fault clearing is assumed to be the normally distributed the mean value is taken as 5 cycles (based on 50 Hz). And standard deviation is assumed equal to 0.01. The location of fault is varied from 0 - 60 % of the P.U. length of line. The results are obtained for the different parameters e.g. machine inertia constant (H), machine constant (G), fault location, types of fault, addition of transmission lines in parallel. The nature of the curves with the base values and new values of variables are given in tabular form. The results are presented from the next page onwards.

```
TABLE 4.3 (THREE PHASE FAULT)
--------------------------------------------------------------
       DISTANCE     Y12 IN(P.U.)     TC IN(SEC.)
       IN(P.U.)
--------------------------------------------------------------

       1.999999E-2    3.417016E-2     7.999996E-2
       3.999998E-2    6.548433E-2     7.999996E-2
       6.000000E-2    9.425136E-2     8.999996E-2
       7.999997E-2    1.207349E-1     8.999996E-2
       9.999996E-2    1.451613E-1     8.999996E-2
       1.200000E-1    1.677256E-1     8.999996E-2
       1.399999E-1    1.885964E-1     8.999996E-2
       1.599999E-1    2.079207E-1     9.999994E-2
       1.799999E-1    2.258262E-1     9.999994E-2
       1.999998E-1    2.424242E-1     9.999994E-2
       2.199999E-1    2.578125E-1     9.999994E-2
       2.399998E-1    2.720764E-1     9.999994E-2
       2.599997E-1    2.852906E-1     9.999994E-2
       2.799997E-1    2.975206E-1     1.099999E-1
       2.999997E-1    3.088234E-1     1.099999E-1
       3.199997E-1    3.192487E-1     1.099999E-1
       3.399997E-1    3.288393E-1     1.099999E-1
       3.599997E-1    3.376318E-1     1.099999E-1
       3.799997E-1    3.456572E-1     1.099999E-1
       3.999996E-1    3.529411E-1     1.099999E-1
       4.199996E-1    3.595041E-1     1.099999E-1
       4.399996E-1    3.653616E-1     1.099999E-1
       4.599996E-1    3.705249E-1     1.099999E-1
       4.799996E-1    3.749999E-1     1.199999E-1
       4.999996E-1    3.787878E-1     1.199999E-1
       5.199995E-1    3.818849E-1     1.199999E-1
       5.399994E-1    3.842822E-1     1.199999E-1
       5.599994E-1    3.859650E-1     1.199999E-1
       5.799994E-1    3.869124E-1     1.199999E-1
       5.999994E-1    3.870969E-1     1.199999E-1
       6.199994E-1    3.864830E-1     1.199999E-1
       6.399993E-1    3.850269E-1     1.199999E-1
       6.599993E-1    3.826741E-1     1.199999E-1
       6.799993E-1    3.793587E-1     1.199999E-1
       6.999993E-1    3.750003E-1     1.199999E-1
       7.199993E-1    3.695017E-1     1.099999E-1
       7.399992E-1    3.627454E-1     1.099999E-1
       7.599992E-1    3.545884E-1     1.099999E-1
       7.799992E-1    3.448558E-1     1.099999E-1
       7.999992E-1    3.333338E-1     1.099999E-1
       8.199993E-1    3.197580E-1     1.099999E-1
       8.399993E-1    3.037983E-1     1.099999E-1
       8.599992E-1    2.850388E-1     9.999994E-2
       8.799993E-1    2.629493E-1     9.999994E-2
       8.999992E-1    2.368434E-1     9.999994E-2
       9.199993E-1    2.058181E-1     9.999994E-2
       9.399992E-1    1.686621E-1     8.999996E-2
       9.599992E-1    1.237136E-1     8.999996E-2
       9.799991E-1    6.863032E-2     7.999996E-2
       9.999992E-1    3.667959E-6     7.999996E-2

--------------------------------------------------------------
```

TABLE 4.4 (ASYM. FAULT CAL.)

~~0.40 0.1~~

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
2.000000E-2	4.083142E-1	1.199999E-1
4.000000E-2	4.431541E-1	1.299998E-1
6.000000E-2	4.736969E-1	1.299998E-1
7.999997E-2	5.007288E-1	1.399998E-1
9.999996E-2	5.248385E-1	1.399998E-1
1.200000E-1	5.464780E-1	1.499998E-1
1.399999E-1	5.660014E-1	1.499998E-1
1.599999E-1	5.836909E-1	1.599998E-1
1.799999E-1	5.997746E-1	1.599998E-1
1.999998E-1	6.144394E-1	1.699998E-1
2.199999E-1	6.278391E-1	1.699998E-1
2.399998E-1	6.401034E-1	1.699998E-1
2.599997E-1	6.513395E-1	1.799998E-1
2.799997E-1	6.616390E-1	1.799998E-1
2.999997E-1	6.710792E-1	1.899998E-1
3.199997E-1	6.797259E-1	1.899998E-1
3.399997E-1	6.876349E-1	1.899998E-1
3.599997E-1	6.948535E-1	1.999998E-1
3.799997E-1	7.014217E-1	1.999998E-1
3.999996E-1	7.073726E-1	1.999998E-1
4.199996E-1	7.127343E-1	2.099998E-1
4.399996E-1	7.175285E-1	2.099998E-1
4.599996E-1	7.217731E-1	2.099998E-1
4.799996E-1	7.254798E-1	2.099998E-1
4.999996E-1	7.286577E-1	2.199998E-1
5.199995E-1	7.313094E-1	2.199998E-1
5.399994E-1	7.334342E-1	2.199998E-1
5.599994E-1	7.350260E-1	2.199998E-1
5.799994E-1	7.360741E-1	2.199998E-1
5.999994E-1	7.365622E-1	2.199998E-1
6.199994E-1	7.364675E-1	2.199998E-1
6.399993E-1	7.357606E-1	2.199998E-1
6.599993E-1	7.344045E-1	2.199998E-1
6.799993E-1	7.323519E-1	2.199998E-1
6.999993E-1	7.295457E-1	2.199998E-1
7.199993E-1	7.259145E-1	2.099998E-1
7.399992E-1	7.213711E-1	2.099998E-1
7.599992E-1	7.158075E-1	2.099998E-1
7.799992E-1	7.090907E-1	1.999998E-1
7.999992E-1	7.010541E-1	1.999998E-1
8.199993E-1	6.914898E-1	1.999998E-1
8.399993E-1	6.801321E-1	1.899998E-1
8.599992E-1	6.666405E-1	1.899998E-1
8.799993E-1	6.505699E-1	1.799998E-1
8.999992E-1	6.313261E-1	1.699998E-1
9.199993E-1	6.081015E-1	1.599998E-1
9.399992E-1	5.797638E-1	1.599998E-1
9.599992E-1	5.446727E-1	1.499998E-1
9.799991E-1	5.003464E-1	1.399998E-1
9.999992E-1	4.428073E-1	1.299998E-1

TABLE 4.5 (ASMM. FAULT CAL.)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
2.000000E-2	6.639075E-1	1.799998E-1
4.000000E-2	6.810389E-1	1.899998E-1
6.000000E-2	6.967370E-1	1.999998E-1
7.999997E-2	7.111559E-1	2.099998E-1
9.999996E-2	7.244281E-1	2.099998E-1
1.200000E-1	7.366662E-1	2.199998E-1
1.399999E-1	7.479675E-1	2.299998E-1
1.599999E-1	7.584167E-1	2.399998E-1
1.799999E-1	7.680870E-1	2.399998E-1
1.999998E-1	7.770419E-1	2.499998E-1
2.199999E-1	7.853374E-1	2.599997E-1
2.399998E-1	7.930219E-1	2.599997E-1
2.599997E-1	8.001379E-1	2.699997E-1
2.799997E-1	8.067228E-1	2.799997E-1
2.999997E-1	8.128084E-1	2.899997E-1
3.199997E-1	8.184236E-1	2.899997E-1
3.399997E-1	8.235925E-1	2.999997E-1
3.599997E-1	8.283361E-1	3.099997E-1
3.799997E-1	8.326719E-1	3.099997E-1
3.999996E-1	8.366151E-1	3.199997E-1
4.199996E-1	8.401781E-1	3.299996E-1
4.399996E-1	8.433694E-1	3.299996E-1
4.599996E-1	8.461967E-1	3.399996E-1
4.799996E-1	8.486639E-1	3.399996E-1
4.999996E-1	8.507730E-1	3.499996E-1
5.199995E-1	8.525230E-1	3.499996E-1
5.399994E-1	8.539098E-1	3.499996E-1
5.599994E-1	8.549282E-1	3.499996E-1
5.799994E-1	8.555669E-1	3.599996E-1
5.999994E-1	8.558143E-1	3.599996E-1
6.199994E-1	8.556518E-1	3.599996E-1
6.399993E-1	8.550580E-1	3.499996E-1
6.599993E-1	8.540073E-1	3.499996E-1
6.799993E-1	8.524658E-1	3.499996E-1
6.999993E-1	8.503940E-1	3.399996E-1
7.199993E-1	8.477434E-1	3.399996E-1
7.399992E-1	8.444549E-1	3.299996E-1
7.599992E-1	8.404569E-1	3.299996E-1
7.799992E-1	8.356620E-1	3.199997E-1
7.999992E-1	8.299629E-1	3.099997E-1
8.199993E-1	8.232267E-1	2.999997E-1
8.399993E-1	8.152872E-1	2.899997E-1
8.599992E-1	8.059352E-1	2.799997E-1
8.799993E-1	7.949044E-1	2.699997E-1
8.999992E-1	7.818489E-1	2.499998E-1
9.199993E-1	7.663137E-1	2.399998E-1
9.399992E-1	7.476389E-1	2.299998E-1
9.599992E-1	7.251365E-1	2.099998E-1
9.799991E-1	6.974754E-1	1.999998E-1
9.999992E-1	6.629853E-1	1.799998E-1

TABLE 4.6 :(ASYM. FAULT CAL.)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
2.000000E-2	8.431324E-1	3.299996E-1
4.000000E-2	8.662647E-1	3.799996E-1
6.000000E-2	8.865957E-1	1.000000E-2
7.999997E-2	9.045843E-1	1.000000E-2
9.999996E-2	9.205936E-1	1.000000E-2
1.200000E-1	9.349134E-1	1.000000E-2
1.399999E-1	9.477785E-1	1.000000E-2
1.599999E-1	9.593805E-1	1.000000E-2
1.799999E-1	9.698774E-1	1.000000E-2
1.999998E-1	9.794010E-1	1.000000E-2
2.199999E-1	9.880605E-1	1.000000E-2
2.399998E-1	9.959491E-1	1.000000E-2
2.599997E-1	1.003144E+0	1.000000E-2
2.799997E-1	1.009713E+0	1.000000E-2
2.999997E-1	1.015712E+0	1.000000E-2
3.199997E-1	1.021190E+0	1.000000E-2
3.399997E-1	1.026188E+0	1.000000E-2
3.599997E-1	1.030741E+0	1.000000E-2
3.799997E-1	1.034879E+0	1.000000E-2
3.999996E-1	1.038627E+0	1.000000E-2
4.199996E-1	1.042008E+0	1.000000E-2
4.399996E-1	1.045037E+0	1.000000E-2
4.599996E-1	1.047731E+0	1.000000E-2
4.799996E-1	1.050099E+0	1.000000E-2
4.999996E-1	1.052150E+0	1.000000E-2
5.199995E-1	1.053889E+0	1.000000E-2
5.399994E-1	1.055318E+0	1.000000E-2
5.599994E-1	1.056435E+0	1.000000E-2
5.799994E-1	1.057238E+0	1.000000E-2
5.999994E-1	1.057718E+0	1.000000E-2
6.199994E-1	1.057864E+0	1.000000E-2
6.399993E-1	1.057661E+0	1.000000E-2
6.599993E-1	1.057089E+0	1.000000E-2
6.799993E-1	1.056121E+0	1.000000E-2
6.999993E-1	1.054726E+0	1.000000E-2
7.199993E-1	1.052862E+0	1.000000E-2
7.399992E-1	1.050479E+0	1.000000E-2
7.599992E-1	1.047513E+0	1.000000E-2
7.799992E-1	1.043887E+0	1.000000E-2
7.999992E-1	1.039498E+0	1.000000E-2
8.199993E-1	1.034222E+0	1.000000E-2
8.399993E-1	1.027897E+0	1.000000E-2
8.599992E-1	1.020310E+0	1.000000E-2
8.799993E-1	1.011184E+0	1.000000E-2
8.999992E-1	1.000143E+0	1.000000E-2
9.199993E-1	9.866699E-1	1.000000E-2
9.399992E-1	9.700328E-1	1.000000E-2
9.599992E-1	9.491636E-1	1.000000E-2
9.799991E-1	9.224365E-1	1.000000E-2
9.999992E-1	8.872566E-1	1.000000E-2

TABLE 4.7 (THREE PHASE FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
1.999999E-2	3.417016E-2	6.000000E-2
3.999998E-2	6.548433E-2	6.000000E-2
6.000000E-2	9.425136E-2	6.000000E-2
7.999997E-2	1.207349E-1	6.000000E-2
9.999996E-2	1.451613E-1	6.999997E-2
1.200000E-1	1.677256E-1	6.999997E-2
1.399999E-1	1.885964E-1	6.999997E-2
1.599999E-1	2.079207E-1	6.999997E-2
1.799999E-1	2.258262E-1	6.999997E-2
1.999998E-1	2.424242E-1	6.999997E-2
2.199999E-1	2.578125E-1	6.999997E-2
2.399998E-1	2.720764E-1	6.999997E-2
2.599997E-1	2.852906E-1	6.999997E-2
2.799997E-1	2.975206E-1	7.999996E-2
2.999997E-1	3.088234E-1	7.999996E-2
3.199997E-1	3.192487E-1	7.999996E-2
3.399997E-1	3.288393E-1	7.999996E-2
3.599997E-1	3.376318E-1	7.999996E-2
3.799997E-1	3.456572E-1	7.999996E-2
3.999996E-1	3.529411E-1	7.999996E-2
4.199996E-1	3.595041E-1	7.999996E-2
4.399996E-1	3.653616E-1	7.999996E-2
4.599996E-1	3.705249E-1	7.999996E-2
4.799996E-1	3.749999E-1	7.999996E-2
4.999996E-1	3.787878E-1	7.999996E-2
5.199995E-1	3.818849E-1	7.999996E-2
5.399994E-1	3.842822E-1	7.999996E-2
5.599994E-1	3.859650E-1	7.999996E-2
5.799994E-1	3.869124E-1	7.999996E-2
5.999994E-1	3.870969E-1	7.999996E-2
6.199994E-1	3.864830E-1	7.999996E-2
6.399993E-1	3.850269E-1	7.999996E-2
6.599993E-1	3.826741E-1	7.999996E-2
6.799993E-1	3.793587E-1	7.999996E-2
6.999993E-1	3.750003E-1	7.999996E-2
7.199993E-1	3.695017E-1	7.999996E-2
7.399992E-1	3.627454E-1	7.999996E-2
7.599992E-1	3.545884E-1	7.999996E-2
7.799992E-1	3.448558E-1	7.999996E-2
7.999992E-1	3.333338E-1	7.999996E-2
8.199993E-1	3.197580E-1	7.999996E-2
8.399993E-1	3.037983E-1	7.999996E-2
8.599992E-1	2.850388E-1	6.999997E-2
8.799993E-1	2.629493E-1	6.999997E-2
8.999992E-1	2.368434E-1	6.999997E-2
9.199993E-1	2.058181E-1	6.999997E-2
9.399992E-1	1.686621E-1	6.999997E-2
9.599992E-1	1.237136E-1	6.000000E-2
9.799991E-1	6.863032E-2	6.000000E-2
9.999992E-1	3.667959E-6	6.000000E-2

