OPTIMAL SEQUENCE OF SWITCHING COMPENSATORS FOR SYSTEM STABILITY IMPROVEMENT

A DISSERTATION

Submitted in partial fulfilment of
the requirements for the award of the Degree
of
MASTER OF ENGINEERING
in
ELECTRICAL ENGINEERING (POWER SYSTEM ENGINEERING)

By
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CERTIFICATE

Certified that the thesis entitled "OPTIMAL SEQUENCE OF SWITCHING COMPENSATORS FOR SYSTEM STABILITY IMPROVEMENT", being submitted by Shri A. K. Jain in partial fulfilment of the requirements for the award of the degree of MASTER OF ENGINEERING IN ELECTRICAL ENGINEERING (POWER SYSTEM ENGINEERING), of the University of Roorkee, Roorkee is a record of candidate's own work carried out by him under our supervision and guidance. The matter embodied in this thesis has not been submitted for award of any other Degree or Diploma. The candidate has worked for about two years from January, 1979 to January, 1981 in preparing this dissertation, at this University and outside.

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ABSTRACT

Single Machine connected to infinite bus with two tie-lines is considered to study the effect of reactance on the system at different conditions. Different conditions here is meant by steady state, transient state (during fault) and Post fault. In steady state, it has been proved that the introduction of reactance (certain Value) enhances the stability region.

For during fault and post fault study on Operating Point has been chosen and the fault has been made to occur at machine terminal itself i.e. very near to the bus in one of the lines. The most severe fault i.e. 3 Phase fault has been considered.

It has been observed that during fault the system remains in step and after clearance of the fault if the system is left like that i.e. no introduction of reactance is made the system goes out for both the cases i.e. after fault if both the tie-lines are assumed to be commissioned or only one line is assumed to be commissioned. This condition can be avoided by switching suitable value of reactance at the time of clearance of the fault and it will reamin in the system till the oscillation is damped out. After that the system will be brought back to the original condition. That is to say the suitable value of reactances are to be switched in and switched out at proper interval of time.

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CONTENTS

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NOMENCLATURE

All quantities in per unit on machine base.

i_d, i_q	armature current, direct and quadrature axis components.
e_d, e_q	armature voltage, direct and quadrature axis components.
e_t	terminal voltage.
E'_q	voltage proportional to direct axis flux linkages
E_{fd}	generator field voltage (one per unit is the value for 1 per unit terminal voltage on the air gap line, open circuit).
X_e	external reactance .
r_e	external resistance.
r_a	armature resistance.
S	Laplace operator.
δ	angle between quadrature axis and infinite bus.
$p\delta$	per unit speed deviation from synchronous.
T_e	electrical torque.
T_m	Mechanical torque.
H	**Inertia** constant, seconds.
M	**Inertia** coefficient = 2H, Seconds.
D_m	damping coefficient.
E	infinite bus voltage.

Subscript O means steady-state value.
Prefix Δ indicates small change.
Dots over the symbol denote the number of differentiation w.r.t. time.

Other symbols used have the usual meaning.

CHAPTER - I

REVIEW OF LITERATURE

INTRODUCTION

Recently there has been considerable attention given to improvement of system stability by excitation control [1-2] or by Controlled switching of system impedances [3-4].

In ref [1] the phenomena of stability of synchronous machines under small perturbations has been examined by taking the case of a single machine connected to a large system through external impedance. The object of this paper is to develop insights into the effects of excitation systems and to establish an understanding of the stabilizing requirements for such systems. A liniarized small perturbation relations of a single generator supplying an infinite bus through external impedance in the form of a block diagram has been discussed. The same block diagram has been used in this work also. The only difference is that there are two new vectors Z and W which will come into picture in case of system disturbance only.

In ref [2], the analysis of ref [1] has been extended . The change of the parameters K_1 to K_6 of the block diagram describing the system has been investigated for different loading and power factors. A general conclusion about the variation of such parameters by changing the operating conditions has been drawn, which is an important factor in dynamic stability study. Here in this work the change in K_1 to K_6 has been seen for different loading conditions at different system reactances. This will be clear in Chapter III of this dissertation. Where a table of results has been shown.

Switching of series capacitors upon occurrence of a disturbance improves the system stability [3]. The same idea can be utilised in this work also.

Improvement in the system stability can be achieved by making changes in the network in different way in different conditions [4]. An optimal sequence can be determined for making changes in the network.

PRESENT WORK

Here in this work the system considered is single machine connected to infinite bus with two tie-lines. The effect of reactance on this system at different conditions has been studied.

In Chapter II the formulation is reported.

In Chapter III , it has been proved that the introduction of reactance (certain value) enhances the stability region in steady state.

In Chapter IV the transient stability study has been done. System differential equations has been derived. Runge-Kutta fourth order technique has been applied to solve these equations. A programme has been developed (which is given in the appendices) on EC-75P 72 Steps programmable Calculator. During fault and post fault, study has been done. For this an operating point has been selected. For this particular operating point it has been seen that the system goes unstable after clearance of the fault. This situation can be avoided by switching suitable value of reactance at the time of clearance of the fault and this reactance will remain in the system till the oscillation is damped out. After oscillation is damped out the reactances will be switched out from the system.

In Chapter V the Lyapunov technique has been utilised to check the stability of the system.

CHAPTER II

FORMULATION OF THE PROBLEM

Figure 1 shows the block diagram of a single machine supplying an infinite bus through external impedance. The analysis of the phenomena of stability of synchronous machines under small perturbations as examined by Demello and Concordia [1], has been utilised.

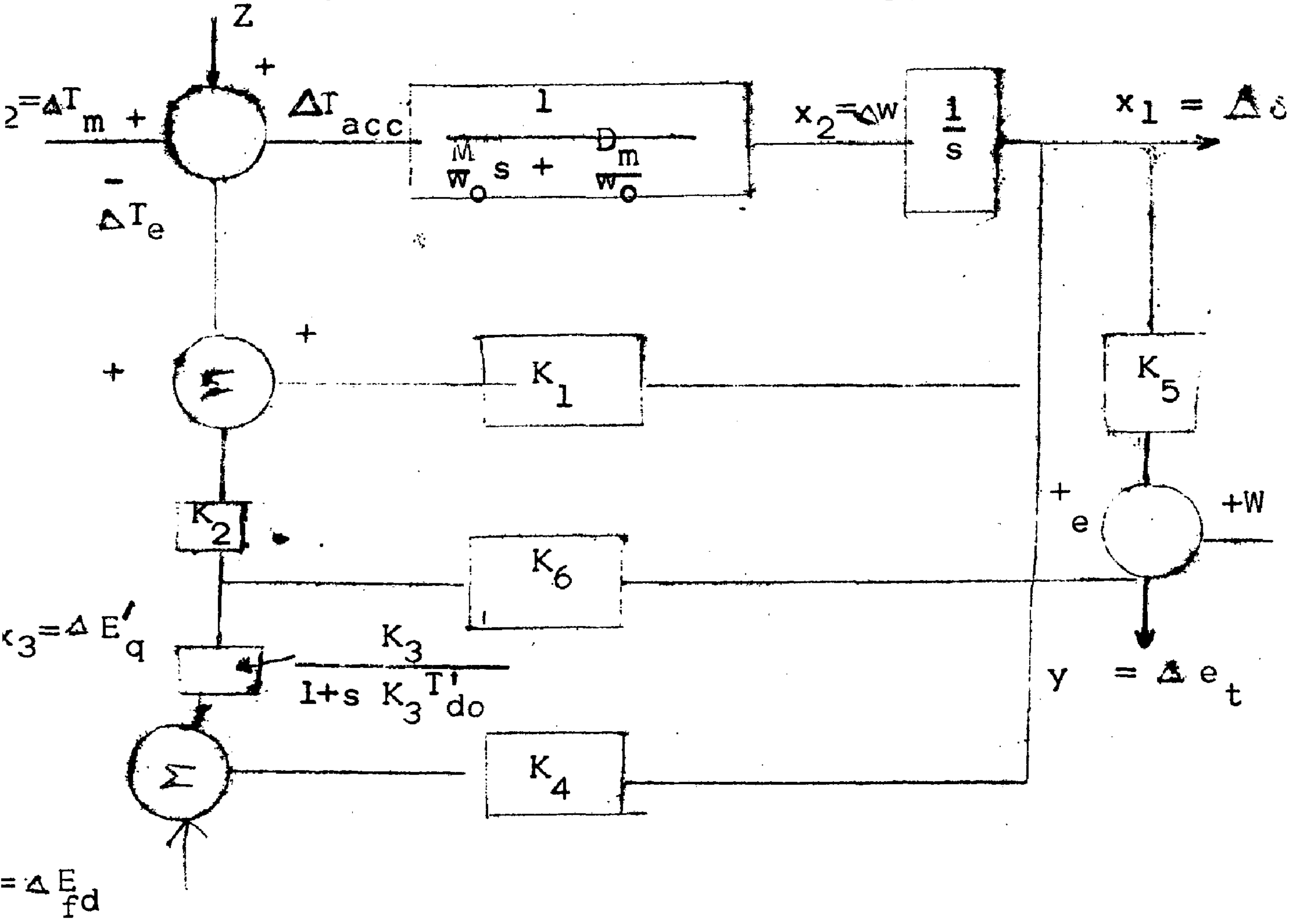


Fig. 1

Here Z and W will come into picture in case of disturbance only.

