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Certified that the attached Thesis/Dissertation on Stability Studies of a Power System with Large Asynchronous Loads

was submitted by
Sri R.K. Bansal

and accepted for the award of Degree of ~~Doctor of Philosophy~~/Master of Engineering in W.R.D.

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STABILITY STUDIES OF A POWER SYSTEM WITH LARGE ASYNCHRONOUS LOADS

A Dissertation
submitted in partial fulfilment
of the requirements for the degree
of
MASTER OF ENGINEERING
in
WATER RESOURCES DEVELOPMENT

By
R.A. BANSAL

WATER RESOURCES DEVELOPMENT TRAINING CENTRE
UNIVERSITY OF ROORKEE
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December, 1969

CERTIFICATE

Certified that the dissertation entitled " STABILITY STUDIES OF A POWER SYSTEM WITH LARGE ASYNCHRONOUS LOADS " which is being submitted by Sri R.A.Bansal in partial fulfilment for the award of the degree of Master of Engineering in "WATER RESOURCES DEVELOPMENT " of University of Roorkee is a record of the candidate'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.

This is further to certify that he has worked for a period of 15 months from October 1968 to December 1969 for preparing dissertation for Master of Engineering Degree at the University.

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CONTENTS:

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LIST OF SYMBOLS :

P= Active power of Synchronous Generator.
Q= Reactive power of Synchronous Generator.
Ea= Generator E.M.F.
V= Load terminal voltage.
X= Load reactance.
δ= Torque angle of the machine.
s = % slip of Induction motor.
R_2= Resistance of the rotor circuit of the induction, motor.
X_2= Reactance of the rotor circuit of the induction motor.
r_2= Resistance rotor circuit referred to primary.
x_2= Resistance rotor circuit referred to primary.
T= Torque developed by Induction motor.
Q_μ= Reactive magnetising power of Inductor motor.
Q_s= P Induction motor reactive power associated with the stator and rotor leakage.
Scr= Critical slip.
Vcr= Critical terminal voltage, of induction motor.
W= Anguler velocity frequency of the system.
En= Generator E.M.F.s wherein n=1,2,3,4,5.
Pn= Generator power n=1,2,3,4.
Hn= Inertia constant of each Generator unit n=1,2,3,4.
Vm= Load terminal voltage at Muradnagar.
Ym= Load Admitance at Muradnagar.
Q= Phase angle of Vm.
Δt= Time interval for swing curve = 0.01 sec.

*****

ASSUMPTION:

1. E.M.F's of generators behind the transient reactance to remain constant during the transient period.
2. Voltage regulator and governor effect not considered.
3. Line charging currents and transformer no load currents are neglected.
4. Effect of D-amper windings not considered.
5. The effect of change in frequency on the line admitances has been neglected.
6. The effect of in-stantaneous frequency has been considered on the load.

SYNOPSIS

The importance of Power System load characteristics under transient conditions has been strassed in the literature, but little information is available particularly regarding frequency dipendence; general c-onditions regarding the behaviour of active and reactive load components with frequency have been considered and stability studies have been carried out on the Western U.P. Grid. An efferts has been made to compare the stability considering the loads to be constant impedence and considering them to be frequency and voltage dependence. A detailed procedure is developed from considering the voltage dependence and frequency dependence of the loads in transient stability studies of the system.

CHAPTER - I.

INTRODUCTION

CHAPTER I.

INTRODUCTION

1.1 The Power development in India is of vital importance to do the continuous progress. Electric power is required in increasing amounts for the operation of mills and factories, for transportation, for communication, and for domestic use. It has been said that nation's progess can be largely measured in terms of kilowatt houfs consumed per capita; for as the electric-energy consumption is large, so the inefficient human labour energy will be small.

Whether power is generated near the place where it is utilised or whether it is being transmitted, it is essential that the reliability of the power supply should be high. Major interruptions can no longer be tolerated. The systems, therefore, must be so designed and operated that maximum reliability is obtained, and so that consumers as infrequently as possible, preferably never, are deprived of the electric energy to which they subscribe.

1.11 ORIGIN OF THE STABILITY PROBLEM:

Defining stability in a broad sense, it may be said that the stability of a power system is in general the ability of the system to oprate intact in the steady state, as well as during disturbances.