G=0.5

TABLE 4.8 (L-G FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
2.000000E-2	8.431324E-1	2.399998E-1
4.000000E-2	8.662647E-1	2.699997E-1
6.000000E-2	8.865957E-1	1.000000E-2
7.999997E-2	9.045843E-1	1.000000E-2
9.999996E-2	9.205936E-1	1.000000E-2
1.200000E-1	9.349134E-1	1.000000E-2
1.399999E-1	9.477785E-1	1.000000E-2
1.599999E-1	9.593805E-1	1.000000E-2
1.799999E-1	9.698774E-1	1.000000E-2
1.999998E-1	9.794010E-1	1.000000E-2
2.199999E-1	9.880605E-1	1.000000E-2
2.399998E-1	9.959491E-1	1.000000E-2
2.599997E-1	1.003144E+0	1.000000E-2
2.799997E-1	1.009713E+0	1.000000E-2
2.999997E-1	1.015712E+0	1.000000E-2
3.199997E-1	1.021190E+0	1.000000E-2
3.399997E-1	1.026188E+0	1.000000E-2
3.599997E-1	1.030741E+0	1.000000E-2
3.799997E-1	1.034879E+0	1.000000E-2
3.999996E-1	1.038627E+0	1.000000E-2
4.199996E-1	1.042008E+0	1.000000E-2
4.399996E-1	1.045037E+0	1.000000E-2
4.599996E-1	1.047731E+0	1.000000E-2
4.799996E-1	1.050099E+0	1.000000E-2
4.999996E-1	1.052150E+0	1.000000E-2
5.199995E-1	1.053889E+0	1.000000E-2
5.399994E-1	1.055318E+0	1.000000E-2
5.599994E-1	1.056435E+0	1.000000E-2
5.799994E-1	1.057238E+0	1.000000E-2
5.999994E-1	1.057718E+0	1.000000E-2
6.199994E-1	1.057864E+0	1.000000E-2
6.399993E-1	1.057661E+0	1.000000E-2
6.599993E-1	1.057089E+0	1.000000E-2
6.799993E-1	1.056121E+0	1.000000E-2
6.999993E-1	1.054726E+0	1.000000E-2
7.199993E-1	1.052862E+0	1.000000E-2
7.399992E-1	1.050479E+0	1.000000E-2
7.599992E-1	1.047513E+0	1.000000E-2
7.799992E-1	1.043887E+0	1.000000E-2
7.999992E-1	1.039498E+0	1.000000E-2
8.199993E-1	1.034222E+0	1.000000E-2
8.399993E-1	1.027897E+0	1.000000E-2
8.599992E-1	1.020310E+0	1.000000E-2
8.799993E-1	1.011184E+0	1.000000E-2
8.999992E-1	1.000143E+0	1.000000E-2
9.199993E-1	9.866699E-1	1.000000E-2
9.399992E-1	9.700328E-1	1.000000E-2
9.599992E-1	9.491636E-1	1.000000E-2
9.799991E-1	9.224365E-1	1.000000E-2
9.999992E-1	8.872566E-1	1.000000E-2

G=0.5(P.U.)

TABLE 4.9 (THREE PHASE FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
1.999999E-2	3.417016E-2	9.999994E-2
3.999998E-2	6.548433E-2	9.999994E-2
6.000000E-2	9.425136E-2	9.999994E-2
7.999997E-2	1.207349E-1	1.099999E-1
9.999996E-2	1.451613E-1	1.099999E-1
1.200000E-1	1.677256E-1	1.099999E-1
1.399999E-1	1.885964E-1	1.099999E-1
1.599999E-1	2.079207E-1	1.199999E-1
1.799999E-1	2.258262E-1	1.199999E-1
1.999998E-1	2.424242E-1	1.199999E-1
2.199999E-1	2.578125E-1	1.199999E-1
2.399998E-1	2.720764E-1	1.199999E-1
2.599997E-1	2.852906E-1	1.299998E-1
2.799997E-1	2.975206E-1	1.299998E-1
2.999997E-1	3.088234E-1	1.299998E-1
3.199997E-1	3.192487E-1	1.299998E-1
3.399997E-1	3.288393E-1	1.299998E-1
3.599997E-1	3.376318E-1	1.299998E-1
3.799997E-1	3.456572E-1	1.299998E-1
3.999996E-1	3.529411E-1	1.399998E-1
4.199996E-1	3.595041E-1	1.399998E-1
4.399996E-1	3.653616E-1	1.399998E-1
4.599996E-1	3.705249E-1	1.399998E-1
4.799996E-1	3.749999E-1	1.399998E-1
4.999996E-1	3.787878E-1	1.399998E-1
5.199995E-1	3.818849E-1	1.399998E-1
5.399994E-1	3.842822E-1	1.399998E-1
5.599994E-1	3.859650E-1	1.399998E-1
5.799994E-1	3.869124E-1	1.399998E-1
5.999994E-1	3.870969E-1	1.399998E-1
6.199994E-1	3.864830E-1	1.399998E-1
6.399993E-1	3.850269E-1	1.399998E-1
6.599993E-1	3.826741E-1	1.399998E-1
6.799993E-1	3.793587E-1	1.399998E-1
6.999993E-1	3.750003E-1	1.399998E-1
7.199993E-1	3.695017E-1	1.399998E-1
7.399992E-1	3.627454E-1	1.399998E-1
7.599992E-1	3.545884E-1	1.399998E-1
7.799992E-1	3.448558E-1	1.299998E-1
7.999992E-1	3.333338E-1	1.299998E-1
8.199993E-1	3.197580E-1	1.299998E-1
8.399993E-1	3.037983E-1	1.299998E-1
8.599992E-1	2.850388E-1	1.299998E-1
8.799993E-1	2.629493E-1	1.199999E-1
8.999992E-1	2.368434E-1	1.199999E-1
9.199993E-1	2.058181E-1	1.199999E-1
9.399992E-1	1.686621E-1	1.099999E-1
9.599992E-1	1.237136E-1	1.099999E-1
9.799991E-1	6.863032E-2	9.999994E-2
9.999992E-1	3.667959E-6	9.999994E-2

G=1.5(P.U.)

TABLE 4.10 (L-G FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
2.000000E-2	8.431324E-1	3.999996E-1
4.000000E-2	8.662647E-1	4.699995E-1
6.000000E-2	8.865957E-1	1.000000E-2
7.999997E-2	9.045843E-1	1.000000E-2
9.999996E-2	9.205936E-1	1.000000E-2
1.200000E-1	9.349134E-1	1.000000E-2
1.399999E-1	9.477785E-1	1.000000E-2
1.599999E-1	9.593805E-1	1.000000E-2
1.799999E-1	9.698774E-1	1.000000E-2
1.999998E-1	9.794010E-1	1.000000E-2
2.199999E-1	9.880605E-1	1.000000E-2
2.399998E-1	9.959491E-1	1.000000E-2
2.599997E-1	1.003144E+0	1.000000E-2
2.799997E-1	1.009713E+0	1.000000E-2
2.999997E-1	1.015712E+0	1.000000E-2
3.199997E-1	1.021190E+0	1.000000E-2
3.399997E-1	1.026188E+0	1.000000E-2
3.599997E-1	1.030741E+0	1.000000E-2
3.799997E-1	1.034879E+0	1.000000E-2
3.999996E-1	1.038627E+0	1.000000E-2
4.199996E-1	1.042008E+0	1.000000E-2
4.399996E-1	1.045037E+0	1.000000E-2
4.599996E-1	1.047731E+0	1.000000E-2
4.799996E-1	1.050099E+0	1.000000E-2
4.999996E-1	1.052150E+0	1.000000E-2
5.199995E-1	1.053889E+0	1.000000E-2
5.399994E-1	1.055318E+0	1.000000E-2
5.599994E-1	1.056435E+0	1.000000E-2
5.799994E-1	1.057238E+0	1.000000E-2
5.999994E-1	1.057718E+0	1.000000E-2
6.199994E-1	1.057864E+0	1.000000E-2
6.399993E-1	1.057661E+0	1.000000E-2
6.599993E-1	1.057089E+0	1.000000E-2
6.799993E-1	1.056121E+0	1.000000E-2
6.999993E-1	1.054726E+0	1.000000E-2
7.199993E-1	1.052862E+0	1.000000E-2
7.399992E-1	1.050479E+0	1.000000E-2
7.599992E-1	1.047513E+0	1.000000E-2
7.799992E-1	1.043887E+0	1.000000E-2
7.999992E-1	1.039498E+0	1.000000E-2
8.199993E-1	1.034222E+0	1.000000E-2
8.399993E-1	1.027897E+0	1.000000E-2
8.599992E-1	1.020310E+0	1.000000E-2
8.799993E-1	1.011184E+0	1.000000E-2
8.999992E-1	1.000143E+0	1.000000E-2
9.199993E-1	9.866699E-1	1.000000E-2
9.399992E-1	9.700328E-1	1.000000E-2
9.599992E-1	9.491636E-1	1.000000E-2
9.799991E-1	9.224365E-1	1.000000E-2
9.999992E-1	8.872566E-1	1.000000E-2

G=1.5(P.U.)

TABLE 4.11 (THREE PHASE FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
1.999999E-2	3.417016E-2	4.999998E-2
3.999998E-2	6.548433E-2	4.999998E-2
6.000000E-2	9.425136E-2	4.999998E-2
7.999997E-2	1.207349E-1	4.999998E-2
9.999996E-2	1.451613E-1	4.999998E-2
1.200000E-1	1.677256E-1	6.000000E-2
1.399999E-1	1.885964E-1	6.000000E-2
1.599999E-1	2.079207E-1	6.000000E-2
1.799999E-1	2.258262E-1	6.000000E-2
1.999998E-1	2.424242E-1	6.000000E-2
2.199999E-1	2.578125E-1	6.000000E-2
2.399998E-1	2.720764E-1	6.000000E-2
2.599997E-1	2.852906E-1	6.000000E-2
2.799997E-1	2.975206E-1	6.000000E-2
2.999997E-1	3.088234E-1	6.000000E-2
3.199997E-1	3.192487E-1	6.000000E-2
3.399997E-1	3.288393E-1	6.000000E-2
3.599997E-1	3.376318E-1	6.999997E-2
3.799997E-1	3.456572E-1	6.999997E-2
3.999996E-1	3.529411E-1	6.999997E-2
4.199996E-1	3.595041E-1	6.999997E-2
4.399996E-1	3.653616E-1	6.999997E-2
4.599996E-1	3.705249E-1	6.999997E-2
4.799996E-1	3.749999E-1	6.999997E-2
4.999996E-1	3.787878E-1	6.999997E-2
5.199995E-1	3.818849E-1	6.999997E-2
5.399994E-1	3.842822E-1	6.999997E-2
5.599994E-1	3.859650E-1	6.999997E-2
5.799994E-1	3.869124E-1	6.999997E-2
5.999994E-1	3.870969E-1	6.999997E-2
6.199994E-1	3.864830E-1	6.999997E-2
6.399993E-1	3.850269E-1	6.999997E-2
6.599993E-1	3.826741E-1	6.999997E-2
6.799993E-1	3.793587E-1	6.999997E-2
6.999993E-1	3.750003E-1	6.999997E-2
7.199993E-1	3.695017E-1	6.999997E-2
7.399992E-1	3.627454E-1	6.999997E-2
7.599992E-1	3.545884E-1	6.999997E-2
7.799992E-1	3.448558E-1	6.999997E-2
7.999992E-1	3.333338E-1	6.999997E-2
8.199993E-1	3.197580E-1	6.000000E-2
8.399993E-1	3.037983E-1	6.000000E-2
8.599992E-1	2.850388E-1	6.000000E-2
8.799993E-1	2.629493E-1	6.000000E-2
8.999992E-1	2.368434E-1	6.000000E-2
9.199993E-1	2.058181E-1	6.000000E-2
9.399992E-1	1.686621E-1	6.000000E-2
9.599992E-1	1.237136E-1	4.999998E-2
9.799991E-1	6.863032E-2	4.999998E-2
9.999992E-1	3.667959E-6	4.999998E-2

H=1.0(P.U.)