Let us assume $x_1 = \Delta\delta$, $x_2 = \Delta w$ and $x_3 = \Delta E_q'$

x_1, x_2 , x_3 are the three states of the system.

Therefore it can be written that:

$$\frac{x_2}{s} = x_1$$

$$\therefore \quad \dot{x}_1 = x_2 \qquad (1)$$

Then $\Delta T_e = K_1 x_1 + K_2 x_3$

$$\frac{\Delta w}{\Delta T_m - \Delta T_e + Z} = \frac{w_o}{M s + D_m}$$

i.e. $$\frac{x_2}{u_2 - K_1 x_1 - K_2 x_3 + Z} = \frac{w_o}{M s + D_m}$$

or, $$\dot{x}_2 M + D_m x_2 = w_o u_2 - K_1 x_1 w_o - K_2 x_3 w_o + w_o Z$$

$$\dot{x}_2 = - \frac{w_o}{M} k_1 x_1 - \frac{D_m}{M} x_2 - \frac{w_o}{M} K_2 x_3 + \frac{w_o}{M} u_2 + \frac{w_o}{M} Z \qquad (2)$$

Again $$\frac{K_3}{1 + s K_3 T'_{do}} = \frac{K_3}{u_1 - K_4 x_1}$$

or , $K_3(u_1 - K_4 x_1) = x_3 + \dot{x}_3 K_3 T'_{do}$

$$\dot{x}_3 = -\left[\frac{K_4}{T'_{do}}\right] x_1 - \left[\frac{1}{K_3 \; T'_{do}}\right] x_3 + \left[\frac{1}{T'_{do}}\right] u_1 \qquad (3)$$

Eqs. 1, 2 and 3 can be written in the matrix form -

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ -\frac{w_o}{M} K_1 & -\frac{D_m}{M} & -\frac{w_o}{M} K_2 \\ -\frac{K_4}{T'_{do}} & 0 & -\frac{1}{K_3 \; T'_{do}} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & \frac{w_o}{M} \\ \frac{1}{T'_{do}} & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

$$+ \begin{bmatrix} 0 \\ \frac{w_o}{M} \\ 0 \end{bmatrix} \begin{bmatrix} Z \end{bmatrix}$$

From the output

$$y = e_t = K_5 \, \Delta\delta + K_6 \, \Delta E'_q + W$$

$$= K_5 \, x_1 + K_6 x_3 + W$$

$$y = [K_5 \quad 0 \quad K_6] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + [W]$$

Finally it can be written as

$$y = [\,K_5 \quad 0 \quad K_6\,] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + [0]\,[u] + [1]\,[W]$$

In the generalized form $\dot{x}$ and y can be written as:

$$\dot{x} = A\,x + B\,u + F\,Z$$

$$y = C\,x + E\,u + G\,W$$

$$\therefore \quad A = \begin{bmatrix} 0 & 1 & 0 \\ -\frac{w_o}{M}K_1 & -\frac{D_m}{M} & -\frac{w_o}{M}K_2 \\ -\frac{K_4}{T'_{do}} & 0 & -\frac{1}{K_3 T'_{do}} \end{bmatrix} ; \quad B = \begin{bmatrix} 0 & 0 \\ 0 & \frac{w_o}{M} \\ \frac{1}{T'_{do}} & 0 \end{bmatrix}$$

$$F = \begin{bmatrix} 0 \\ \frac{w_o}{M} \\ 0 \end{bmatrix}$$

$$C = [\,K_5 \quad 0 \quad K_6\,] \; ; \qquad E = [0] \; ; \qquad G = [1]$$

Here, B, F , E , G are constants. A is the system matrix and C is the output matrix. Only A and C will vary at different conditions and will affect the operation.

For finding A and C the Phillips-Heffron K constants are to beknown. These constants are derived ~~divided~~ in [1] and they are as follows :

$$K_1 = \frac{E_{qo}\ E}{A} [\ r_e \sin\delta_o + (\ X_e + X'_d)\ \cos\delta_o\ ]$$

$$+ \frac{i_{qo}\ E_o}{A} \left[(X_q - X'_d)\ (X_e + X_q)\ \sin\delta_o - r_e (X_q - X'_d) \cos\delta_o \right]$$

$$K_2 = \left[\frac{r_e\ E_{qo}}{A} + i_{q_o} (\ 1 + \frac{(X_e + X_q)(X_q - X'_d)}{A} \right]$$

$$K_3 = \left[\ 1 + \frac{(X_e + X_q)\ (X_d - X'_d\ )}{A} \right]^{-1}$$

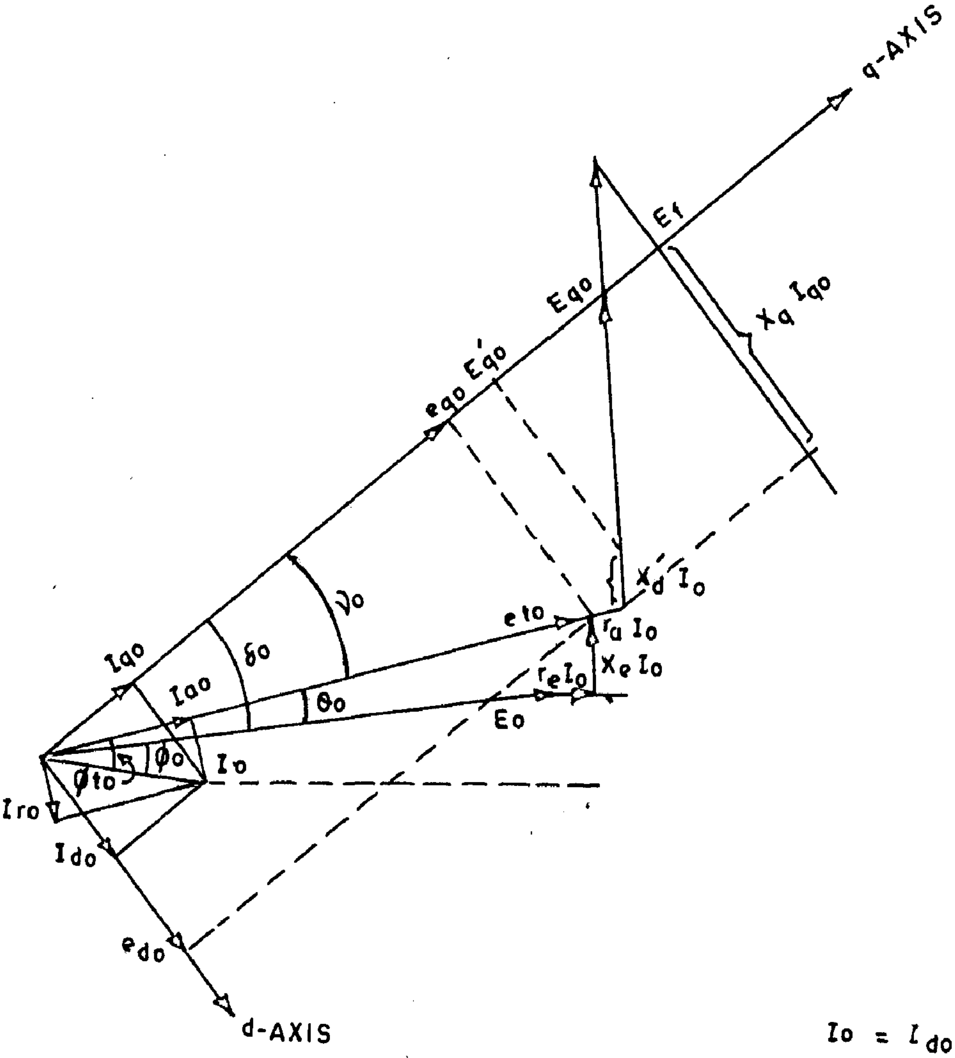
$$K_4 = \frac{E_o (X_d - X'_d)}{A} [(X_e + X_q)\sin\delta_o - r_e \cos\delta_o\ ]$$

$$K_5 = \frac{e_{do}}{e_{to}}\ X_q \left[\frac{r_e\ E_o\ \sin\delta_o + (X_e + X'_d)\ E_o \cos\delta_o}{A} \right]$$

$$+ \frac{e_{qo}}{e_{to}}\ X'_d \left[\frac{r_e\ E_o\ \cos\delta_o - (X_e + X_q)\ E_o\ \sin\delta_o}{A} \right]$$

$$K_6 = \frac{e_{qo}}{e_{to}} \left[1 - \frac{X'_d\ (X_e + X_q)}{A} \right] + \frac{e_{do}}{e_{to}}\ X_q\ \frac{r_e}{A}$$