The question of stability is, strictly,

is, [illegible], not a new one. As long as alternating current circuits have been in operation, it has been definitly known that there is a limit to the amount of power which can be transmitted over a given line to a given load centre. It has also been known that, with several synchronous [illegible] machine tried to the same circuit, synchronism among these machines can not always be maintained. So long as the alternating current systems were small and simple, the problem of stability and maintenance of synchronism was neigher particularly pertinent nor a difficult one. The loads carried by these small systems were usually so low that normal operation hardly ever took place at loadings close to the critical conditions.

The question of system stability has sprung to the foreground when super power transmission is being considered seriously. At the same time interest is increase in the already known fact that savings might be obtained by interconnections of independent systems, and this, coupled with the desire on the port of many companies to merge and carry through such interconnections, added still further to the interest in bulk power transmission systems. These problems first became [illegible] acute in the United States, and American Electrical Engineers have been Pioneers in discovering the essential factors which contribute to instability and in devising methods of improving the stable operation of Power Systems.

For economic reasons the loads which must be carried by long distance transmission lines today are large, and margin between normal, or maximum load, and critical load limiting conditions is often comparatively small. In designing such lines therefore, it is essential that due consideration be given to the question of stability. Such lines must be able to carry successfully the maximum amounts of load in the steady state. They must also, and this is just as important, be able to survive disturbances of a severe nature.

1.2 DEFINITIONS OF STABILITY TERMS :

The nomenclature in connection with stability is covered by the following definitions:-

1. STABILITY: Stability is the ability of a power system to remain in synchronous equilibrium under steady operating conditions, and to regain a state of equilibrium after a disturbance has taken place.

2. STEADY STATE STABILITY:

(a) STEADY STATE STABILITY WITHOUT AUTOMATIC DEVICES:

Steady State stability without automatic devices (Static Stability) exist in a power system when it operates in synchronous equilibrium under steady load conditions and with strictly constant armature and field currents in all synchronous machines without the aid of automatic devices. (The term automatic devices usually referes to regulators and exciters used to very the field currents automatically.)

(b) STEADY STATE STABILITY WITH AUTOMATIC DEVICES:

Steady state stability with automatic devices (dynamic stability) exists in a power system when it operates in synchronous equilibrium under steady load conditions withthe aid of automatic devices.

3. TRANSIENT STABILITY:

(a) TRANSIENT STABILITY WITHOUT AUTOMATIC DEVICES:

Transient stability without automatic devices exists in a Power System when it regains a state of equilibrium, without the aid of automatic devices, after a disturbance (such as a sudden application of load or the dropping of a line section etc.) has taken place.

(b) TRANSIENT STABILITY WITH AUTOMATIC DEVICES:

Transient stability with automatic devices exists in a Power System when it regains a state of equilibrium, with the aid of automatic devices after a disturbance has taken place.

4. STABILITY LIMIT :

A stability limit (Power Limit) is a value of maximum power which a power system will carry with stability. It applies in general to some system link, and may be specified at any point such as at a generator or motor, shaft, at the terminals of a machine, or at some point on a transmission line. In every case, however a stability limit is influnced by the characteristic of all elements which make up the system.

5. STEADY STATE STABILITY LIMIT:

The steady state stability limit of a [illegible] link in power system is the maximum power which can be carried by that link with the system operating under conditions of steady state stability i.e. load is applied gradually.

6. TRANSIENT STABILITY LIMIT:

The transient stability limit of a link in a power system is the maximum power which may be carried by that link with the system operating under conditions of transient stability. The transient stability limit is dependent upon the kind and duration of disturbance as well as upon the previous steady operating conditions of the system. The disturbance must be completly described as, for instance, the addition of a given load at a specified point, the tripping out of a link section, a fault of a given type at some point with its subsequent point its subsequent clearing after the lapse of a definite time etc.

1.3 CONSIDERATION OF LOAD CHARACTERISTIC INSTABILITY STUDY:

For power system planning and operation under normal and emergency conditions, voltage dependent and frequency dependent behaviour of system loads should be studied, because voltage and frequency are powerful parameters available for control. The composition of various system loads is usually known to the Planning Engineer, as well as , to the Power Controller for load flow and stability studies under steady state and disturbed conditions.

The more usual loads met in practice include induction motors, filament lamps, element heaters, discharge lamps, arc furnaces, electric welders and mercury are rectifiers, all of which are voltage dependent and except for filament lamps and element heaters, are also frequency dependent.