TABLE 4.12 (L-G FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
2.000000E-2	8.431324E-1	1.899998E-1
4.000000E-2	8.662647E-1	2.199998E-1
6.000000E-2	8.865957E-1	1.000000E-2
7.999997E-2	9.045843E-1	1.000000E-2
9.999996E-2	9.205936E-1	1.000000E-2
1.200000E-1	9.349134E-1	1.000000E-2
1.399999E-1	9.477785E-1	1.000000E-2
1.599999E-1	9.593805E-1	1.000000E-2
1.799999E-1	9.698774E-1	1.000000E-2
1.999998E-1	9.794010E-1	1.000000E-2
2.199999E-1	9.880605E-1	1.000000E-2
2.399998E-1	9.959491E-1	1.000000E-2
2.599997E-1	1.003144E+0	1.000000E-2
2.799997E-1	1.009713E+0	1.000000E-2
2.999997E-1	1.015712E+0	1.000000E-2
3.199997E-1	1.021190E+0	1.000000E-2
3.399997E-1	1.026188E+0	1.000000E-2
3.599997E-1	1.030741E+0	1.000000E-2
3.799997E-1	1.034879E+0	1.000000E-2
3.999996E-1	1.038627E+0	1.000000E-2
4.199996E-1	1.042008E+0	1.000000E-2
4.399996E-1	1.045037E+0	1.000000E-2
4.599996E-1	1.047731E+0	1.000000E-2
4.799996E-1	1.050099E+0	1.000000E-2
4.999996E-1	1.052150E+0	1.000000E-2
5.199995E-1	1.053889E+0	1.000000E-2
5.399994E-1	1.055318E+0	1.000000E-2
5.599994E-1	1.056435E+0	1.000000E-2
5.799994E-1	1.057238E+0	1.000000E-2
5.999994E-1	1.057718E+0	1.000000E-2
6.199994E-1	1.057864E+0	1.000000E-2
6.399993E-1	1.057661E+0	1.000000E-2
6.599993E-1	1.057089E+0	1.000000E-2
6.799993E-1	1.056121E+0	1.000000E-2
6.999993E-1	1.054726E+0	1.000000E-2
7.199993E-1	1.052862E+0	1.000000E-2
7.399992E-1	1.050479E+0	1.000000E-2
7.599992E-1	1.047513E+0	1.000000E-2
7.799992E-1	1.043887E+0	1.000000E-2
7.999992E-1	1.039498E+0	1.000000E-2
8.199993E-1	1.034222E+0	1.000000E-2
8.399993E-1	1.027897E+0	1.000000E-2
8.599992E-1	1.020310E+0	1.000000E-2
8.799993E-1	1.011184E+0	1.000000E-2
8.999992E-1	1.000143E+0	1.000000E-2
9.199993E-1	9.866699E-1	1.000000E-2
9.399992E-1	9.700328E-1	1.000000E-2
9.599992E-1	9.491636E-1	1.000000E-2
9.799991E-1	9.224365E-1	1.000000E-2
9.999992E-1	8.872566E-1	1.000000E-2

H=1.0(P.U.)

TABLE 4.13 (THREE PHASE FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
1.999999E-2	3.417016E-2	1.099999E-1
3.999998E-2	6.548433E-2	1.199999E-1
6.000000E-2	9.425136E-2	1.199999E-1
7.999997E-2	1.207349E-1	1.199999E-1
9.999996E-2	1.451613E-1	1.299998E-1
1.200000E-1	1.677256E-1	1.299998E-1
1.399999E-1	1.885964E-1	1.299998E-1
1.599999E-1	2.079207E-1	1.299998E-1
1.799999E-1	2.253262E-1	1.399998E-1
1.999998E-1	2.424242E-1	1.399998E-1
2.199999E-1	2.578125E-1	1.399998E-1
2.399998E-1	2.720764E-1	1.399998E-1
2.599997E-1	2.852906E-1	1.399998E-1
2.799997E-1	2.975206E-1	1.499998E-1
2.999997E-1	3.088234E-1	1.499998E-1
3.199997E-1	3.192487E-1	1.499998E-1
3.399997E-1	3.288393E-1	1.499998E-1
3.599997E-1	3.376318E-1	1.499998E-1
3.799997E-1	3.456572E-1	1.499998E-1
3.999996E-1	3.529411E-1	1.599998E-1
4.199996E-1	3.595041E-1	1.599998E-1
4.399996E-1	3.653616E-1	1.599998E-1
4.599996E-1	3.705249E-1	1.599998E-1
4.799996E-1	3.749999E-1	1.599998E-1
4.999996E-1	3.787878E-1	1.599998E-1
5.199995E-1	3.818849E-1	1.599998E-1
5.399994E-1	3.842822E-1	1.599998E-1
5.599994E-1	3.859650E-1	1.599998E-1
5.799994E-1	3.869124E-1	1.599998E-1
5.999994E-1	3.870969E-1	1.599998E-1
6.199994E-1	3.864830E-1	1.599998E-1
6.399993E-1	3.850269E-1	1.599998E-1
6.599993E-1	3.826741E-1	1.599998E-1
6.799993E-1	3.793587E-1	1.599998E-1
6.999993E-1	3.750003E-1	1.599998E-1
7.199993E-1	3.695017E-1	1.599998E-1
7.399992E-1	3.627454E-1	1.599998E-1
7.599992E-1	3.545884E-1	1.599998E-1
7.799992E-1	3.448558E-1	1.499998E-1
7.999992E-1	3.333338E-1	1.499998E-1
8.199993E-1	3.197580E-1	1.499998E-1
8.399993E-1	3.037983E-1	1.499998E-1
8.599992E-1	2.850388E-1	1.399998E-1
8.799993E-1	2.629493E-1	1.399998E-1
8.999992E-1	2.368434E-1	1.399998E-1
9.199993E-1	2.058181E-1	1.299998E-1
9.399992E-1	1.686621E-1	1.299998E-1
9.599992E-1	1.237136E-1	1.199999E-1
9.799991E-1	6.863032E-2	1.199999E-1
9.999992E-1	3.667959E-6	1.099999E-1

H=6.0(P.U.)

TABLE 4.14 (L-G FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
2.000000E-2	8.431324E-1	4.699995E-1
4.000000E-2	8.662647E-1	5.399994E-1
6.000000E-2	8.865957E-1	1.000000E-2
7.999997E-2	9.045843E-1	1.000000E-2
9.999996E-2	9.205936E-1	1.000000E-2
1.200000E-1	9.349134E-1	1.000000E-2
1.399999E-1	9.477785E-1	1.000000E-2
1.599999E-1	9.593805E-1	1.000000E-2
1.799999E-1	9.698774E-1	1.000000E-2
1.999998E-1	9.794010E-1	1.000000E-2
2.199999E-1	9.880605E-1	1.000000E-2
2.399998E-1	9.959491E-1	1.000000E-2
2.599997E-1	1.003144E+0	1.000000E-2
2.799997E-1	1.009713E+0	1.000000E-2
2.999997E-1	1.015712E+0	1.000000E-2
3.199997E-1	1.021190E+0	1.000000E-2
3.399997E-1	1.026183E+0	1.000000E-2
3.599997E-1	1.030741E+0	1.000000E-2
3.799997E-1	1.034879E+0	1.000000E-2
3.999996E-1	1.038627E+0	1.000000E-2
4.199996E-1	1.042008E+0	1.000000E-2
4.399996E-1	1.045037E+0	1.000000E-2
4.599996E-1	1.047731E+0	1.000000E-2
4.799996E-1	1.050099E+0	1.000000E-2
4.999996E-1	1.052150E+0	1.000000E-2
5.199995E-1	1.053889E+0	1.000000E-2
5.399994E-1	1.055318E+0	1.000000E-2
5.599994E-1	1.056435E+0	1.000000E-2
5.799994E-1	1.057238E+0	1.000000E-2
5.999994E-1	1.057718E+0	1.000000E-2
6.199994E-1	1.057864E+0	1.000000E-2
6.399993E-1	1.057661E+0	1.000000E-2
6.599993E-1	1.057089E+0	1.000000E-2
6.799993E-1	1.056121E+0	1.000000E-2
6.999993E-1	1.054726E+0	1.000000E-2
7.199993E-1	1.052862E+0	1.000000E-2
7.399992E-1	1.050479E+0	1.000000E-2
7.599992E-1	1.047513E+0	1.000000E-2
7.799992E-1	1.043887E+0	1.000000E-2
7.999992E-1	1.039493E+0	1.000000E-2
8.199993E-1	1.034222E+0	1.000000E-2
8.399993E-1	1.027897E+0	1.000000E-2
8.599992E-1	1.020310E+0	1.000000E-2
8.799993E-1	1.011184E+0	1.000000E-2
8.999992E-1	1.000143E+0	1.000000E-2
9.199993E-1	9.865699E-1	1.000000E-2
9.399992E-1	9.700328E-1	1.000000E-2
9.599992E-1	9.491636E-1	1.000000E-2
9.799991E-1	9.224365E-1	1.000000E-2
9.999992E-1	8.872566E-1	1.000000E-2

H=6.0(P.U.)

TABLE 4.15 (THREE PHASE FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
1.999999E-2	3.417016E-2	8.999996E-2
3.999998E-2	6.548433E-2	8.999996E-2
6.000000E-2	9.425136E-2	8.999996E-2
7.999997E-2	1.207349E-1	8.999996E-2
9.999996E-2	1.451613E-1	8.999996E-2
1.200000E-1	1.677256E-1	9.999994E-2
1.399999E-1	1.885964E-1	9.999994E-2
1.599999E-1	2.079207E-1	9.999994E-2
1.799999E-1	2.258262E-1	9.999994E-2
1.999998E-1	2.424242E-1	9.999994E-2
2.199999E-1	2.578125E-1	1.099999E-1
2.399998E-1	2.720764E-1	1.099999E-1
2.599997E-1	2.852906E-1	1.099999E-1
2.799997E-1	2.975206E-1	1.099999E-1
2.999997E-1	3.088234E-1	1.099999E-1
3.199997E-1	3.192487E-1	1.099999E-1
3.399997E-1	3.288393E-1	1.099999E-1
3.599997E-1	3.376318E-1	1.199999E-1
3.799997E-1	3.456572E-1	1.199999E-1
3.999996E-1	3.529411E-1	1.199999E-1
4.199996E-1	3.595041E-1	1.199999E-1
4.399996E-1	3.653616E-1	1.199999E-1
4.599996E-1	3.705249E-1	1.199999E-1
4.799996E-1	3.749999E-1	1.199999E-1
4.999996E-1	3.787878E-1	1.199999E-1
5.199995E-1	3.813849E-1	1.199999E-1
5.399994E-1	3.842822E-1	1.199999E-1
5.599994E-1	3.859650E-1	1.199999E-1
5.799994E-1	3.869124E-1	1.199999E-1
5.999994E-1	3.870969E-1	1.199999E-1
6.199994E-1	3.864830E-1	1.199999E-1
6.399993E-1	3.850269E-1	1.199999E-1
6.599993E-1	3.826741E-1	1.199999E-1
6.799993E-1	3.793587E-1	1.199999E-1
6.999993E-1	3.750003E-1	1.199999E-1
7.199993E-1	3.695017E-1	1.199999E-1
7.399992E-1	3.627454E-1	1.199999E-1
7.599992E-1	3.545884E-1	1.199999E-1
7.799992E-1	3.443558E-1	1.199999E-1
7.999992E-1	3.333338E-1	1.199999E-1
8.199993E-1	3.197580E-1	1.099999E-1
8.399993E-1	3.037983E-1	1.099999E-1
8.599992E-1	2.850388E-1	1.099999E-1
8.799993E-1	2.629493E-1	1.099999E-1
8.999992E-1	2.368434E-1	9.999994E-2
9.199993E-1	2.058181E-1	9.999994E-2
9.399992E-1	1.686621E-1	9.999994E-2
9.599992E-1	1.237136E-1	8.999996E-2
9.799991E-1	6.863032E-2	8.999996E-2
9.999992E-1	3.667959E-6	7.999996E-2

F=45.0(C.P.S.)

TABLE 4.16. (L-G FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
2.000000E-2	8.431324E-1	3.499996E-1
4.000000E-2	8.662647E-1	3.999996E-1
6.000000E-2	8.865957E-1	1.000000E-2
7.999997E-2	9.045843E-1	1.000000E-2
9.999996E-2	9.205936E-1	1.000000E-2
1.200000E-1	9.349134E-1	1.000000E-2
1.399999E-1	9.477785E-1	1.000000E-2
1.599999E-1	9.593805E-1	1.000000E-2
1.799999E-1	9.698774E-1	1.000000E-2
1.999998E-1	9.794010E-1	1.000000E-2
2.199999E-1	9.880605E-1	1.000000E-2
2.399998E-1	9.959491E-1	1.000000E-2
2.599997E-1	1.003144E+0	1.000000E-2
2.799997E-1	1.009713E+0	1.000000E-2
2.999997E-1	1.015712E+0	1.000000E-2
3.199997E-1	1.021190E+0	1.000000E-2
3.399997E-1	1.026188E+0	1.000000E-2
3.599997E-1	1.030741E+0	1.000000E-2
3.799997E-1	1.034879E+0	1.000000E-2
3.999996E-1	1.038627E+0	1.000000E-2
4.199996E-1	1.042008E+0	1.000000E-2
4.399996E-1	1.045037E+0	1.000000E-2
4.599996E-1	1.047731E+0	1.000000E-2
4.799996E-1	1.050099E+0	1.000000E-2
4.999996E-1	1.052150E+0	1.000000E-2
5.199995E-1	1.053889E+0	1.000000E-2
5.399994E-1	1.055318E+0	1.000000E-2
5.599994E-1	1.056435E+0	1.000000E-2
5.799994E-1	1.057238E+0	1.000000E-2
5.999994E-1	1.057718E+0	1.000000E-2
6.199994E-1	1.057864E+0	1.000000E-2
6.399993E-1	1.057661E+0	1.000000E-2
6.599993E-1	1.057089E+0	1.000000E-2
6.799993E-1	1.056121E+0	1.000000E-2
6.999993E-1	1.054726E+0	1.000000E-2
7.199993E-1	1.052862E+0	1.000000E-2
7.399992E-1	1.050479E+0	1.000000E-2
7.599992E-1	1.047513E+0	1.000000E-2
7.799992E-1	1.043887E+0	1.000000E-2
7.999992E-1	1.039498E+0	1.000000E-2
8.199993E-1	1.034222E+0	1.000000E-2
8.399993E-1	1.027897E+0	1.000000E-2
8.599992E-1	1.020310E+0	1.000000E-2
8.799993E-1	1.011184E+0	1.000000E-2
8.999992E-1	1.000143E+0	1.000000E-2
9.199993E-1	9.866699E-1	1.000000E-2
9.399992E-1	9.700328E-1	1.000000E-2
9.599992E-1	9.491636E-1	1.000000E-2
9.799991E-1	9.224365E-1	1.000000E-2
9.999992E-1	8.872566E-1	1.000000E-2

F=45.0(C.P.S.)