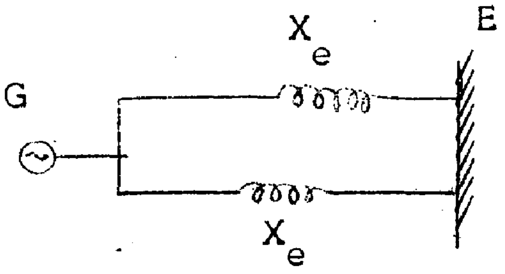
where, $A = [\ r_e^2 + (X_e + X'_d)\ (X_q + X_e)]$



$$I_o = I_{do} + jI_{qo}$$
$$= I_{ao} + jI_{ro}$$
ACTIVE REACTIVE

FIG. 2-STANDARD MACHINE VECTOR DIAGRAM

The steady state operating values of δ_o, E_{qo}, e_{do} and e_{qo} are derived from the standard machine vector diagram expressed as a function of steady-state terminal voltage e_{to}, and steady-state real and reactive load currents I_{do} and I_{qo},



Here, the known parameters are :

x_q , x_e , and r_a, r_e loading at infinite bus in terms of

E_o, P_o, Q_o

Then,

$$\emptyset_o = \tan^{-1} \frac{Q_o}{P_o} \qquad (1)$$

$$I_o = \frac{P_o}{E_o \cos\left(\tan^{-1} \frac{Q_o}{P_o}\right)} \qquad (2)$$

Taking E_o as reference.

$$e_{to} = \sqrt{(E_o + r_e I_o \cos\emptyset_o + x_e I_o \sin\emptyset_o)^2 + (X_e I_o \cos\emptyset_o - r_e I_o \sin\emptyset_o)^2} \qquad (3)$$

$$\Theta_o = \tan^{-1} \frac{x_e I_o \cos\emptyset_o - r_e I_o \sin\emptyset_o}{E_o + r_e I_o \cos\emptyset_o + x_e I_o \sin\emptyset_o} \qquad (4)$$

$$\therefore \quad \phi_{to} = \phi_o + \theta_o \tag{5}$$

$$I_{ao} = I_o \cos \phi_{to} \tag{6}$$

$$I_{rg} = I_o \sin \phi_{to} \tag{7}$$

Likewise

$$E_{qo} = \sqrt{(e_{to} + r_a I_o \cos\phi_{to} + x_q I_o \sin \phi_{to})^2 + (x_q I_o \cos \phi_{to} - r_a I_o \sin \phi_{to})^2} \tag{8}$$

$$\text{and} \quad \gamma_o = \tan^{-1} \frac{x_q I_o \cos \phi_{to} - r_a I_o \sin \phi_{to}}{e_{to} + r_a I_o \cos \phi_{to} + x_q I_o \sin\phi_{to}} \tag{9}$$

$$\therefore \quad \delta_o = \theta_o + \gamma_o \tag{10}$$

$$\rightarrow s_o \; e_{qo} = e_{to} \cos \gamma_o \tag{11}$$

$$e_{do} = e_{to} \sin \gamma_o \tag{12}$$

So, knowing E_o, x_d, x_q, x'_d, x_e r_a and r_e for any set of P_o and q_o, it is possible to find $\phi_o, I_o, e_{to}, \phi_{to}, \theta_o,$ $I_{ao}, I_{ro}, E_{qo}, \gamma_o, \delta_o, e_{do}, e_{qo}$ and so Phillips-Heffron K_1 to K_6 constants. Then system matrix A and output matrix C can be determined. The programme for the Equations is given in the Appendix.

DATA USED ARE :

1. Machine Constants for Tie-Line (in p.u. on machine base)

Machine Constants

$x_d = 1.6$, $X_q = 1.55$

$x'_d = 0.32$, $T'_{do} = 6.0$

Tie - Line

$r_e = 0.0$, $X_e = 0.4$.

This means for individual tie line $r_e = 0$, $x_e = 0.8$.

2. Loading

Real power (P)	0	-	1.0
Reactive Power (Q)	1.0	to	_0.4

Terminal voltage $e_t = 1.0 \rightarrow E_o = 1.0$ at infinite bus.

CHAPTER III

ENHANCEMENT OF DYNAMIC STABILITY REGION

3.1 INTRODUCTION

The familiar steady-state stability criterion with constant field voltage defines the stability limit as the condition for which the steady-state synchronizing power coefficient $K_1 - K_2 K_3 K_4$ is zero.

Here, in this work the synchronizing power coefficient $K_1 - K_2 K_3 K_4$ is computed for different values of P and Q at different system reactance X_e. The aim of computing $K_1 - K_2 K_3 K_4$ is to ~~be~~ see the effect of X_e on this coefficient. A graph has been plotted showing the locus of this coefficient on P-Q plane.

Then system matrix A is computed at selected points i.e., in the neighbourhood of $K_7 = K_1 - K_2 K_3 K_4 = 0$ points for different X_es. Then eigen values has been found out for the same. The object for finding out the eigen values of such cases is to see whether the unstable points can be shifted towards stable region with the help of different X_es. A graph has been plotted between PVS eigen values at different X_es.

3.2 COMPUTATIONAL PROCEDURE

At different X_e = .1, .2, .3, .4, .5, .6, .7, .8, the

1. Phillips - Heffron k_1----k_6 Constants are computed
2. $k_7 = k_1 - k_2 k_3 k_4$ is Calculated.
3. System matrix A is formed
4. Polynomial is found out.
5. Then eigen velues are determined one by one.

.3 SAMPLE OF COMPUTATIONAL RESULTS

At $X_e = 0.4$, $P_o = 1.0$ and $K_3 = 0.36$ for all the values.

$_o$	I_o	ϕ_o	e_{to}	θ_o	ϕ_{to}	I_{ao}	I_{ro}	E_{qo}	γ_o	δ_o	e_{qo}	e_{do}	K_1	K_2	K_4	K_5	K_6	K_7*
.0	1.41	445°	1.45	15.91	60.91	0.69	1.23	3.52	17.55	33.46	1.38	.44	2.66	.77	0.98	.06	.53	2.39
.8	1.28	38.66	1.38	16.85	55.51	0.72	1.06	3.22	20.44	37.29	1.29	.48	2.4	.84	1.08	.06	.52	2.07
.6	1.17	30.96	1.30	17.92	48.88	0.77	0.88	2.92	24.1	42.02	1.19	.53	2.11	.93	1.19	.05	.51	1.71
.4	1.08	21.8	1.23	19.07	40.87	0.82	0.71	2.65	28.56	47.63	1.08	.59	1.81	1.03	1.32	.04	.49	1.32
.2	1.02	11.31	1.15	20.33	31.64	0.87	0.54	2.39	34.22	54.55	0.95	.65	1.46	1.13	1.45	.04	.46	0.87
.0	1.0	0.0	1.08	21.8	21.8	0.93	0.37	2.19	41.0	62.8	0.82	.71	1.07	1.24	1.58	.05	.43	0.36
.2	-1.02	168.7	1.0	23.5	192.2	1.0	0.22	2.04	49.2	72.7	0.65	.76	0.67	1.33	1.70	.07	.36	-.14
.4	-1.08	158.2	0.93	25.5	133.7	1.08	0.07	1.97	58.11	83.6	0.49	.79	0.23	1.38	1.77	.13	.30	-.65