TABLE 4.17 (THREE PHASE FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
1.999999E-2	3.417016E-2	7.999996E-2
3.999998E-2	6.548433E-2	7.999996E-2
6.000000E-2	9.425136E-2	7.999996E-2
7.999997E-2	1.207349E-1	7.999996E-2
9.999996E-2	1.451613E-1	7.999996E-2
1.200000E-1	1.677256E-1	7.999996E-2
1.399999E-1	1.885964E-1	8.999996E-2
1.599999E-1	2.079207E-1	8.999996E-2
1.799999E-1	2.258262E-1	8.999996E-2
1.999998E-1	2.424242E-1	8.999996E-2
2.199999E-1	2.578125E-1	8.999996E-2
2.399998E-1	2.720764E-1	8.999996E-2
2.599997E-1	2.852906E-1	9.999994E-2
2.799997E-1	2.975206E-1	9.999994E-2
2.999997E-1	3.088234E-1	9.999994E-2
3.199997E-1	3.192487E-1	9.999994E-2
3.399997E-1	3.288393E-1	9.999994E-2
3.599997E-1	3.376318E-1	9.999994E-2
3.799997E-1	3.456572E-1	9.999994E-2
3.999996E-1	3.529411E-1	9.999994E-2
4.199996E-1	3.595041E-1	9.999994E-2
4.399996E-1	3.653616E-1	9.999994E-2
4.599996E-1	3.705249E-1	9.999994E-2
4.799996E-1	3.749999E-1	1.099999E-1
4.999996E-1	3.787878E-1	1.099999E-1
5.199995E-1	3.818849E-1	1.099999E-1
5.399994E-1	3.842822E-1	1.099999E-1
5.599994E-1	3.859650E-1	1.099999E-1
5.799994E-1	3.869124E-1	1.099999E-1
5.999994E-1	3.870969E-1	1.099999E-1
6.199994E-1	3.864830E-1	1.099999E-1
6.399993E-1	3.850269E-1	1.099999E-1
6.599993E-1	3.826741E-1	1.099999E-1
6.799993E-1	3.793587E-1	1.099999E-1
6.999993E-1	3.750003E-1	1.099999E-1
7.199993E-1	3.695017E-1	9.999994E-2
7.399992E-1	3.627454E-1	9.999994E-2
7.599992E-1	3.545884E-1	9.999994E-2
7.799992E-1	3.448558E-1	9.999994E-2
7.999992E-1	3.333338E-1	9.999994E-2
8.199993E-1	3.197580E-1	9.999994E-2
8.399993E-1	3.037983E-1	9.999994E-2
8.599992E-1	2.850388E-1	9.999994E-2
8.799993E-1	2.629493E-1	8.999996E-2
8.999992E-1	2.368434E-1	8.999996E-2
9.199993E-1	2.058181E-1	8.999996E-2
9.399992E-1	1.686621E-1	7.999996E-2
9.599992E-1	1.237136E-1	7.999996E-2
9.799991E-1	6.863032E-2	7.999996E-2
9.999992E-1	3.667959E-6	6.999997E-2

F=60.0(C.P.S.)

```
        TABLE 4.18        (L-G FAULT)
----------------------------------------------------------------
       DISTANCE          Y12 IN(P.U.)     TC IN(SEC.)
       IN(P.U.)

       2.000000E-2       8.431324E-1      2.999997E-1
       4.000000E-2       8.662647E-1      3.499996E-1
       6.000000E-2       8.865957E-1      1.000000E-2
       7.999997E-2       9.045843E-1      1.000000E-2
       9.999996E-2       9.205936E-1      1.000000E-2
       1.200000E-1       9.349134E-1      1.000000E-2
       1.399999E-1       9.477785E-1      1.000000E-2
       1.599999E-1       9.593805E-1      1.000000E-2
       1.799999E-1       9.698774E-1      1.000000E-2
       1.999998E-1       9.794010E-1      1.000000E-2
       2.199999E-1       9.880605E-1      1.000000E-2
       2.399998E-1       9.959491E-1      1.000000E-2
       2.599997E-1       1.003144E+0      1.000000E-2
       2.799997E-1       1.009713E+0      1.000000E-2
       2.999997E-1       1.015712E+0      1.000000E-2
       3.199997E-1       1.021190E+0      1.000000E-2
       3.399997E-1       1.026188E+0      1.000000E-2
       3.599997E-1       1.030741E+0      1.000000E-2
       3.799997E-1       1.034879E+0      1.000000E-2
       3.999996E-1       1.038627E+0      1.000000E-2
       4.199996E-1       1.042008E+0      1.000000E-2
       4.399996E-1       1.045037E+0      1.000000E-2
       4.599996E-1       1.047731E+0      1.000000E-2
       4.799996E-1       1.050099E+0      1.000000E-2
       4.999996E-1       1.052150E+0      1.000000E-2
       5.199995E-1       1.053889E+0      1.000000E-2
       5.399994E-1       1.055318E+0      1.000000E-2
       5.599994E-1       1.056435E+0      1.000000E-2
       5.799994E-1       1.057238E+0      1.000000E-2
       5.999994E-1       1.057718E+0      1.000000E-2
       6.199994E-1       1.057864E+0      1.000000E-2
       6.399993E-1       1.057661E+0      1.000000E-2
       6.599993E-1       1.057089E+0      1.000000E-2
       6.799993E-1       1.056121E+0      1.000000E-2
       6.999993E-1       1.054726E+0      1.000000E-2
       7.199993E-1       1.052862E+0      1.000000E-2
       7.399992E-1       1.050479E+0      1.000000E-2
       7.599992E-1       1.047513E+0      1.000000E-2
       7.799992E-1       1.043837E+0      1.000000E-2
       7.999992E-1       1.039498E+0      1.000000E-2
       8.199993E-1       1.034222E+0      1.000000E-2
       8.399993E-1       1.027897E+0      1.000000E-2
       8.599992E-1       1.020310E+0      1.000000E-2
       8.799993E-1       1.011184E+0      1.000000E-2
       8.999992E-1       1.000143E+0      1.000000E-2
       9.199993E-1       9.866699E-1      1.000000E-2
       9.399992E-1       9.700328E-1      1.000000E-2
       9.599992E-1       9.491636E-1      1.000000E-2
       9.799991E-1       9.224365E-1      1.000000E-2
       9.999992E-1       8.872566E-1      1.000000E-2

----------------------------------------------------------------
              F=60.0(CCP.S.)
```

TABLE 4.19 (THREE PHASE FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
1.999999E-2	3.417016E-2	9.999994E-2
3.999998E-2	6.548433E-2	1.099999E-1
6.000000E-2	9.425136E-2	1.099999E-1
7.999997E-2	1.207349E-1	1.099999E-1
9.999996E-2	1.451613E-1	1.099999E-1
1.200000E-1	1.677256E-1	1.199999E-1
1.399999E-1	1.885964E-1	1.199999E-1
1.599999E-1	2.079207E-1	1.199999E-1
1.799999E-1	2.258262E-1	1.199999E-1
1.999998E-1	2.424242E-1	1.299998E-1
2.199999E-1	2.578125E-1	1.299998E-1
2.399998E-1	2.720764E-1	1.299998E-1
2.599997E-1	2.852906E-1	1.299998E-1
2.799997E-1	2.975206E-1	1.299998E-1
2.999997E-1	3.088234E-1	1.299998E-1
3.199997E-1	3.192487E-1	1.399998E-1
3.399997E-1	3.288393E-1	1.399998E-1
3.599997E-1	3.376318E-1	1.399998E-1
3.799997E-1	3.456572E-1	1.399998E-1
3.999996E-1	3.529411E-1	1.399998E-1
4.199996E-1	3.595041E-1	1.399998E-1
4.399996E-1	3.653616E-1	1.399998E-1
4.599996E-1	3.705249E-1	1.499998E-1
4.799996E-1	3.749999E-1	1.499998E-1
4.999996E-1	3.787878E-1	1.499998E-1
5.199995E-1	3.818849E-1	1.499998E-1
5.399994E-1	3.842822E-1	1.499998E-1
5.599994E-1	3.859650E-1	1.499998E-1
5.799994E-1	3.869124E-1	1.499998E-1
5.999994E-1	3.870969E-1	1.499998E-1
6.199994E-1	3.864830E-1	1.499998E-1
6.399993E-1	3.850269E-1	1.499998E-1
6.599993E-1	3.826741E-1	1.499998E-1
6.799993E-1	3.793587E-1	1.499998E-1
6.999993E-1	3.750003E-1	1.499998E-1
7.199993E-1	3.695017E-1	1.399998E-1
7.399992E-1	3.627454E-1	1.399998E-1
7.599992E-1	3.545884E-1	1.399998E-1
7.799992E-1	3.448558E-1	1.399998E-1
7.999992E-1	3.333338E-1	1.399998E-1
8.199993E-1	3.197580E-1	1.399998E-1
8.399993E-1	3.037983E-1	1.299998E-1
8.599992E-1	2.850388E-1	1.299998E-1
8.799993E-1	2.629493E-1	1.299998E-1
8.999992E-1	2.368434E-1	1.199999E-1
9.199993E-1	2.058181E-1	1.199999E-1
9.399992E-1	1.686621E-1	1.199999E-1
9.599992E-1	1.237136E-1	1.099999E-1
9.799991E-1	6.863032E-2	1.099999E-1
9.999992E-1	3.667959E-6	9.999994E-2

PS=0.95(P.U.)

TABLE 4.20 (L-G FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
2.000000E-2	8.431324E-1	1.000000E-2
4.000000E-2	8.662647E-1	1.000000E-2
6.000000E-2	8.865957E-1	1.000000E-2
7.999997E-2	9.045843E-1	1.000000E-2
9.999996E-2	9.205936E-1	1.000000E-2
1.200000E-1	9.349134E-1	1.000000E-2
1.399999E-1	9.477785E-1	1.000000E-2
1.599999E-1	9.593805E-1	1.000000E-2
1.799999E-1	9.698774E-1	1.000000E-2
1.999998E-1	9.794010E-1	1.000000E-2
2.199999E-1	9.880605E-1	1.000000E-2
2.399998E-1	9.959491E-1	1.000000E-2
2.599997E-1	1.003144E+0	1.000000E-2
2.799997E-1	1.009713E+0	1.000000E-2
2.999997E-1	1.015712E+0	1.000000E-2
3.199997E-1	1.021190E+0	1.000000E-2
3.399997E-1	1.026188E+0	1.000000E-2
3.599997E-1	1.030741E+0	1.000000E-2
3.799997E-1	1.034879E+0	1.000000E-2
3.999996E-1	1.038627E+0	1.000000E-2
4.199996E-1	1.042008E+0	1.000000E-2
4.399996E-1	1.045037E+0	1.000000E-2
4.599996E-1	1.047731E+0	1.000000E-2
4.799996E-1	1.050099E+0	1.000000E-2
4.999996E-1	1.052150E+0	1.000000E-2
5.199995E-1	1.053889E+0	1.000000E-2
5.399994E-1	1.055318E+0	1.000000E-2
5.599994E-1	1.056435E+0	1.000000E-2
5.799994E-1	1.057238E+0	1.000000E-2
5.999994E-1	1.057718E+0	1.000000E-2
6.199994E-1	1.057864E+0	1.000000E-2
6.399993E-1	1.057661E+0	1.000000E-2
6.599993E-1	1.057089E+0	1.000000E-2
6.799993E-1	1.056121E+0	1.000000E-2
6.999993E-1	1.054726E+0	1.000000E-2
7.199993E-1	1.052862E+0	1.000000E-2
7.399992E-1	1.050479E+0	1.000000E-2
7.599992E-1	1.047513E+0	1.000000E-2
7.799992E-1	1.043887E+0	1.000000E-2
7.999992E-1	1.039498E+0	1.000000E-2
8.199993E-1	1.034222E+0	1.000000E-2
8.399993E-1	1.027897E+0	1.000000E-2
8.599992E-1	1.020310E+0	1.000000E-2
8.799993E-1	1.011184E+0	1.000000E-2
8.999992E-1	1.000143E+0	1.000000E-2
9.199993E-1	9.866699E-1	1.000000E-2
9.399992E-1	9.700328E-1	1.000000E-2
9.599992E-1	9.491636E-1	1.000000E-2
9.799991E-1	9.224365E-1	1.000000E-2
9.999992E-1	8.872566E-1	1.000000E-2

PS=0.95(P.U.)

TABLE 4.21 (THREE PHASE FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
1.999999E-2	3.417016E-2	1.199999E-1
3.999998E-2	6.548433E-2	1.299998E-1
6.000000E-2	9.425136E-2	1.299998E-1
7.999997E-2	1.207349E-1	1.299998E-1
9.999996E-2	1.451613E-1	1.399998E-1
1.200000E-1	1.677256E-1	1.399998E-1
1.399999E-1	1.885964E-1	1.399998E-1
1.599999E-1	2.079207E-1	1.499998E-1
1.799999E-1	2.258262E-1	1.499998E-1
1.999998E-1	2.424242E-1	1.499998E-1
2.199999E-1	2.578125E-1	1.499998E-1
2.399998E-1	2.720764E-1	1.599998E-1
2.599997E-1	2.852906E-1	1.599998E-1
2.799997E-1	2.975206E-1	1.599998E-1
2.999997E-1	3.088234E-1	1.599998E-1
3.199997E-1	3.192487E-1	1.599998E-1
3.399997E-1	3.288393E-1	1.699998E-1
3.599997E-1	3.376318E-1	1.699998E-1
3.799997E-1	3.456572E-1	1.699998E-1
3.999996E-1	3.529411E-1	1.699998E-1
4.199996E-1	3.595041E-1	1.699998E-1
4.399996E-1	3.653616E-1	1.699998E-1
4.599996E-1	3.705249E-1	1.699998E-1
4.799996E-1	3.749999E-1	1.799998E-1
4.999996E-1	3.787878E-1	1.799998E-1
5.199995E-1	3.818849E-1	1.799998E-1
5.399994E-1	3.842822E-1	1.799998E-1
5.599994E-1	3.859650E-1	1.799998E-1
5.799994E-1	3.869124E-1	1.799998E-1
5.999994E-1	3.870969E-1	1.799998E-1
6.199994E-1	3.864830E-1	1.799998E-1
6.399993E-1	3.850269E-1	1.799998E-1
6.599993E-1	3.826741E-1	1.799998E-1
6.799993E-1	3.793587E-1	1.799998E-1
6.999993E-1	3.750003E-1	1.799998E-1
7.199993E-1	3.695017E-1	1.699998E-1
7.399992E-1	3.627454E-1	1.699998E-1
7.599992E-1	3.545884E-1	1.699998E-1
7.799992E-1	3.448558E-1	1.699998E-1
7.999992E-1	3.333338E-1	1.699998E-1
8.199993E-1	3.197580E-1	1.599998E-1
8.399993E-1	3.037983E-1	1.599998E-1
8.599992E-1	2.850388E-1	1.599998E-1
8.799993E-1	2.629493E-1	1.499998E-1
8.999992E-1	2.368434E-1	1.499998E-1
9.199993E-1	2.058181E-1	1.499998E-1
9.399992E-1	1.686621E-1	1.399998E-1
9.599992E-1	1.237136E-1	1.299998E-1
9.799991E-1	6.863032E-2	1.299998E-1
9.999992E-1	3.667959E-6	1.199999E-1

PS=0.90(P.U.)