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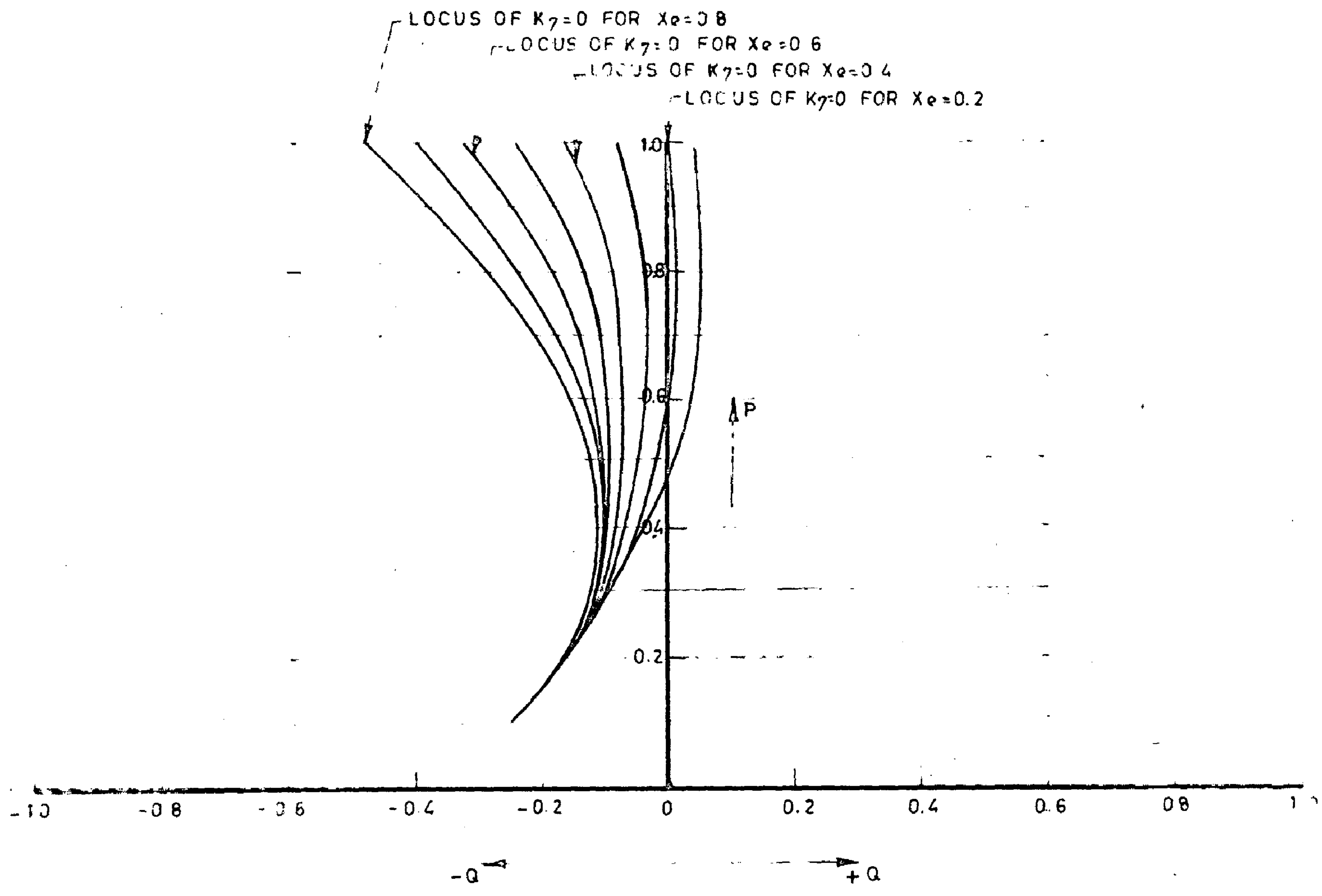
$$[A_{1.0,-.2}] = \begin{bmatrix} 0 & 1 & 0 \\ -21.04 & -1.6 & -41.76 \\ -.28 & 0 & -.46 \end{bmatrix}$$

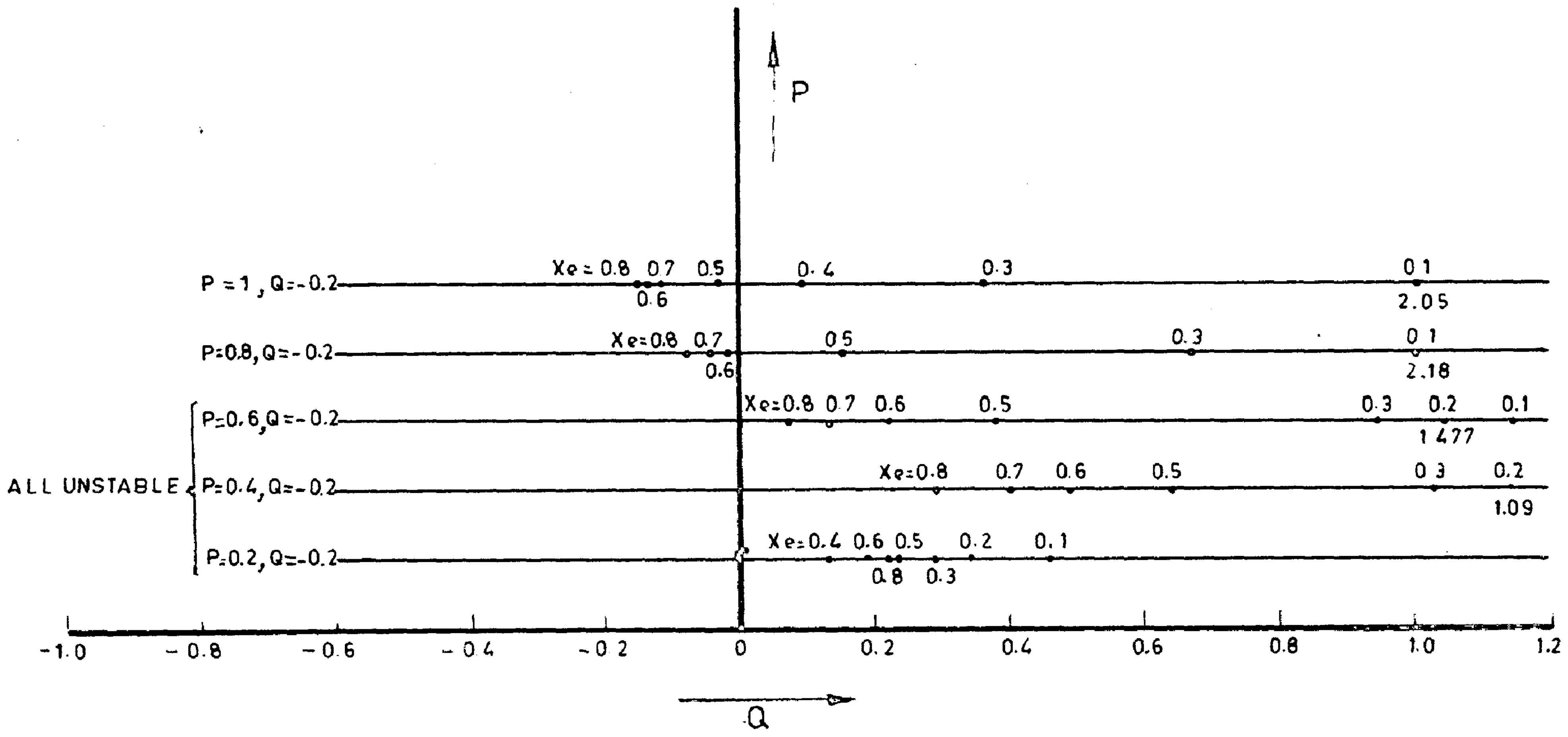
$$\therefore -\lambda^3 - 2.06\lambda^2 - 21.78\lambda + 2.01 = 0$$

and $\lambda = .09, \; -1.03 \pm 1.01\,j$

* $K_7 = K_1 - K_2 K_3 K_4$


LOCUS OF K7=0 FOR Xe=0 8
LOCUS OF K7=0 FOR Xe=0 6
LOCUS OF K7=0 FOR Xe=0 4
LOCUS OF K7=0 FOR Xe=0.2
P
1.0
0.8
0.6
0.4
0.2
-1.0
-0 8
-0 6
-0.4
-0.2
0
0.2
0.4
0.6
0 8
1
-Q
+Q

PVS EIGEN VALUES AT DIFFERENT Xe



3.4 CONCLUSION

(i) Locus of $K_7 = 0$ on P-Q Plane has been drawn. The locus of $K_7 = 0$ shifts towards left hand as the value of X_e goes on increasing. That is to say the stability region increases with the increase of X_e in the low rang of Q.

(ii) Eigen value also shifts towards stable region in some cases e.g. for $P = 1$, $Q = -.2$ at $X_e = .4$, the System eigen value falls in unstable region but as the reactance is increased the system eigen value shifts to stable region.

So, enhancement of dynamic stability region can be achieved with certain value of system reactance.

CHAPTER IV

TRANSIENT STABILITY STUDY

4.1 INTRODUCTION

For studying transient stability first the system differential equation is derived. Then for during fault the system condition is found out. After that the post fault study is made. In post fault it is observed that the system goes unstable for $x_e = .4$, $x_e = .8$, $x_e = 1.6$ and 3.2, 2.4 and for $x_e = 1.8$, 2.0 the oscillation is damped out that is system is stable for a band of reactance.