TABLE 4.22 (L-G FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
2.000000E-2	8.431324E-1	1.000000E-2
4.000000E-2	8.662647E-1	1.000000E-2
6.000000E-2	8.865957E-1	1.000000E-2
7.999997E-2	9.045843E-1	1.000000E-2
9.999996E-2	9.205936E-1	1.000000E-2
1.200000E-1	9.349134E-1	1.000000E-2
1.399999E-1	9.477785E-1	1.000000E-2
1.599999E-1	9.593805E-1	1.000000E-2
1.799999E-1	9.698774E-1	1.000000E-2
1.999998E-1	9.794010E-1	1.000000E-2
2.199999E-1	9.880605E-1	1.000000E-2
2.399998E-1	9.959491E-1	1.000000E-2
2.599997E-1	1.003144E+0	1.000000E-2
2.799997E-1	1.009713E+0	1.000000E-2
2.999997E-1	1.015712E+0	1.000000E-2
3.199997E-1	1.021190E+0	1.000000E-2
3.399997E-1	1.026188E+0	1.000000E-2
3.599997E-1	1.030741E+0	1.000000E-2
3.799997E-1	1.034879E+0	1.000000E-2
3.999996E-1	1.038627E+0	1.000000E-2
4.199996E-1	1.042008E+0	1.000000E-2
4.399996E-1	1.045037E+0	1.000000E-2
4.599996E-1	1.047731E+0	1.000000E-2
4.799996E-1	1.050099E+0	1.000000E-2
4.999996E-1	1.052150E+0	1.000000E-2
5.199995E-1	1.053889E+0	1.000000E-2
5.399994E-1	1.055318E+0	1.000000E-2
5.599994E-1	1.056435E+0	1.000000E-2
5.799994E-1	1.057238E+0	1.000000E-2
5.999994E-1	1.057718E+0	1.000000E-2
6.199994E-1	1.057864E+0	1.000000E-2
6.399993E-1	1.057661E+0	1.000000E-2
6.599993E-1	1.057089E+0	1.000000E-2
6.799993E-1	1.056121E+0	1.000000E-2
6.999993E-1	1.054726E+0	1.000000E-2
7.199993E-1	1.052862E+0	1.000000E-2
7.399992E-1	1.050479E+0	1.000000E-2
7.599992E-1	1.047513E+0	1.000000E-2
7.799992E-1	1.043887E+0	1.000000E-2
7.999992E-1	1.039498E+0	1.000000E-2
8.199993E-1	1.034222E+0	1.000000E-2
8.399993E-1	1.027897E+0	1.000000E-2
8.599992E-1	1.020310E+0	1.000000E-2
8.799993E-1	1.011184E+0	1.000000E-2
8.999992E-1	1.000143E+0	1.000000E-2
9.199993E-1	9.866699E-1	1.000000E-2
9.399992E-1	9.700328E-1	1.000000E-2
9.599992E-1	9.491636E-1	1.000000E-2
9.799991E-1	9.224365E-1	1.000000E-2
9.999992E-1	8.872566E-1	1.000000E-2

PS=9.90(P.U.)

TABLE 4.23 (THREE PHASE FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
1.999999E-2	3.570823E-2	9.999996E-3
3.999998E-2	6.294190E-2	9.999996E-3
6.000000E-2	8.813308E-2	9.999996E-3
7.999997E-2	1.114834E-1	9.999996E-3
9.999996E-2	1.331678E-1	9.999996E-3
1.200000E-1	1.533386E-1	9.999996E-3
1.399999E-1	1.721290E-1	9.999996E-3
1.599999E-1	1.896558E-1	9.999996E-3
1.799999E-1	2.060220E-1	9.999996E-3
1.999998E-1	2.213183E-1	9.999996E-3
2.199999E-1	2.356251E-1	9.999996E-3
2.399998E-1	2.490140E-1	9.999996E-3
2.599997E-1	2.615481E-1	9.999996E-3
2.799997E-1	2.732839E-1	9.999996E-3
2.999997E-1	2.842714E-1	9.999996E-3
3.199997E-1	2.945556E-1	9.999996E-3
3.399997E-1	3.041761E-1	9.999996E-3
3.599997E-1	3.131683E-1	9.999996E-3
3.799997E-1	3.215636E-1	9.999996E-3
3.999996E-1	3.293896E-1	9.999996E-3
4.199996E-1	3.366709E-1	9.999996E-3
4.399996E-1	3.434289E-1	9.999996E-3
4.599996E-1	3.496814E-1	9.999996E-3
4.799996E-1	3.554449E-1	9.999996E-3
4.999996E-1	3.607320E-1	9.999996E-3
5.199995E-1	3.655537E-1	9.999996E-3
5.399994E-1	3.699182E-1	9.999996E-3
5.599994E-1	3.738312E-1	9.999996E-3
5.799994E-1	3.772963E-1	9.999996E-3
5.999994E-1	3.803146E-1	9.999996E-3
6.199994E-1	3.828846E-1	9.999996E-3
6.399993E-1	3.850023E-1	9.999996E-3
6.599993E-1	3.866611E-1	9.999996E-3
6.799993E-1	3.878512E-1	9.999996E-3
6.999993E-1	3.885597E-1	9.999996E-3
7.199993E-1	3.887702E-1	9.999996E-3
7.399992E-1	3.884626E-1	9.999996E-3
7.599992E-1	3.876123E-1	9.999996E-3
7.799992E-1	3.861895E-1	9.999996E-3
7.999992E-1	3.841589E-1	9.999996E-3
8.199993E-1	3.814786E-1	9.999996E-3
8.399993E-1	3.780991E-1	9.999996E-3
8.599992E-1	3.739614E-1	9.999996E-3
8.799993E-1	3.689960E-1	9.999996E-3
8.999992E-1	3.631203E-1	9.999996E-3
9.199993E-1	3.562357E-1	9.999996E-3
9.399992E-1	3.482242E-1	9.999996E-3
9.599992E-1	3.389443E-1	9.999996E-3
9.799991E-1	3.282242E-1	9.999996E-3
9.999992E-1	3.158546E-1	9.999996E-3

LINE REACTANCE=0.6(P.U.)

TABLE 4.24 (L-G FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
2.000000E-2	7.885242E-1	1.200000E-2
4.000000E-2	8.129909E-1	1.200000E-2
6.000000E-2	8.341829E-1	1.200000E-2
7.999997E-2	8.526966E-1	1.200000E-2
9.999996E-2	8.689899E-1	1.200000E-2
1.200000E-1	8.834213E-1	1.200000E-2
1.399999E-1	8.962747E-1	1.200000E-2
1.599999E-1	9.077775E-1	1.200000E-2
1.799999E-1	9.181142E-1	1.200000E-2
1.999998E-1	9.274360E-1	1.200000E-2
2.199999E-1	9.358675E-1	1.200000E-2
2.399998E-1	9.435123E-1	1.200000E-2
2.599997E-1	9.504573E-1	1.200000E-2
2.799997E-1	9.567750E-1	1.200000E-2
2.999997E-1	9.625280E-1	1.200000E-2
3.199997E-1	9.677679E-1	1.200000E-2
3.399997E-1	9.725395E-1	1.200000E-2
3.599997E-1	9.768802E-1	1.200000E-2
3.799997E-1	9.808218E-1	1.200000E-2
3.999996E-1	9.843921E-1	1.200000E-2
4.199996E-1	9.876135E-1	1.200000E-2
4.399996E-1	9.905044E-1	1.200000E-2
4.599996E-1	9.930807E-1	1.200000E-2
4.799996E-1	9.953539E-1	1.200000E-2
4.999996E-1	9.973339E-1	1.200000E-2
5.199995E-1	9.990255E-1	1.200000E-2
5.399994E-1	1.000433E+0	1.200000E-2
5.599994E-1	1.001555E+0	1.200000E-2
5.799994E-1	1.002391E+0	1.200000E-2
5.999994E-1	1.002932E+0	1.200000E-2
6.199994E-1	1.003171E+0	1.200000E-2
6.399993E-1	1.003092E+0	1.200000E-2
6.599993E-1	1.002676E+0	1.200000E-2
6.799993E-1	1.001900E+0	1.200000E-2
6.999993E-1	1.000733E+0	1.200000E-2
7.199993E-1	9.991361E-1	1.200000E-2
7.399992E-1	9.970590E-1	1.200000E-2
7.599992E-1	9.944402E-1	1.200000E-2
7.799992E-1	9.912016E-1	1.200000E-2
7.999992E-1	9.872423E-1	1.200000E-2
8.199993E-1	9.824344E-1	1.200000E-2
8.399993E-1	9.766094E-1	1.200000E-2
8.599992E-1	9.695449E-1	1.200000E-2
8.799993E-1	9.609411E-1	1.200000E-2
8.999992E-1	9.503829E-1	1.200000E-2
9.199993E-1	9.372846E-1	1.200000E-2
9.399992E-1	9.207860E-1	1.200000E-2
9.599992E-1	8.995800E-1	1.200000E-2
9.799991E-1	8.715702E-1	1.200000E-2
9.999992E-1	8.331821E-1	1.200000E-2

LINE REACTANCE=0.60(P.U.)

TABLE 4.25 (THREE PHASE FAULT)

DISTANCE IN(P.U.)	Y12 IN(P.U.)	TC IN(SEC.)
1.999999E-2	2.689722E-2	1.599998E-1
3.999998E-2	5.211728E-2	1.599998E-1
6.000000E-2	7.577588E-2	1.599998E-1
7.999997E-2	9.797655E-2	1.699998E-1
9.999996E-2	1.188118E-1	1.699998E-1
1.200000E-1	1.383647E-1	1.699998E-1
1.399999E-1	1.567096E-1	1.699998E-1
1.599999E-1	1.739130E-1	1.799998E-1
1.799999E-1	1.900347E-1	1.799998E-1
1.999998E-1	2.051281E-1	1.799998E-1
2.199999E-1	2.192410E-1	1.799998E-1
2.399998E-1	2.324158E-1	1.799998E-1
2.599997E-1	2.446902E-1	1.899998E-1
2.799997E-1	2.560974E-1	1.899998E-1
2.999997E-1	2.666665E-1	1.899998E-1
3.199997E-1	2.764226E-1	1.899998E-1
3.399997E-1	2.853871E-1	1.899998E-1
3.599997E-1	2.935778E-1	1.899998E-1
3.799997E-1	3.010092E-1	1.899998E-1
3.999996E-1	3.076922E-1	1.999998E-1
4.199996E-1	3.136345E-1	1.999998E-1
4.399996E-1	3.188404E-1	1.999998E-1
4.599996E-1	3.233111E-1	1.999998E-1
4.799996E-1	3.270439E-1	1.999998E-1
4.999996E-1	3.300328E-1	1.999998E-1
5.199995E-1	3.322683E-1	1.999998E-1
5.399994E-1	3.337364E-1	1.999998E-1
5.599994E-1	3.344192E-1	1.999998E-1
5.799994E-1	3.342940E-1	1.999998E-1
5.999994E-1	3.333334E-1	1.999998E-1
6.199994E-1	3.315042E-1	1.999998E-1
6.399993E-1	3.287672E-1	1.999998E-1
6.599993E-1	3.250762E-1	1.999998E-1
6.799993E-1	3.203771E-1	1.999998E-1
6.999993E-1	3.146070E-1	1.999998E-1
7.199993E-1	3.076927E-1	1.999998E-1
7.399992E-1	2.995489E-1	1.899998E-1
7.599992E-1	2.900768E-1	1.899998E-1
7.799992E-1	2.791611E-1	1.899998E-1
7.999992E-1	2.666673E-1	1.899998E-1
8.199993E-1	2.524378E-1	1.899998E-1
8.399993E-1	2.362877E-1	1.799998E-1
8.599992E-1	2.179934E-1	1.799998E-1
8.799993E-1	1.973104E-1	1.799998E-1
8.999992E-1	1.739142E-1	1.799998E-1
9.199993E-1	1.474371E-1	1.699998E-1
9.399992E-1	1.174280E-1	1.699998E-1
9.599992E-1	8.333503E-2	1.599998E-1
9.799991E-1	4.447665E-2	1.599998E-1
9.999992E-1	2.270647E-6	1.599998E-1

LINE REACTANCE=0.25(P.U.)