4.2 Derivation of the system differential Equation:

$$x_1 = \delta - \delta_o = \Delta\delta$$

$$x_2 = w - w_o = \Delta w$$

$$x_3 = Eq' - Eq_o' = \Delta Eq'$$

From fig. (1) it can be written →

$$(P_m - P_e) = [\frac{M}{w_o} s + \frac{D_m}{w_o}]\Delta w$$

$$\frac{\Delta w}{s} = \Delta\delta$$

$$\Delta w = s\Delta\delta$$

$$x_2 = s x_1$$

$$\therefore \dot{x}_1 = x_2$$

$$P_m - P_e = \frac{M}{w_o} s(\triangle w) + \frac{D_m}{w_o} \triangle w$$

$$P_m - P_e = \frac{M}{w_o} \dot{x}_2 + \frac{D_m}{w_o} x_2$$

$$\therefore \quad \dot{x}_2 = \frac{w_o}{M}(P_m - P_e) - \frac{D_m}{M} x_2.$$

and $$\dot{x}_3 = \left(\frac{x_d - x'_d}{x_d' + x_e} \quad \frac{E}{T_{do}'} \right) \cos(x_1 + \delta_o) - \frac{x_d + x_e}{x_d' + x_e} \frac{E}{T_{do}'} + \frac{E_{fd}}{T_{do}'}$$

From standard m/c vector diagram.

i.e. $\dot{x}_1 = x_2$

$\dot{x}_2 = f(P_m\ P_e,\ x_2)$; P_m is assumed constant

$\dot{x}_3 = f(E_{fd},\ x_1)$; E_{fd} is assumed constant

$$P_e = \frac{E(x_3 + E_{qo}')}{x_d' + x_e} \operatorname{Sin}(x_1 + \delta_o) - \frac{E^2 (x_q - x_d') \sin 2(x_1 + \delta_o)}{2(x_d' + x_e)(x_q + x_e)}$$

$$= f(x_3,\ x_1)$$

Initially at t = 0, i.e. when the fault occurs

$x_1 = 0$

$x_2 = 0$

$x_3 = 0$

$P_e = 0$

$\therefore \dot{x}_1 = 0$

$\dot{x}_2 = \frac{w_o}{M} P_m$

$\dot{x}_3 = 0$

It means first of all change in x_2 takes place thereafter change in x_1 occurs. then change in x_3 occurs.

i.e. the system diff. equations take the following shape

1. For during fault condition :

$$\dot{x}_1 = x(2)$$

$$\dot{x}_2 = 31.4 * .8 - 1.6 * x\ (2)$$

$$\dot{x}_3 = .67 * \cos\ (x(1) + .62) - .61$$

2. For Post Fault Condition :

$$P_e = \frac{1(x(3)+{}^{E}qo')}{.32+x_e} \sin(x_1+\delta_o) - \frac{1}{2}\ \frac{1.55 - .32}{(.32+x_e)(1.55+x_e)} * \\ * \sin 2(x_1+\delta_o)$$

$$\dot{x}_2 = 31.4 * (.8 - P_e) - 1.6 * x(2)$$

$$\dot{x}_1 = x(2)$$

$$\dot{x}_3 = \frac{0.60 - 0.32}{0.32 + x_e} * \frac{1}{6} * \cos\ (x(1) + \delta_o) - \text{Constant}$$

4.3 TABLE OF RESULTS

(i) For during fault

$$\dot{x}_2 = 25.12 - 1.6 * x(2)$$

S.No.	t	x_i	$\Delta' x_i$	$\Delta'' x_i$	$\Delta''' x_i$	$\Delta^{iv} x_i$	x_{i+1} i.e.x(2)
1	0	0	.25	.25	.25	.25	.25
2	.01	.25	.25	.25	.25	.24	.5
3	.02	.5	.24	.24	.24	.24	.74
4	.03	.74	.24	.24	.24	.24	.98
5	.04	.98	.24	.23	.23	.23	1.21
6	.05	1.21	.23	.23	.23	.23	1.44
7	.06	1.44	.23	.23	.23	.22	1.67
8	.07	1.67	.22	.22	.22	.22	1.89
9	.08	1.89	.22	.22	.22	.22	2.11
10	.09	2.11	.22	.22	.22	.21	2.33
11	.10	2.33	.21	.21	.21	.21	2.54
12	.11	2.54	.21	.21	.21	.21	2.75
13	.12	2.75	.21	.21	.21	.20	2.96
14	.13	2.96	.20	.20	.20	.20	3.16
15	.14	3.16	.20	.20	.20	.20	3.36
16	.15	3.36	.20	.20	.20	.19	3.56
17	.16	3.56	.19	.19	.19	.19	3.75
18	.17	3.75	.19	.19	.19	.19	3.94
19	.18	3.94	.19	.19	.19	.19	4.13
20	.19	4.13	.19	.18	.18	.18	4.31
21	.20	4.31	.18	.18	.18	.18	4.49

$\dot{x}_1 = x(2)$

Sl. No.	t	x_i	$\overset{i}{\Delta} x_i$	$\overset{ii}{\Delta} x_i$	$\overset{iii}{\Delta} x_i$	$\overset{iv}{\Delta} x_i$	x_{i+1} i.e. x(1)
1	0	0	0	0	0	0	0.0
2	.01	.25.	.0025	.0025	.0025	.0025	.0025
3	.02	.5	.01	.01	.01	.01	.01
4	.03	.74	.01	.01	.01	.01	.02
5	.04	.98	.01	.01	.01	.01	.03
6	.05	1.21	.01	.01	.01	.01	.04
7	.06	1.44	.01	.01	.01	.01	.05
8	.07	1.67	.02	.02	.02	.02	.07
9	.08	1.89	.02	.02	.02	.02	.09
10	.09	2.11	.02	.02	.02	.02	.11
11	.10	2.33	.02	.02	.02	.02	.13
12	.11	2.54	.03	.03	.03	.03	.16
13	.12	2.75	.03	.03	.03	.03	.19
14.	.13	2.96	''	''	''	''	.22
15	.14	3.16	''	''	''	''	.25
16	.15	3.36	''	''	''	''	.28
17	.16	3.56	.04	.04	.04	.04	.32
18	.17	3.75	''	''	''	''	.36
19	.18	3.94	''	''	''	''	.40
20	.19	4.13	''	''	''	''	.44
21	.20	4.31	''	''	''	''	.48

x_3 = .67 * cos (x(1)+.62)-.61

S. No.	t	x_i	$\Delta^{'} x_i$ (-)	$\Delta^{''} x_i$ (-)	$\Delta^{'''} x_i$ (-)	$\Delta^{iv} x_i$ (-)	x_{i+1} i.e. x(1) (-)
1	0.0	0	.0006	.0006	.0006	.0006	.0006
2	.01	0	.0007	.0007	.0007	.0007	.0013
3	.02	0025	.0006	.0006	.0006	.0006	.0019
4	.03	.01	.0006	.0006	.0006	.0006	.0026
5	.04	.02	.0007	.0007	.0007	.0007	.0033
6	.05	.03	.0007	.0007	.0007	.0007	.0041
7	.06	.04	.0008	.0008	.0008	.0008	.0049
8	.07	.05	.0008	.0008	.0008	.0008	.0057
9.	.08	.07	.0009	.0009	.0009	.0009	.0067
10	.09	.09	.0010	.0010	.0010	.0010	.0077
11	.1	.11	.0011	.0011	.0011	.0011	.0088
12	.11	.13	.0012	.0011	.0011	.0011	.0100
13	.12	.16	.0013	.0013	.0013	.0013	.0113
14	.13	.19	.0014	.0014	.0014	.0014	.0128
15	.14	.22	.0016	.0016	.0016	.0016	.0144
16	.15	.25	.00.17	.0017	.0017	.0017	.0162
17.	.16	.28	.0019	.0019	.0019	.0019	.0181
18	.17	.32	.0021	.0021	.0021	.0021	.0203
19	.18	.36	.0023	.0023	.0023	.0023	.0226
20	.19	.40	.0025	.0025	.0025	.0025	.0252
21	.20	.44	.0028	.0028	.0028	.0028	.0280

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(ii) For Post Fault

Operating Point is .8+ j.6

System reactance (x_e) = 0.4

$\dot{X}_2$ = 31.4 (.8 - P_e) - 1.6 * X(2)

Sl No	t	X(2)	P_e	31.4 * (.8-P_e)	$\Delta' x_i$	$\Delta'' x_i$	$\Delta''' x_i$	$\Delta^{iv} x_i$	x_{i+1} x(2)
1.	.2	4.31	2.82	-63.53	-3.53	-3.38	-3.39	-3.25	.93
2.	.25	.93	3.26	-77.39	-3.94	-3.79	-3.79	-3.64	-2.86
3.	.30	-2.88	3.34	-79.87	-3.76	-3.61	-3.62	-3.47	-6.48
4.	.35	-6.48	3.05	-70.79	-3.02	-2.90	-2.91	-2.79	-9.38
5.	.4	-9.38	2.29	-46.80	-1.59	-1.53	-1.53	-1.47	-10.91
6.	.45	-10.91	1.01	-6.74	.54	.51	.52	.49	-10.40
7.	.5	-10.40	- .52	41.48	2.91	2.79	2.79	2.68	-7.61
8.	.55	-7.61	-1.96	86.53	4.94	4.74	4.75	4.53	-2.86
9.	.6	-2.86	-2.90	116.1	6.03	5.79	5.80	5.57	2.94
10.	.65	2.94	-3.19	125.27	6.03	5.79	5.80	5.56	8.73
11.	.7	8.73	-2.88	115.61	5.08	4.88	4.89	4.68	13.62
12.	.75	13.62	-1.78	81.06	2.96	2.85	2.85	2.74	16.47
13.	.8	16.47	.11	21.70	- .23	-.22	-.22	-.21	16.25
14.	.85	16.25	2.35	-48.56	-3.73	-3.58	-3.58	-3.44	12.67
15.	.9	12.67	3.69	-90.68	-5.55	-5.33	-5.33	-5.12	7.34