TABLE 4.26 (L-G FAULT)

DISTANCE IN(P.U.)	X12 IN(P.U.)	TC IN(SEC.)
2.000000E-2	6.216959E-1	9.999996E-3
4.000000E-2	6.377209E-1	9.999996E-3
6.000000E-2	6.542992E-1	9.999996E-3
7.999997E-2	6.675367E-1	9.999996E-3
9.999996E-2	6.817161E-1	9.999996E-3
1.200000E-1	6.938018E-1	9.999996E-3
1.399999E-1	7.043417E-1	9.999996E-3
1.599999E-1	7.152211E-1	9.999996E-3
1.799999E-1	7.247130E-1	9.999996E-3
1.999998E-1	7.334825E-1	9.999996E-3
2.199998E-1	7.415852E-1	9.999996E-3
2.399998E-1	7.490701E-1	9.999996E-3
2.599997E-1	7.559797E-1	9.999996E-3
2.799997E-1	7.623521E-1	9.999996E-3
2.999997E-1	7.682199E-1	9.999996E-3
3.199997E-1	7.736112E-1	9.999996E-3
3.399997E-1	7.785508E-1	9.999996E-3
3.599997E-1	7.830602E-1	9.999996E-3
3.799997E-1	7.871577E-1	9.999996E-3
3.999996E-1	7.908584E-1	9.999996E-3
4.199996E-1	7.941753E-1	9.999996E-3
4.399996E-1	7.971183E-1	9.999996E-3
4.599995E-1	7.996955E-1	9.999996E-3
4.799996E-1	8.019115E-1	9.999996E-3
4.999995E-1	8.037696E-1	9.999996E-3
5.199995E-1	8.052709E-1	9.999996E-3
5.399994E-1	8.064138E-1	9.999996E-3
5.599994E-1	8.071929E-1	9.999996E-3
5.799994E-1	8.075923E-1	9.999996E-3
5.999994E-1	8.076320E-1	9.999996E-3
6.199994E-1	8.072592E-1	9.999996E-3
6.399993E-1	8.064977E-1	9.999996E-3
6.599993E-1	8.052967E-1	9.999996E-3
6.799993E-1	8.036420E-1	9.999996E-3
6.999993E-1	8.015947E-1	9.999996E-3
7.199993E-1	7.988431E-1	9.999996E-3
7.399992E-1	7.956309E-1	9.999996E-3
7.599992E-1	7.918019E-1	9.999996E-3
7.799992E-1	7.873097E-1	9.999996E-3
7.999992E-1	7.820555E-1	9.999996E-3
8.199993E-1	7.759795E-1	9.999996E-3
8.399993E-1	7.690671E-1	9.999996E-3
8.599992E-1	7.608111E-1	9.999996E-3
8.799993E-1	7.515952E-1	9.999996E-3
8.999992E-1	7.408371E-1	9.999996E-3
9.199993E-1	7.285261E-1	9.999996E-3
9.399992E-1	7.142983E-1	9.999996E-3
9.599992E-1	6.975460E-1	9.999996E-3
9.799991E-1	6.780349E-1	9.999996E-3
9.999992E-1	6.550083E-1	9.999996E-3

LINE REACTANCE=0.25(P.U.)

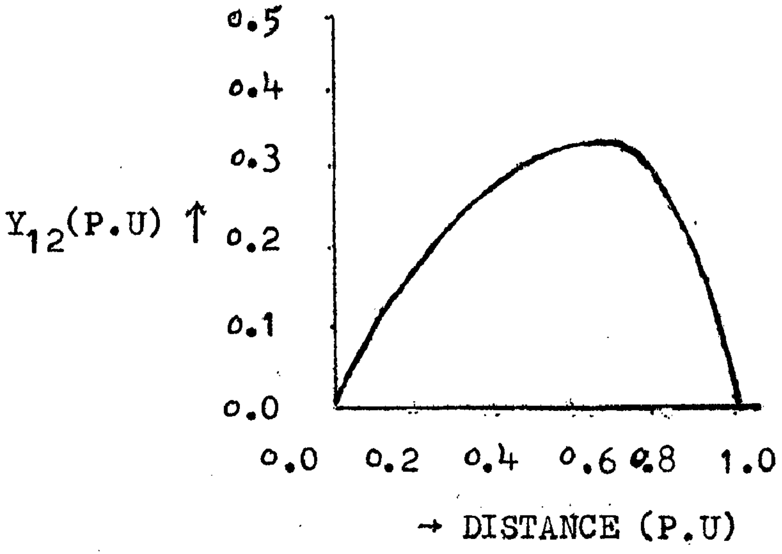


Fig.4.8 VARIATION IN TRANSFER ADMITTANCE WITH THE DISTANCE OF THE FAULT FROM SENDING END

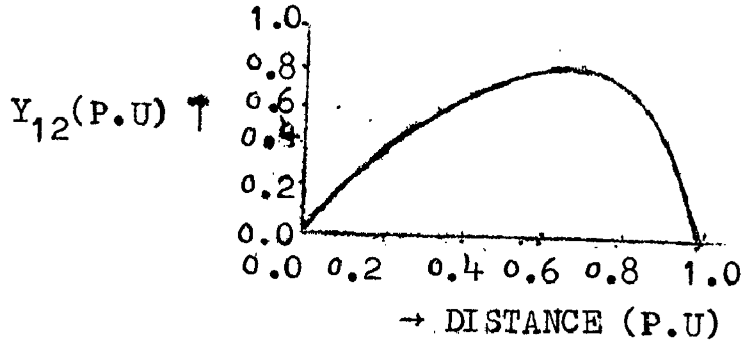


Fig.4.9 VARIATION IN TRANSFER ADMITTANCE WITH THE DISTANCE OF THE FAULT FROM SENDING END

Table 4.27

Probability distribution function of transfer admittance

(For symmetrical fault)

Transfer Admittance Y_{12} (P.U.)	Probability $(Y > y_{12})$
0 .1	0.9837
0 .15	0.9699
0 .20	0.9520
0 .25	0.9045
0 .30	0.8148
0 .35	0.6271
0 .36	0.5558
0 .37	0.4967
0 .38	0.2922
0 .385	0.1694

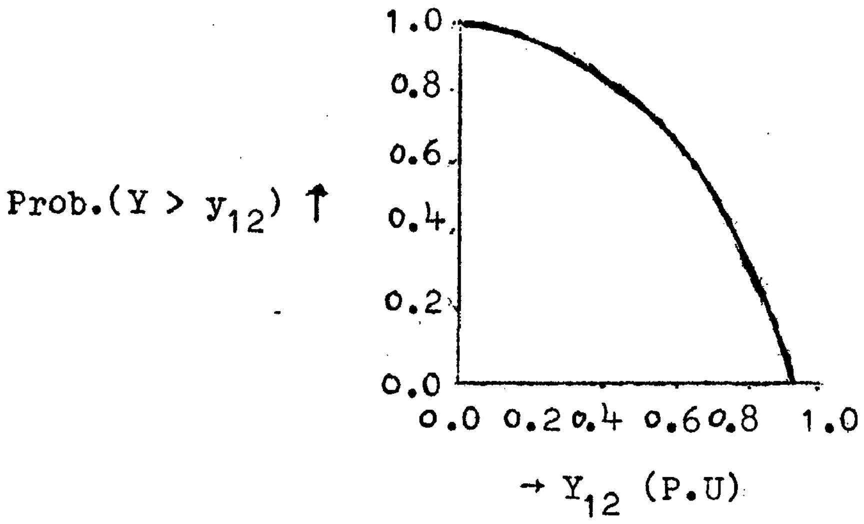


Fig.4.10 PROBABILITY DISTRIBUTION FUNCTION OF TRANSFER ADMITTANCE

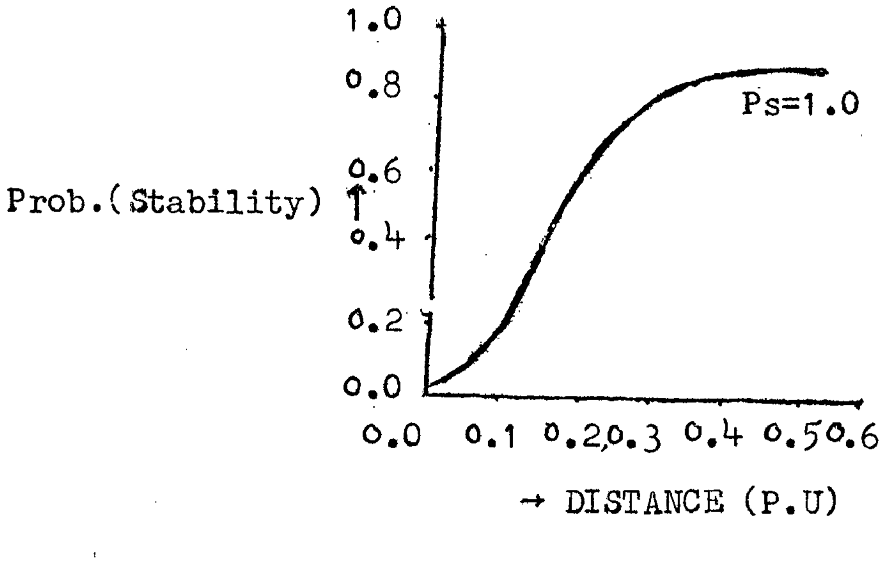


Fig.4.11 EFFECT OF THREE PHASE FAULT ON THE PROBABILITY OF STABILITY

Table 4.28

Effect of fault location on probability of stability

(For symmetrical fault)

Distance (P.U.)	Probability of stability
0.1	0.1978
0.15	0.3729
0.20	0.5138
0.25	0.6919
0.30	0.8446
0.35	0.9349
0.5	0.9715
0.53	0.9765
0.55	0.9789
0.56	0.9799
0.58	0.9816

Table 4.29

Effect of Faults on Prob. (Stability)

Power (Ps) in (P.U.)	Probability of Stability			
	L-L-L fault	L-L-G fault	L-L fault	L-G fault
0.35	0.9978	0.9988	0.9998	0.9998
0.4	0.9899	0.9975	0.9981	0.9988
0.5	0.7988	0.9972	0.9979	0.9985
0.6	0.41211	0.9969	0.9962	0.9983
0.7	0.01355	0.8721	0.9953	0.9982
0.8	0.00129	0.7995	0.9944	0.9980
0.9	0	0.3998	0.8398	0.9879
1.0	0	0.0178	0.0035	0.9775

Table 4.30

Fault clearing time (Symmetrical fault)

Power (Ps) in (P.U.)	Probability of stability when fault clearing time		
	3 cycles	5 cycles	10 cycles
0.6	0.9990	0.9989	0.8397
0.7	0.9988	0.9987	0.7599
0.8	0.9985	0.9985	0.1885
0.9	0.9983	0.7885	0.0
1.0	0.0	0.0	-

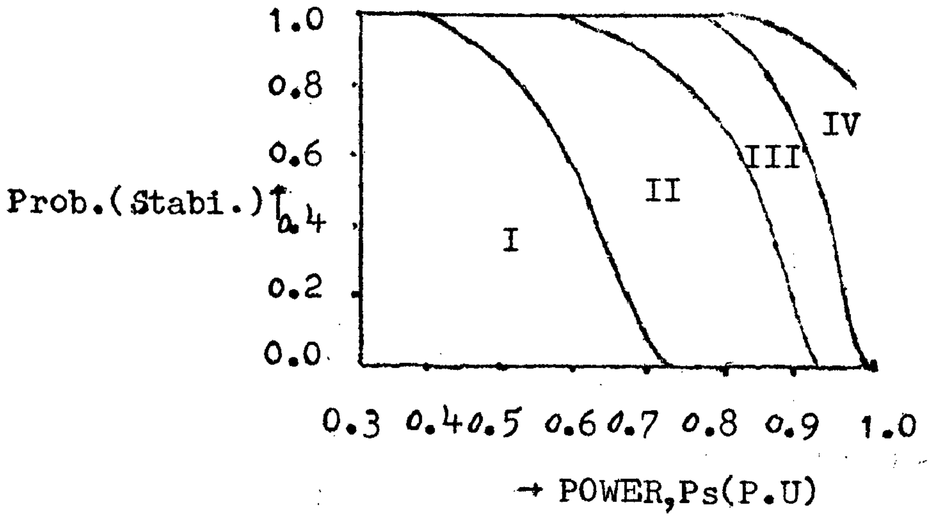


Fig.4.12 EFFECT OF THE TYPES OF FAULT

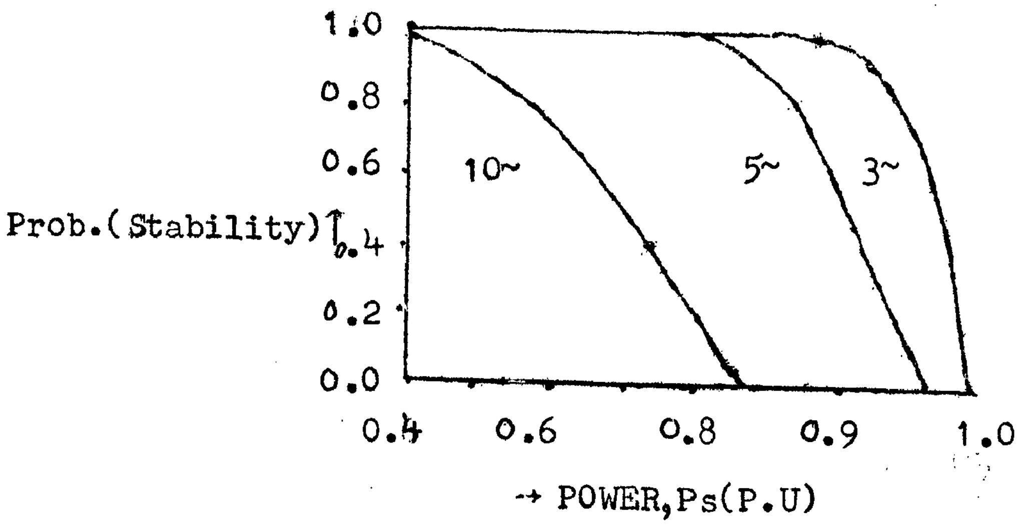


Fig.4.13 EFFECT OF FAULT CLEARING TIME

Table 4.31

Effect of Machine Inertia on Prob. (Stability)

Power (Ps) in (P.U.)	Probability of stability		
	H=1.5(P.U)	H=3.0(P.U)	H=6.0(P.U)
0.6	0.9888	0.9988	0.9998
0.7	0.9012	0.9985	0.9995
0.8	0.7814	0.9982	0.9989
0.9	0.0138	0.8957	0.9987
9.5	0.0	0.0127	0.8543
1.0	0.0	0.0	0.0

Table 4.32

Addition of parallel transmission lines

Power (Ps) in (P.U.)	Probability of stability	
	X_L=.5(P.U)	X_L=.25
0.6	0.9988	0.9998
0.7	0.9985	0.9997
0.8	0.9982	0.9995
0.9	0.8957	0.9989
1.0	0.0	0.9987

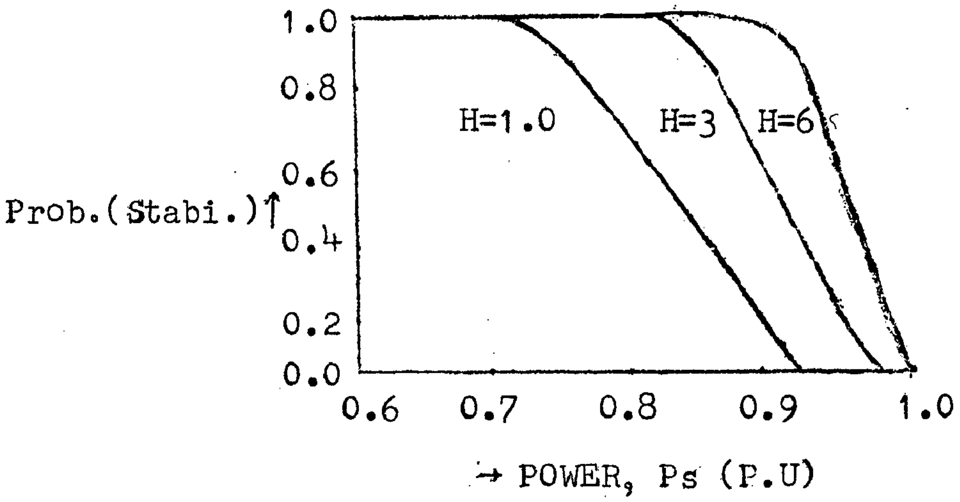


Fig.4.14 EFFECT OF MACHINE INERTIA CONSTANT ON PROBABILITY OF STABILITY

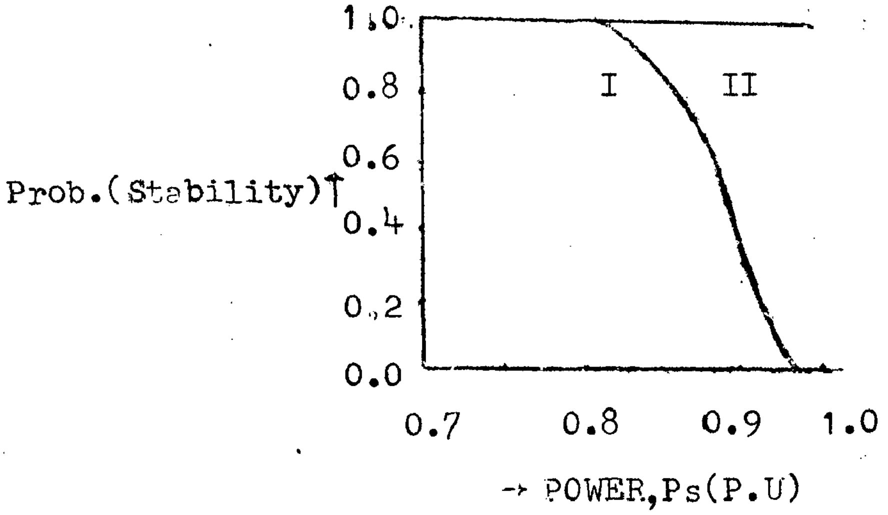


Fig.4.15 EFFECT OF NUMBER OF PARALLEL TRANSMISSION LINES ON PROBABILITY OF STABILITY

4.4 Comments on Results:

Following are the comments on the various Results obtained for system examples:

4.4.1 Comments on results for system example 1: Results obtained for the system example 1 are tabulated in table 4.2 for different types of fault, on various sections of this system. The various current values corresponding to the respective types of faults are shown in Fig.4.6. The fault which draws the highest current is asymmetrical fault. Fault calculations are carried out by [6] using asymmetrical fault calculations method. With the unbalance case and sequence component for the system are shown in Fig.4.6. Even with the assesment due to the spreading of fault current, the unbalancing imposes a severe strain on the generating machines, in both way mechanically as well as thermally. The currents in healthy phases of the line are due to a non-proportionality in the sequence impedance values. If both the sections had the same ratio of sequence impedances, there would be no current in healthy phase of the system. It is perhaps, some what unexpected that the current in each phase, for the phase to phase fault should be less than for the line to ground fault. The absence of the zero sequence component accounts for this reduction in severity. The fault currents in the generator windings are dangerous to the machine, because they amount virtually to single phase currents.

The three phase short circuit needs little comment for the explanation, except to say that it is frequently taken as the worst possible case with very small probability of occurrence (Appendix-I). The calculations show for the postulated conditions, this assumption to be fallacious. By and large, with occurrence, it can be taken to be the least severe case where directly grounded networks are used. Because of the combined phase and ground faults, which is the worst case among all the asymmetrical fault cases, if once the severity of the single-line-ground fault is appreciated, the result will not be surprising.

The knowledge of the currents in several branches of a network under the different possible fault conditions which permits the selection of different operating and protective devices and enables a check on the different capacity of the devices to be made, which also furnishes a warning for the application of unsuitable equipments for the power system.

4.4.2 Comments on results for system example 2: The results obtained for the system example 2 are given in Tables 4.27 - 4.32. The detailed analysis with the effect of different variables is as follows. The probability distribution with the transfer admittance (Y_{12}) is given in table 4.26 and curve is shown in Fig.4.8 for the three phase fault. The probability ($Y \geq y_{12}$) decreases unity to zero when transfer admittance (Y_{12}) increases from zero to its maximum value.

In similar way the characteristics are obtained for asymmetrical faults. The probability distribution corresponding to the variation of transfer admittance values are studied.

The effect of the fault location on stability Index has been studied for the three phase fault. The fault clearing time is assumed to be normally distributed with the mean value of distance 0.5 P.U. and standard deviation is taken as .2 P.U. for the base value. The location of fault is varied from zero to 1.0 (P.U) value of line length. The table 4.27 shows the results for given system data and for the Ps = 1.0 P.U. The curve is shown in Fig.4.11. That probability of stability increases with increase in distance from the generator location. When the value of Ps is decreased the value of probability increases and reaches to unity.

The result obtained for different types of fault in terms of probability of stability for the different values of Ps. The results are given in Table 4.29, it is clear that probability of stability is very much dependent on the fault type the severity of the fault increases from a single line to ground fault to three phase fault. The comparative study of these results is shown by the curve from Fig.4.12.

For all the types of fault it is assumed that clearing time is to be normally distributed with mean value 5 cycles (based on 50 Hz) and with a 10 % standard deviation of the mean value. The different curves of Fig.4.10 are shown for the three phase fault, double line to ground line to line and line to ground faults respectively.

The fault clearing time also affect the probability of stability. The results with effects of such random variables are given in table 4.30. The curves are given in fig.4.13 clarified the effect as the fault clearing time varies from 3 cycles to 10 cycles. The probability of stability varies from unity to zero with increasing of Ps value. As the clearing time is increased the probability of stability for a given power level is decreased.

Machine inertia constant H affect the critical clearing time, it is some what directly proportional to the square root of machine inertia constant. The results with variation of this variable H are given in table 4.31. The curve 4.14 is drawn for probability of stability verses Ps. The probability of stability increases with increased H. This improvement is the marginal one with the higher values of Ps and H. Improvement of machine inertia constant is the best for improvement of system stability.

The index — provide the practical justification for the system example results with the effect of addition of more number of parallel transmission line circuits are given in table 4.32 and curves are shown in fig.4.15. Curve I is corresponding to the base values and curve II is corresponding with the new data after the addition of transmission line. Both these curve provide a comparative and comprehensive study of a system before and after addition of transmission line in parallel, with the system circuit. When one transmission line circuit is connected parallel with the base circuit the probability of stability is very close to unity when the value of Ps is unity. There it is concluded that by the addition of transmission line circuit in parallel the stability of system is increased under the transient conditions.

The above discussion and system examined in this chapter has been with in limits set for comprehensive study but explains the variability of the random variables e.g. fault type and fault location. For more complicated system where all the parts of informations are required for judicious use of network reduction which makes the problem meaningful and useful for the power system transient stability studies.

CHAPTER-V

CONCLUSIONS AND SUGGESTIONS

It is concluded from the results for fault calculations that fault severity increases from single line to ground fault to three phase fault and severity of fault is also stringent near the slack bus i.e. severity also increases when fault location is shifted from receiving end section towards the sending end section of the system. The analysis of the results presented in chapter-IV provides a comprehensive study of these fault calculations for the different types of fault and their location. This analysis is more or less helpful for the explanation of system example 2 , which uses probabilistic considerations. The detailed analysis for system example 2 for probability of stability verified the results, although the values of probability indices are calculated for probability of stability, but risk index may be obtained by the application of relations of chapter II. The proposed approach may be used to obtain the critical areas for the transient stability either as probability of stability or, as probability of instability.

The most critically analysed results of probability of stability in the form of Index with some certain levels can be used to examine the results for both the types of fault e.g. symmetrical type fault as well as asymmetrical types of fault.

These results obtained by new approach are useful for initial planning studies where the solution for power system problems incorporating to probabilistic assessment is adequately required. Further, the stability evaluation by deterministic methods provide a conservative assessment with the application of probabilistic approach the specific types of probability distributions are used to analyse the practical system from Mohamadpur to Ram Nagar (Roorkee). The available data has been used for the calculation of the Index(table) for probability of fault occurrence the approach.

Further this approach can be extended for the complicated systems and from the practical data available for a long duration for the system the realistic distribution can be obtained for different contingencies. The application of these data used to determine the proper distribution which will naturally provide more realistic results for the assesment of the transient stability. With the reliable data or statistics for the fault clearing devices e.g. protective schemes including circuit breakers, relay and back up protection etc., will be helpful to determine the distribution function for fault clearing time t_1 and fault critical clearing time t_c.

Following are the areas in which the work may be extended and the results thus obtained will be of great use to power system engineers:

(1) In the present work fault impedance has been neglected

but by considering the fault impedance the results will differ.

(2) The approach may be extended to multimachine systems. Though it may be difficult to develop exact method, therefore even if the approximate methods are developed it will be a good addition to the literature in the area of power system stability study.

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* * *

APPENDIX - I

For System Example 2:

Mohamadpur Hydro-Power Station to Ram Nagar, Roorkee, distribution Centre. The parameters of the study system components are:

(a) Generator:

Voltage behind the transient reactance = 1.20 P.U.

Inertia constant (K-W-Sec/KVA) H = 3.0

Rated current transient reactance, Xd' = 0.3 P.U.

Negative Sequence Reactance X_2 = 0.25 P.U.

Zero Sequence Reactance X_0 = 0.05 P.U.

(b) Transformers:

Positive Sequence Reactance = Negative Sequence
= Zero Sequence Reactance

$X_1 = X_2 = X_0 = 0.1$ P.U.

(c) Transmission line:

Positive Sequence Reactance = Negative Sequence Reactance
= 0.5 P.U.

Zero Sequence Reactance = 1.0 P.U.

Voltage at the infinite bus = 1.0 P.U.

The single line diagram of this system is given in Fig.4.7. The failure statistics for this system is given in table I(1). All the values are taken in P.U. based on the rating of the generating machine G.

System Generating Capacity = 9.3 M.W.

66 KV Double Circuit Line.

Length of Line = 20 Kms.

(From power station to Ram Nagar (Roorkee distribution Centre).

OCB1 Number 63.

OCB2 Number 64.

Table -I(1)

Fault Data For (1976-1979) Years

S.No.	Type of fault	I Zone Circuit		II Zone Circuit		III Zone Circuit		Total No. of Fault	Frequency ~~(CPS)~~ (per yr)
		I	II	I	II	I	II		
1	L-L-L	0	0	1	1	0	0	2	0.25
2	L-L-G	0	0	1	1	2	0	4	0.50
3	L-L	1	1	2	2	4	0	10	1.25
4	L-E	3	8	6	3	8	2	30	3.50

Table - I(2)

Incidence of different types of faults

S.No.	Type of fault	% of fault	Probability
1	L-L-L	6.25	0.04667
2	L-L-G	17.50	0.13069
3	L-L	16.40	0.12248
4	L-G	93.75	0.70015

Sum of all the probability values = 0.9999

APPENDIX - II (A)