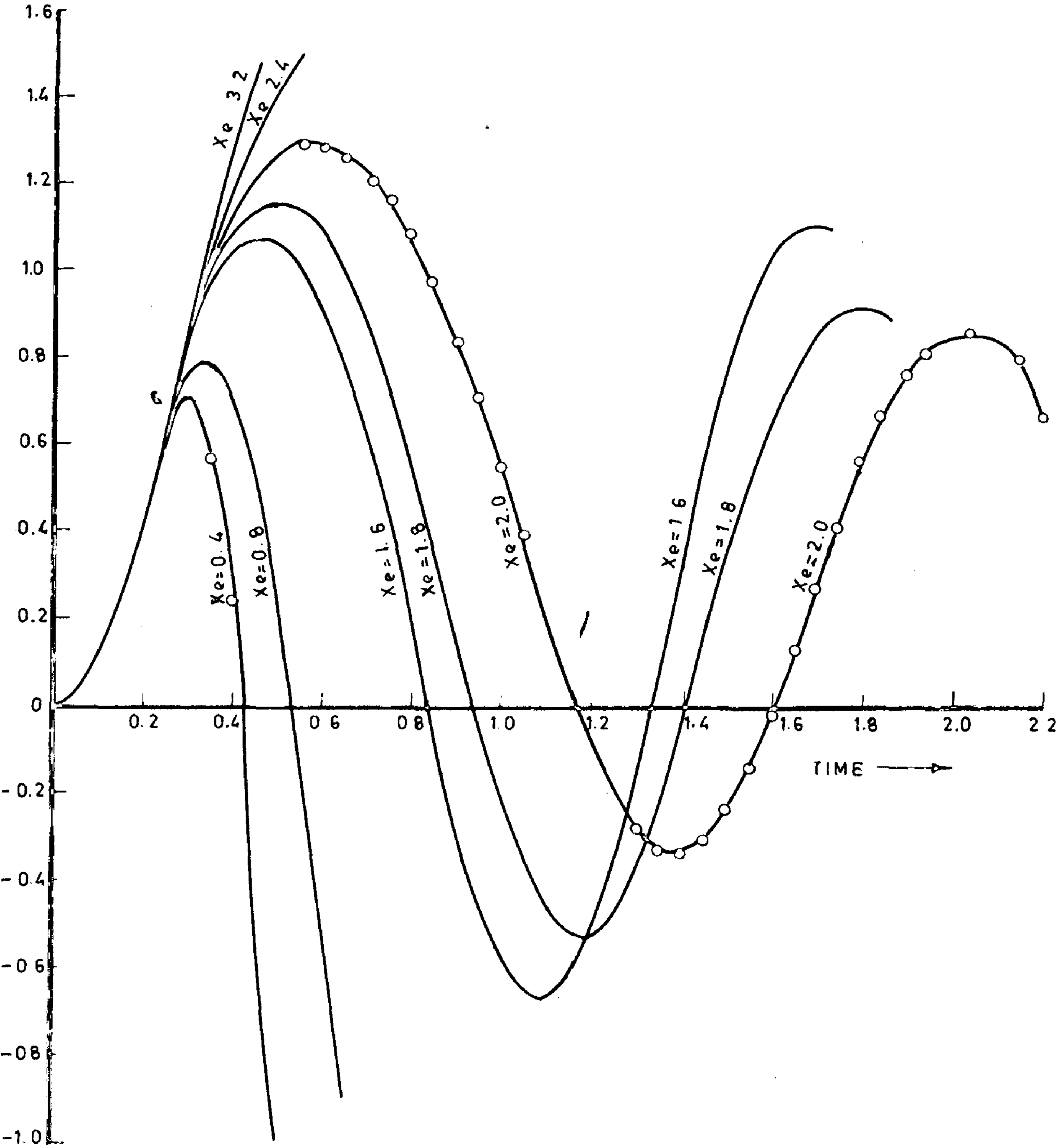
$\dot{x}_1 = x(2)$

S.No.	t	x(2)	$\Delta' x_i$	$\Delta'' x_i$	$\Delta''' x_i$	$\Delta^{iv} x_i$	x_{i+1} =x(1)
1	.2	4.31	.22	.22	.22	.23	.66
2	.25	.93	.05	.05	.05	.05	.71
3	.3	-2.86	- .14	-.15	-.15	-.15	.56
4	.35	-6.48	- .32	-.33	-.33	-.34	.23
5	.4	-9.38	- .47	-.48	-.48	-.49	-.25
6	.45	-10.91	-.55	-.56	-.56	-.57	-.81
7	.5	-10.40	-.52	-.53	-.53	-.55	-1.34
8	.55	-7.61	-.38	-.39	-.39	-.40	-1.73
9	.6	-2.86	-.14	-.15	-.15	-.15	-1.88
10	.65	2.94	.15	.15	.15	.15	-1.73
11	.7	8.73	.44	.45	.45	.46	-1.28
12	.75	13.62	.68	.70	.70	.72	-0.58
13	.8	16.47	.82	.84	.84	.87	.26
14	.85	16.25	.82	.83	.83	.85	1.09
15	.9	12.67	.63	.65	.65	.67	1.74

$$\dot{x}_3 = .3 * \cos\,(x(1) + .62) - .24$$

S.No.	t	x(1)	$\Delta' x_i$	$\Delta'' x_i$	$\Delta''' x_i$	$\Delta^{iv} x_i$	$x_{i+1}=x(3)$
1	.2	.44	-.0046	-.0046	-.0046	-.0046	-.0346
2	.25	.66	-.0077	-.0076	-.0076	-.0076	-.0422
3	.3	.71	-.0084	-.0084	-.0084	-.0083	-.0506
4	.35	.56	-.0063	-.0062	-.0062	-.0062	-.0568
5	.4	.23	-.0021	-.0021	-.0021	-.0021	-.0589
6	.45	-.25	-.0020	-.0020	-.0020	-.0020	-.0609
7	.5	-.81	.0027	.0027	.0027	.0027	-.0582
8	.55	-1.34	-.0007	-.0007	-.0007	-.0007	-.0589
9	.6	-1.73	-.0053	-.0054	-.0054	-.0054	-.0643
10	.65	-1.88	-.0074	-.0075	-.0075	-.0075	-.0718
11	.7	-1.73	-.0053	-.0053	-.0053	-.0053	-.0772
12	.75	-1.28	-.0002	-.0002	-.0002	-.0002	-.0774
13	.8	-.58	.003	.003	.003	.003	-.0744
14	.85	.26	-.0024	-.0024	-.0024	-.0024	-.0768
15	.9	1.09	-.0141	-.0140	-.0140	-.0140	-.0908

OPERATING POINT 0.8 + j.6



4.4 CONCLUSION

It is seen that the system remains stable during fault and after fault if the system is left like that it goes unstable. This situation is avoided by switching suitable value of reactance at the time of clearance of the fault. This extra reactance is kept in the system till the oscillation of the system is damped out. After that the system is brought back to the original condition i.e. the system is again with the original value of the reactance.

It is also seen that the system is stable for a band of reactance only. This value is to be chosen optimally. Here in this work it is selected by trial and error.

A graph of x_1 vs Time has been plotted at the operating point for different values of x_e = 3.2, 2.4, 2.0 1.8, 1.6, 0.8 and 0.4 which shows that the system is stable for a band of reactance only.

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CHAPTER V

STABILITY CHECK BY LYAPUNOV METHOD

5.1 INTRODUCTION :

Ref[5] has been used for stability check by lyapunov method where generation of lyapunov function is done with the help of Cartwright's method. Cartwright's method is used because of its simplicity and robustness, though there are other methods also for generating lyapunov function.

Here, the system is of 3rd order where the states are defined as $x_1 = \Delta\delta$, $x_2 = \Delta w$, $x_3 = \Delta E_q'$. In this work it has been experienced that change in E_q' is not appreciable so, assumption of E_q' a constant will not make any difference. Assuming E_q' a constant means assuming $\psi_f =$ constant i.e. field flux linkage is constant.

So, $x_3 = E_q' - E_{q_0}' = 0$ and $\dot{x}_3 = 0$

So, The system order reduces to two and the system differential equation become :

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = \frac{w_o}{M} \quad (P_m - P_e) - \frac{D}{M} \; x_2 \qquad \ldots.(1)$$

5.2 Generation of Lyapunov function :-

Let in general quadratic form lyapunov function for equation (1) be

$$2V = k_1x_1^2 + k_2x_2^2 + k_3x_1x_2$$

Rewriting the system equation

$$\dot{x}_1 = x_2$$

$$x_2 = \frac{w_o}{M}(P_m - P_e) - \frac{D}{M} \quad x_2$$

$$\dot{x}_2 = a_o - a_1x_2 - a_2\sin(x_1+\delta_o) - a_3\sin 2(x_1+\delta_o)$$

$$= -a_1x_2 - f(x_1)$$

Because, $P_e = [\frac{EE_q'}{xd'+x_e}]\ \mathrm{Sin}(x_1+\delta_o) - [\frac{E^2}{2}\ \frac{x_q - x_d'}{(x_d'+x_e)(x_q+x_e)}]$ *

$$\mathrm{Sin}\,2(x_1+\delta_o)$$

$$f(x_1) = a_2\ \mathrm{Sin}(x_1+\delta_o) + a_3\ \mathrm{Sin}2(x_1+\delta_o) - a_o$$

$$as = \frac{w_o}{M} P_m, \quad a_1 = \frac{D}{M}, \quad a_2 = [\frac{w_o}{M}\ \frac{EE_q'}{x_d'+x_e}]$$

$$a_3 = -[\frac{w_o}{M}\ \frac{E^2}{2}\ \frac{x_q - x_d'}{(x_d'+x_e)(x_q+x_e)}]$$

$$f(x_1) = [f_x(x_1)]\ x_1 = a_4x_1$$

where $a_4 = f_{x_1}(x_1) = \frac{d}{dx_1}[f(x_1)]$

So, $\dot{x}_2 = -a_1x_2 - a_4x_1$

On differentiating the lyapunev function

$$2\dot{V} = 2k_1x_1x_2+2k_2x_2(-a_1x_2-a_4x_1)+k_3x_2^2$$

$$+k_3x_1(-a_1x_2-a_4x_1)$$

$$2\dot{V} = -a_4k_3x_1^2 +k_3x_2^2 -2a_1k_2x_2^2 +2k_1x_1x_2-2a_4k_2x_1x_2-a_1k_3x_1x_2$$

$$\therefore \dot{V} = (-a_1k_2+\frac{k_3}{2})x_2^2 \frac{a_4k_3}{2} x_1^2 +(k_1-a_4k_2- \frac{a_1k_3}{2})x_1x_2$$

Now to satisfy L-theorem, any of the following statement needs to be observed for $\dot{V}$ -

(a) a negative semidefinite function of state variable x_2

(b) a negative semidefinite function of state variable x_1.

(c) a negative semidefinite function of state variable x_1 and x_2.

Let $\dot{V}$ be constrained to be negative semidefinite function of x_2. This results in

$k_3 = 0$, $k_1 = a_4k_2$, setting $k_2=1$ arbitrarily gives

$k_1 = a_4$, $k_2=1$, $k_3=0$

$$\therefore \dot{V}_a = -a_1x_2^2 \text{ and } 2V_a = x_2^2 + a_4x_1^2$$

Writting $f(x_1) = a_4x_1$

$$f(y) = a_4y$$

$$\int f(y)dy = \int a_4y\ dy = \frac{a_4y^2}{2}$$

$$\therefore a_4y^2 = 2\int f(y)dy$$

$$2V_a = x_2^2 + a_4x_1^2$$

$$\therefore \quad V_a = \frac{x_2^2}{2} + \frac{a_4 \; x_1^2}{2} = \frac{x_2^2}{2} + \int_0^{x_1} f(y)dy$$

$$= \frac{x_2^2}{2} + \int_0^{x_1} [a_2 \text{ Sin}(y+\delta_o)$$

$$+ a_3 \text{ Sin2 } (y+\delta_o) - a_o]dy$$

$$\dot{V}_a = -a_1 x_2^2$$

$$V_a = \frac{x_2^2}{2} + \int_0^{x_1} [- \frac{w_o}{M} P_m + \frac{w_o}{M} \frac{EE_q{}'}{x_d' + x_e} \text{ Sin}(y + \delta_o)$$

$$- \frac{w_o}{M} \frac{E^2}{2} \frac{x_q - x_d'}{(x_d' + x_e)(x_q + x_e)} \text{ Sin2}(y+\delta_o)]dy$$

$$\dot{V}_a = - \frac{D}{M} \; x_2^2$$

$$V_a = \left[\frac{w_o}{M} \frac{EE_q{}'}{x_d' + x_e} \text{ Sin}(x_1+\delta_o) - \frac{w_o}{M} \frac{E^2}{2} \frac{(x_q - x_d')}{(x_d+x_e)(x_q+x_e)} * \right.$$

$$\left. \text{Sin2}(x_1+\delta_o) - \frac{w_o}{M} P_m \right]$$

$$\nabla V_a \Big|_{(x_1 = \delta_o, \; x_2 = 0)} = 0$$

$$\nabla V_a \Big|_{(x_1 = \delta_{New}, \; x_2 = 0)} = 0$$, From this $x_1 = \delta_{New}$ to find out

$$V_a \Big|_{\delta_{New}} = \frac{x_2^2}{2} + \int_0^{x_1 = \delta_{New}} \left[\frac{w_o}{M} \frac{EEq'}{x_d' + x_e} \text{ Sin } \delta_{New} - \right.$$

$$\left. - \frac{w_o}{M} \frac{E^2}{2} \frac{x_q - x_d'}{(x_d+x_e)(x_q+x_e)} \text{ Sin2 } \delta_{New} - \frac{w_o}{M} P_m \right] dx_1$$

S.No.	X_e	δ_o	δ_{New}	C_{max}
1	.4	35.72	132	-5.68
2	.8	37.97	110	-2.07
3	1.6	42.37	85	-0.59
4	1.8	43.42	80	+ .46
5	2.0	44.57	75	+3.7
6	2.4	46.77	70	- .25
7	3.2	48.97	65	- .43

5.3 CONCLUSION :

It is verified by the lyapunov Theorem also that the system is stable for the reactance value of 1.8 and 2.0 . That is to say the system is stable for a band of reactance only. At x_e = 1.8 and 2.0 the value of C_{max} calculated is positive which indicates that the system is stable for these two values of reactance. For other x_es the values of C_{max} calculated is negative which does not satisfy the lyapunov Theorem hence the system will not be stable for these values of reactances. So, the results obtained in Chapter IV is fully verified by the lyapunov theorem.

APPENDIX

Programme forccalculation of Phillips-Heffron K-constants on EC-75P 72 steps programmable calculator.

```
00   RCL
01   1
02   ÷
03   RCL
04   2
05   =
06   INV
07   TAN
08   R/S (Results
           Ø0)
     STO
     3
09   COS
10   F
11   1/X
12   *
13   RCL
14   2
15   =
16   R/S (I0)
17   STO
18   4
19   RCL
20   3
21   SIN
22   *
23   RCL
24   4
25   *
26   .
27   4
28   +
29   1
30   Y^X
31   2
32   =
33   STO
34   5
35   RCL
36   3
37   COS
38   *
39   RCL
40   4
41   *
42   .
```

```
43    4
44    Y^X
45    2
46    =
47    +
48    RCL
49    5
50    =
51    √X
52    R/S (e_to)
53    Q_O
      STO
      1
      P_O
      STO
      2
      R/S
00    RCL  }
01    1    } φ_O
02    COS
03    *
04    RCL
05    2
06    *
07    .
08    4
09    ÷
10    [
11    RCL
12    1
13    SIN
14    *
15    RCL  }
16    2    } I_O
17    *
18    .
19    4
20    +
21    1
22    ]
23    =
24    INV
25    TAN
26    R/S (θ_O)
27    STO
28    3
29    +
30    RCL
31    1
32    =
33    R/S (φ_to)
34    STO
35    4
```

36
37
38
39
40
41
42
43
44
45
46
47
48
49

00
01
02
03
04

COS
*
RCL
2
=
R/S (I_{ao})
REL
4
SIN
*
RCL
2
=
R/S (I_{ro})
ϕ_o
STO
1
I_o
STO
2
R/S
RCL
1
SIN
*
RCL

05
06
07
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30

2
*
1
.
5
5
+
RCL
3
=
STO
4
*
RCL
4
=
STO
5
RCL
1
COS
*
RCL
2
*
1

31	.	
32	5	
33	5	
34	Y^X	
35	2	
36	=	
37	+	
38	RCL	
39	5	
40	=	
41	$\sqrt{X}$	
42	R/S(E_{qo})	
00	RCL	$\emptyset_{to}$
01	1	
02	COS	
03	*	
04	RCL	I_o
05	2	
06	*	
07	1	
08	.	
09	5	
10	5	
11	÷	
12	I	
13	RCL	
14	1	
15	SIN	
16	*	
17	RCL	
18	2	
19	*	
20	1	
21	.	
22	5	
23	5	
24	+	
25	RCL	
26	3	
27	]	
28	=	
29	INV	
30	TAN	
31	R/S (γ_o)	
32	STO	
33	5	
34	+	
35	RCL	θ_o
36	4	
37	=	
38	R/S (δ_o)	
39	RCL	
40	5	
41	COS	

42	*	
43	RCL	
44	3	
45	=	
46	R/S	(e_{qo})
47	RCL	
48	5	
49	SIN	
50	*	
51	RCL	e_{to}
52	3	
53	=	
54	R/S	(e_{do})
00	RCL	δ_o
01	1	
02	SIN	
03	*	
04	RCL	I_{ro}
05	x2	
06	*	
07	RCL	
08	5	
09	=	
10	STO	
11	4	
12	RCL	
13		
13	1	
14	COS	
15	*	
16	RCL	E_{qo}
17	3	
18	*	
19	RCL	$\frac{1}{x_e + x_q}$
20	6	
21	+	
22	RCL	
23	4	
24	=	
25	R/S	(K_1)
26	RCL	
27	1	
28	SIN	
29	*	
30	RCL	$\frac{1}{x_e + x'_d}$
31	7	
32	=	
33	R/S	(K_2)
34	RCL	
35	1	
36	SIN	
37	*	
38	RCL	$x_d - x'_d$
39		