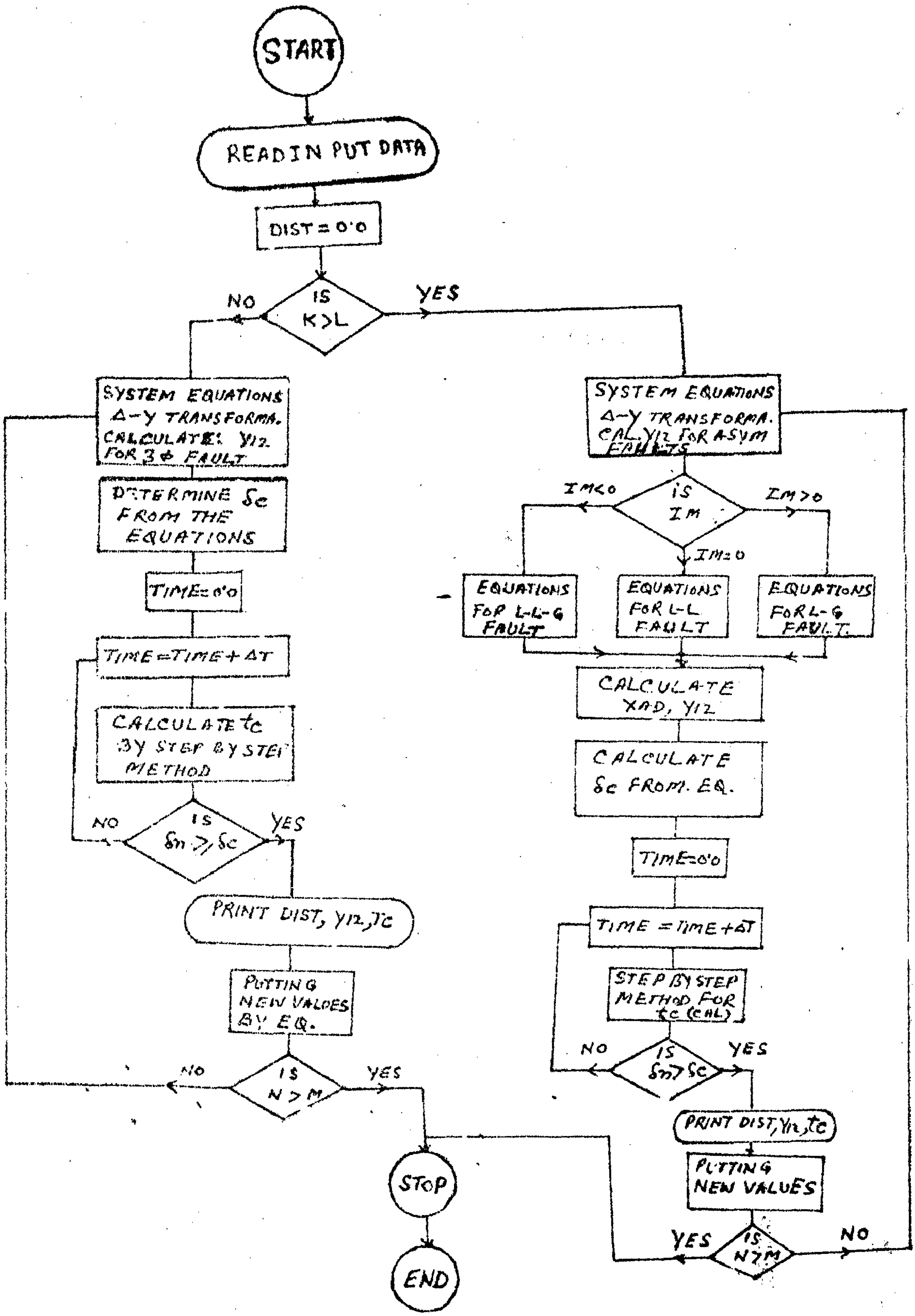

FIG-II(A) FLOW CHART FOR TRANSIENT STABILITY STUDY

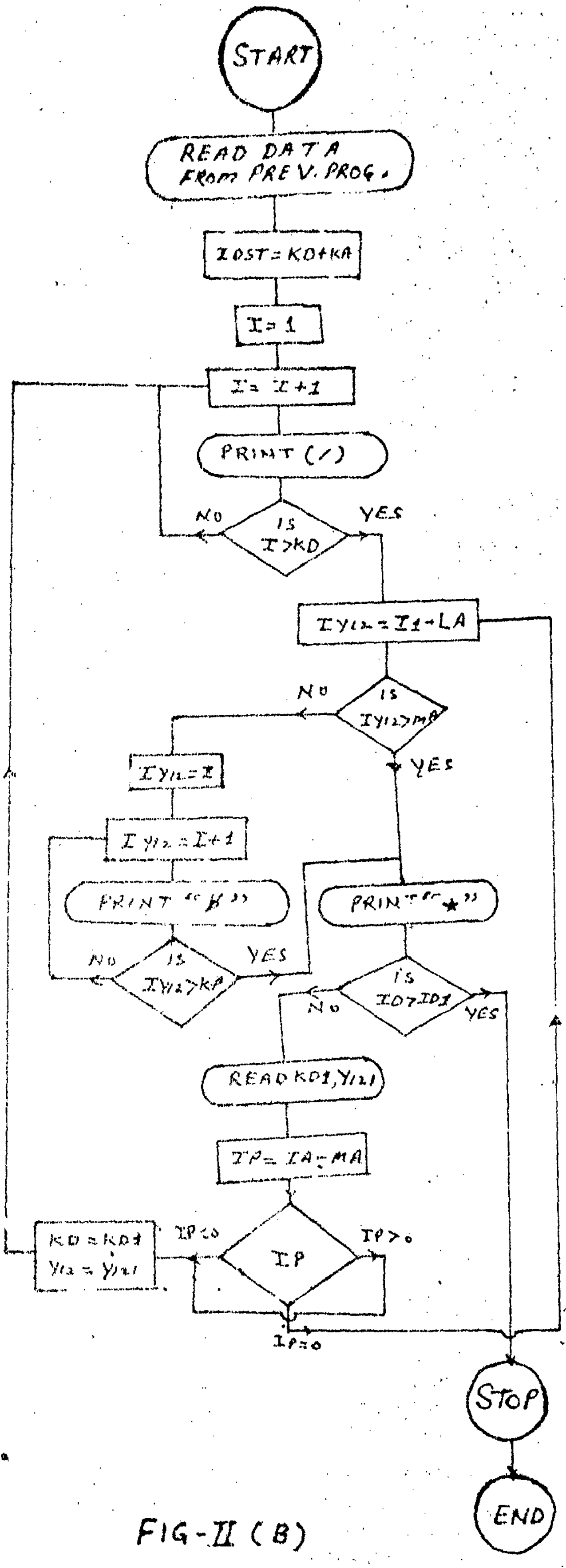

FIG-II (B)

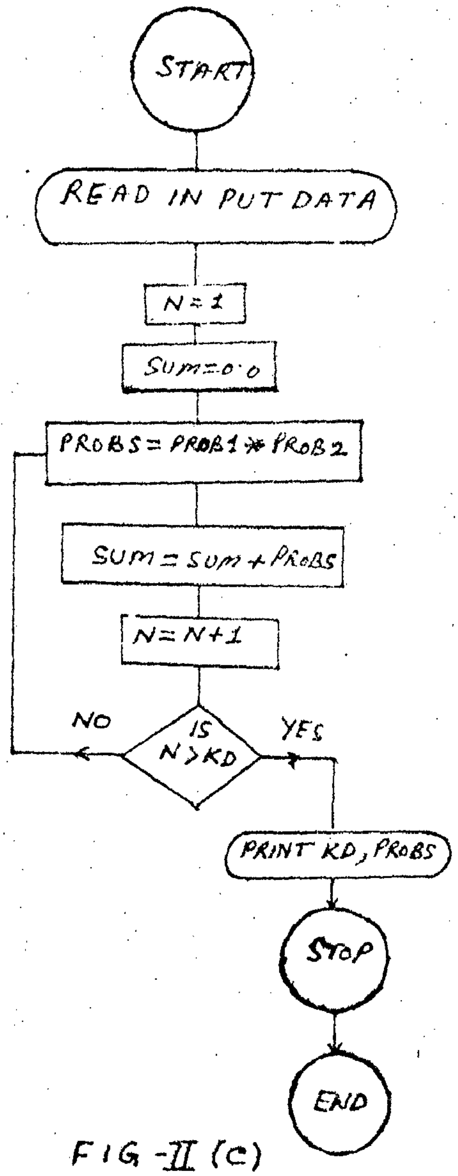

FIG-II (C)

FLOW CHARTS FOR TRANSIENT STABILITY STUDY.

APPENDIX-II(B)

COMPUTER PROGRAM FOR TRANSIENT STABILITY STUDY.

```
      COMMON XG,XI,XTR,EG,EI,XBC,XBN,XCN,AG,AF,PS,XINTV,DINTV
     6,XINTR,XG2,XI2,XBC2,XBN2,XCN2,XG0,XI0,XBC0,XBN0,XCN0
C     N=1,2,3 ASYM FAULT
C     N=4-THREE PHASE FAULT
C     RPSHARMA/PSE/EED/1980/TC.CALCUL./COMPUTER PROG. FOR STABI. CAL
      AH=1.0
 80   N=0
 99   N=N+1
      OPEN(UNIT=2,DEVICE='DSK',FILE='STABI.DAT')
 55   READ(2,222),XG,XI,XTR,EG,EI,XBC,XBN,XCN,AG,AF,PS,XINTV,DINTV,
     4 XINTR,XG2,XI2,XBC2,XBN2,XCN2,XG0,XI0,XBC0,XBN0,XCN0
      READ(2,223),K,M
223   FORMAT(2I5)
222   FORMAT(7F10.6)
      IF(N-4)11,12,12
 11   DO60 IT=1,K
      CALL ASYCAL
      GO TO 13
 12   DO 60 JT=1,K
      CALL SYMCAL
 13   PM=(EG*EI)/X1
      R=R1
      S=R2
      RPMD=(EG*EI)/XAD
      PI=3.14159
      R=((EG*EI)/XAD)/PM
 30   S=((EG*EI)/X2)/PM
      DELO=ATAN(PS/SQRT(PM*PM-PS*PS))
      SPMD=(EG*EI)/X2
      DELM=ATAN(PS/SQRT(S*PM*S*PM-PS*PS))
      DELM=3.14159-DELM
      DIST=DIST+0.02
      RELO=DELO
      RELM=DELM
      Y=R*COS(DELO)
      Z=S*COS(RELM)
      B=S-R
      C=X-Y+Z
      PE=R*PM*SIN(DELO)
      DELC=ATAN(SQRT(B*B-C*C)/C)
      T=3.14159
      DELOD=DELO*180.0/T
      DELMD=DELM*180.0/T
      DELCD=DELC*180.0/T
      DELO=ATAN(PS/SQRT(PM*PM-PS*PS))
      TIMEO=0.0
      PEN=1.0
      PAN=0.0
      SITA=0.0
```

```
      RAM=0.0
      DLNN=DELO*180.0/PI
      TIME1=0.0
  132 PEP=R*PM*SIN(DELO)
      PAP=PS-PEP
      DENP=DELO*180.0/PI
      SHIV=0.0
      GORI=0.0
      TIME2=0.0
      AM=AG*AH/(180.0*AF)
      DT=0.01
      AKO=DT*DT/AM
      PE=R*PM*SIN(DELO)
      PA1=PS-PE
      PAV=PA1*0.5
      AK1=AKO*PAV
      DLTN1=0.0+AK1
      PEHM=0.0
      DELNV=DELO*180.0/PI
      DLT=0.01
      AKS=DLT*DLT/AM
      PE=R*PM*SIN(DELO)
      PAS=PS-PE
      PAV1=PAS/2.0
      AK5=AKS*PAV1
      DLTN5=0.0+AK5
   29 DO 50 J=1,M
      TIME7=TIME7+0.01
      DLN=DELO+AK1*PI/180.0
      DLN1=DLN*180.0/PI
      PE6=R*PM-SIN(DLN)
      PA6=PS-PE6
      AK6=AKO*PA6
      DLN2=AK1+AK6
      DELO=DLN
      AK1=DLN2
      IF(DLN1-DELC)29,39,39
   50 CONTINUE
   39 PRINT151,DIST,Y12,TIME7
  151 FORMAT(3F10.6)
      XBC=XBN+XCN
      XBN=XBC-XCN
      XBN=XBN+XINTR
      XCN=XBC-XBN
      XBN2=XBN2+XINTR
      XCN2=XBC2-XBN2
      XBC2=XBN2+XCN2
      AXTR=2.0*XINTR
```

```
      XBNO=XBNO+AXTR
      XCNO=XBCO-XBNO
      XBCO=XBNO+XCNO
   60 CONTINUE
      IF(N-5)44,77,77,
   44 GO TO 99
   77 IF(AH-12)78,78,79
   78 AH=AH+2
      GO TO 80
   79 STOP
      END


      SUBROUTINE ASYCAL
C     RPSHARMA/PSE/EED/1980/ASYFAULTCAL/COMP. PROG. FOR STABI.CAL.
       COMMON XG,XI,XTR,EG,EI,XBC,XBN,XCN,AG,AF,PS,XINTV,DINTV
     6,XINTR,XG2,XI2,XBC2,XBN2,XCN2,XGO,XIO,XBCO,XBNO,XCNO
   10 X1=XG+XI+XTR/2.0
      X2=XG+XI+XTR
      TIME7=0.0
      DIST=0.0
      A=XBC+XBN+XCN
      XBO=(XBC*XBN)/A
      XCO=(XCN*XBC)/A
      XNO=(XBN*XCN)/A
      XAO=(XG+XBO)
      XDO=(XCO+XI)
      A2=XBC2+XBN2+XCN2
      XBO2=(XBC2*XBN2)/A2
      XCO2=(XCN2*XBC2)/A2
      XNO2=(XBN2*XCN2)/A2
      XAO2=(XG2+XBO2)
      XDO2=(XCO2+XI2)
      XPGI=(XAO2*XDO2)/(XAO2+XDO2)
      X2F=XNO2+XPGI
      AO=XBCO+XBNO+XCNO
      XBOO=(XBCO*XBNO)/AO
      XCOO=(XCNO*XBCO)/AO
      XNOO=(XBNO*XCNO)/AO
      XAOO=(XGO+XBOO)
      XDOO=(XCOO+XIO)
      XOGI=(XAOO*XDOO)/(XAOO+XDOO)
      XOF=XNOO+XOGI
      GO TO(517,521,585),N
  517 XLG=X2F+XOF
      XNOF=XNO+XLG
      GO TO 601
  521 XLL=X2F
      XNOF=XNO+XLL
      GO TO 601
  585 XLLG=(X2F*XOF)/(X2F+XOF)
      XNOF=XNO+XLLG
```

```
 601  XAD=((XAO*XNOF)+(XAO*XDO)+(XDO*XNOF))/XNOF
      Y12=1.0/XAD
      PRINT666,XAD,Y12,DIST
 666  FORMAT(3F10.6)
      RETURN
      END
P

      SUBROUTINE SYMCAL
 C    RPSHARMA/PSE/EED/1980/SYMFAULTCAL/COMP.PROG.FOR STABI.CAL.
       COMMON XG,XI,XTR,EG,EI,XBC,XBN,XCN,AG,AF,PS,XINTV,DINTV
     6,XINTR,XG2,XI2,XBC2,XBN2,XCN2,XGO,XIO,XBCO,XBNO,XCNO
  10  X1=XG+XI+XTR/2.0
      X2=XG+XI+XTR
      TIME7=0.0
      DIST=0.0
      A=XBC+XBN+XCN
      XBO=(XBC*XBN)/A
      XCO=(XCN*XBC)/A
      XAO=(XG+XBO)
      XNO=(XBN*XCN)/A
      XDO=(XCO+XI)
  20  XAD=((XAO*XNO)+(XAO*XDO)+(XDO*XNO))/XNO
      Y12=1.0/XAD
      DIST=DIST+DINTV
      PRINT666,XAD,Y12,DIST
 666  FORMAT(3F10.6)
      RETURN
      END


 C    RPSHARMA/PSE/EED/UOR/1980/CURVE PLOTTING BY COMPUTER
      N=0
      READ 101,DIST,Y12
 101  FORMAT(2F10.6)
      READ 102,DINTV,YDNTV,AR,AK
 102  FORMAT(4F10.6)
      READ 105,M
 105  FORMAT(I5)
  10  DO 515 I=1,DIST
      PRINT 501
 515  CONTINUE
      IY12=Y12-YDNTV
 525  IF(IY12-AR)519,315,315
 315  DO 517 I=1,IY12
      PRINT 505
 517  CONTINUE
 519  PRINT 707
```

```
      READ DIST1,Y121
      Y121=Y121*AK
      IF(DIST-DIST1)60,65,60
 60   IDIST=DIST1-DIST+DINTV
      DIST=DIST1
      Y12=Y121
      GO TO 10
 65   IY12=Y121-Y12+YDNTV
      DIST=DIST1
      Y12=Y121
501   FORMAT(/)
505   FORMAT(1H/)
707   FORMAT(1H*)
      N=N+1
      IF(N-M)3,5,5
  3   GO TO 525
  5   STOP
      END
```

****