40	=	
41	R/S (K_4)	
42	$\frac{x_e}{x_e + x'_d}$ value to be given.	
43	*	
44	RCL	e_{qo}
45	9	
46	÷	
47	RCL	e_{to}
48	0	
49	=	
50	R/S (K_6)	
00	RCL	δ_o
01	1	
02	SIN	
03	*	
04	$x'_d / x_e + x'_d$ (value to be given)	
05	*	
06	RCL	e_{qo}
07	2	
08	÷	
09	RCL	e_{to}
10	3	
11	=	
12	CHS	
13	STO	
14	5	
15	RCL	
16	1	
17	COS	
18	*	
19	RCL	e_{do}
20	4	
21	*	
22	1	
23	.	
24	5	
25	5	
26	÷	
27	RCL	
28	3	
29	÷	
30	[	
31	RCL	
32	3	
33	*	
34	1	
35	.	
36	5	
37	5	
38	+	

```
39      RCL  |
40      6    | k2
41      ]
42      =
43      +
44      RCL
45      5
46      =
47      R/S(k5)
48      RCL
49      6
50      *
51      RCL  |
52      7    | k3
53      *
54      RCL  |
55      8    | k4
56      =
57      CHS
58      STO
59      9
60      +
61      RCL  |
62      0    | k1
63      =
64      R/S (k7)
```

Programme for the formation of the Matrix

```
00      RCL  |
01      9    | k3
02      *
03      6
04      =
05      F
06      1/X
07      CHS
08      R/S (M33)
09      RCL  |
10      1    | k1
11      *
12      3
13      1
14      .
15      4
16      CHS
17      =
18      R/S(M21)
19      RCL  |
20      0    | k4
21      ÷
22      6
23      =
```

24	CHS	
25	R/S (M_{31})	
26	RCL	k_2
27	5	
28	*	
29	3	
30	1	
31	.	
32	4	
33	CHS	
34	=	
35	R/S (M_{23})	

Co-efficient of the Polynomial

36	RCL	M_{22}
37	2	
38	+	
39	RCL	M_{33}
40	3	
41	=	
42	R/S (λ^2)	
43	RCL	
44	2	
45	*	
46	RCL	
47	3	
48	CHS	
49	+	
50	RCL	M_{21}
51	6	
52	=	
53	R/S (λ)	
54	RCL	
55	6	
56	*	
57	RCL	
58	3	
59	CHS	
60	+	
61	[	
62	RCL	M_{31}
63	8	
64	*	
65	RCL	M_{23}
66	7	
67	]	
68	=	
69	R/S (Constant Term)	

Programme for Runge-Kutta Fourth order for Solving Simultaneous Differential Equation during fault.

$\dot{X}_2 = 25.12 - 1.6* X(2)$

```
00          RCL  | 25.12
01          3    |
02          -
03          [
04          RCL  | 1.6
05          4    |
06          *
07          RCL  | X(2)
08          1    |
09          ]
10          =
11          *
12          RCL  | h=.01
13          2    |
14          =
15          R/S  △'Xi
16          ÷
17          2
18          +
19          RCL
20          1
21          *
22          RCL
23          4
24          CHS
25          =
26          +
27          RCL
28          3
29          =
30          *
31          RCL
32          2
33          =
34          R/S △''Xi, △'''Xi
GO  TO  16
35          +
36          RCL
37          1
38          *
39          RCL
40          4
41          CHS
42          =
43          +
44          RCL
45          3
```

46	*	
47	RCL	
48	2	
49	=	
50	R/S $\overset{'''}{\Delta}X_i$	

$\dot{X}_1 \equiv X(2)$

00	RCL	X (2)
01	1	
02	*	
03	RCL	h=.01
04	2	
05	=	
06	R/S $\overset{'}{\Delta}X_i$	
07	÷	
08	2	
09	+	
10	RCL	
11	1	
12	=	
13	*	
14	RCL	
15	2	
16	=	
17	R/S $\overset{''}{\Delta}X_i, \overset{'''}{\Delta}X_i$	

GO TO 07

18	+	
19	RCL	
20	1	
21	=	
22	*	
23	RCL	
24	2	
25	=	
26	R/S $\overset{'''}{\Delta}X_i$	

$\dot{X}_3 = .67 * \text{COS}\,(X(1)+.50) -.83.$

00	RCL	.50
01	5	
02	+	
03	RCL	X(1)
04	1	
05	=	
06	COS	
07	*	
08	RCL	.67
09	3	
10	=	
11	-	
12	RCL	.83
13	4	

14	=	
15	*	
16	RCL	h=.01
17	2	
18	=	
19	R/S $\Delta' X_i$	
20	÷	
21	2	
22	+	
23	RCL	
24	1	
25	+	
26	RCL	
27	5	
28	=	
29	COS	
30	*	
31	RCL	
32	3	
33	=	
34	-	
35	RCL	
36	4	
37	=	
38	*	
39	RCL	
40	2	
41	=	
42	R/S $\Delta'' X_i$, $\Delta''' X_i$	
GO TO 20		
43	+	
44	RCL	
45	1	
46	+	
47	RCL	
48	5	
49	=	
50	COS	
51	*	
52	RCL	
53	3	
54	=	
55	-	
56	RCL	
57	4	
58	=	
59	*	
60	RCL	
61	2	
62	=	
63	R/S $\Delta'''' X_i$	

Programme for Runge-Kutta Fourth order for solving Simultaneous differential equation for post fault condition

$\dot{X}_2 = 31.4\ (.8-P_e)-1.6*X(2)$

```
00    RCL  | .62
01    5    |
02    +
03    RCL  | X (1)
04    1    |
05    =
06    SIN
07    *
08    [
09    RCL  | X(3)
10    3    |
11    +
12    2
13    .
14    6
15    7
16    ]
17    ÷
18    .
19    2
```

```
20    2
21    =
22    STO
23    0
24    RCL
25    5
26    +
27    RCL
28    1
29    *
30    2
31    =
32    SIN
33    *
34    .
35    4
36    4
37    =
38    CHS
39    +
40    RCL
41    0
42    =
43    R/S    Pe
44    CHS
45    +
```

46	.	
47	8	
48	*	
49	3	
50	1	
51	.	
52	4	
53	=	
54	R/S	
55	-	
56	[	
57	1	
58	.	
59	6	
60	*	
61	RCL	
62	2	
63	]	
64	=	
65	*	
66	RCL	
67	4	
68	=	
69	R/S	$\overset{\prime}{\Delta}X_i$
00	R/S	
01	÷	

02	2	
03	+	
04	RCL	X(2)
05	2	
06	*	
07	RCL	1.6
08	6	
09	CHS	
10	=	
11	+	
12	RCL	$31.4(.8-P_e)$
13	8	
14	*	
15	RCL	h=.05
16	4	
17	=	
18	R/S	$\overset{\prime\prime}{\Delta}X_i, \overset{\prime\prime\prime}{\Delta}X_i$
GO TO 00		
19	+	
20	RCL	
21	2	
22	*	
23	RCL	
24	6	
25	CHS	
26	=	
27	+	

28	RCL	
29	8	
30	*	
31	RCL	
32	4	
33	=	
34	R/S $\overset{iv}{\Delta}X_i$	
35	RCL	
36	2	
37	*	
38	RCL $\overset{\prime}{\Delta}X_i$	
39	4	
40	=	
41	R/S	
42	÷	
43	2	
44	+	
45	RCL	
46	2	
47	*	
48	RCL	
49	4	
50	=	
51	R/S $\overset{\prime\prime}{\Delta}X_i, \overset{\prime\prime\prime}{\Delta}X_i$	
GO TO 42		
52	+	
53	RCL	
54	2	
55	*	
56	RCL	
57	4	
58	=	
59	R/S $\overset{iv}{\Delta}X_i$	

$\dot{X}_3 = K_1 * \cos (X(1)+.62)-K_2$

00	RCL	.62
01	5	
02	+	
03	RCL	X(1)
04	1	
05	=	
06	COS	
07	*	
08	RCL	K_1
09	3	
10	=	
11	-	
12	RCL	K_2
13	4	
14	*	
15	RCL	h=.05
16	2	
17	=	

18	R/S $\Delta^{\prime}X_i$
19	÷
20	2
21	+
22	RCL
23	1
24	+
25	RCL
26	5
27	=
28	COS
29	*
30	RCL
31	3
32	-
33	RCL
34	4
35	*
36	RCL
37	2
38	=
39	R/S $\Delta^{\prime\prime}X_i$, $\Delta^{\prime\prime\prime}X_i$

GO TO 19

40	+
41	RCL
42	1
43	+
44	RCL
45	5
46	=
47	COS
48	*
49	RCL
50	3
51	-
52	RCL
53	4
54	*
55	RCL
56	2
57	=
58	R/S $\Delta^{iv}X_i$

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