Owing to lack of adequate information , system loads have usually been represented in system studies in various ways, such asby

(a) Constant shunt impedence at system nominal frequency, giving active and reactive powers directly proportional to the square of the terminal voltage.

(b) Constant current sinks giving active and reactive powers directly proportional to the terminal voltage.

(c) Non linear loads I 1 I.

All the loads mentioned here, except filament lamps and element heaters, vary with system frequency, but little information is available on the frequency dependence.

Active and reactive power variations with instantaneous frequency influence the behaviour of the system under transient conditions. Reactive power governs the voltage drops in the transmission nett work and influences indirectly the out of balance active power for the synchronous machines. The over all load composition as obtained by a load survey can be used in stability studies for steady state and disturbed conditions. During disturbances on the power systems, the various synchronous machines are subjected to electro-mechanical oscillations which cause the frequency in various parts of the system to vary instantaneously in differing degrees. Such frequency variations cause changes in instantaneous values of power system Parameters, which are not normally taken account of in power system studies. As the frequency dependence of induction motor loads on a power system can be significant, and this present studyshows a similar importance for frequency dependence of various loads, and how the system stability is affected on account of the same.

1.4 STATEMENT OF THE PROBLEM AND AUTHER'S APPROACH :

This thesis under-takes the problem of assessing the exact effect of the voltage and frequency characteristics of a composite load on the transient stability limits of a multimachine system. The Western U.P.Grid has been taken as the power system having major Generating stations of Yamuna and Ramganga Hydel Schemes and Harduaganj Steam Station with loads at Muradnagar for the study purposes. The single line diagram of the system is shown in 1.1 and the various data of transmission lines, Generators and transformers are shown in Table 1, 2, and 3 respectively. Muradnagar is a big load Centre in the Western U.P.Grid which receives Power from Yamuna, Delhi, Harduaganj and then distributes to Ghaziabad, Meerut, Modinagar, Muradnagar, Hapur, the places which are most industrialised and contain the maximum induction motor load. The 220KV line between Roorkee and Muradnagar has been considered as the faulted line as in normal condition this line is supposed to carry most of the power to Muradnagar as seen from the load flow diagram of the whole U.P. System shown fig. 1.2 (taken from the nett work analyser report of the U.P. Grid September, 1967) and as such its intruption should cause the maximum disturbance to the system.

LINE IMPEDENCES:

TABLE-I.

Sl. Noe	Name of the line.	Per curcuit values in Ohmic.		Circuit value on 200 MVA base.		
		R_1	X_1	R_2	X_2	Zero sequence.
1.	2.	3.	4.	5.	6.	7.
1.	YamunaIV-Dehradun	7.728	19.706	0.089	0.226	0.791
2.	Dehradun-Rishikesh	8.240	21.012	0.095	0.241	0.844
3.	Rishikesh-J-awalapur	4.64	11.832	0.053	0.136	0.476
4.	Jawalapur-Roorkee	5.152	13.138	0.059	0.151	0.529
5.	Yamuna I-Dehradun	6.720	17.136	0.077	0.197	0.690
6.	Muradnagar-Moradabad	19.84	50.592	0.228	0.581	2.034
7.	Roork-ee-Saharenpur	4.915	12.534	0.056	0.144	0.504
8.	Ramganga-Nehtaur	6.440	15.738	0.037	0.090	0.450
9.	Nehtaur-Moradabad	13.760	25.469	0.079	0.146	0.730
10.	Roorkee-Nehtaur	17.716	32.791	0.102	0.188	0.940
11.	YamunaII-Shamli.	11.850	61.500	0.049	0.254	0.889
12.	Shamli-Muradnagar	7.663	39.770	0.032	0.164	0.574
13.	Yamuna II-Roorkee	7.631	39.606	0.032	0.164	0.574
14.	Harduaganj-Moradabad	11.060	57.400	0.046	0.237	0.830
15.	Roorkee-Muradnagar	13.035	67.650	0.054	0.280	0.98
16.	Harduaganj-Muradnagar	8.777	43.218	0.018	0.089	0.445
17.	Harduaganj-Mainpuri	10.554	51.970	0.022	0.107	0.535

TABLE -II.

DATA OF GENERATORS ON 200 MVA BASE:

Sl. No.	All Machine taken, working.	No. of machine.	Direct axis equ. reactance Xd%.	Direct axis transient reactance Xd'%.	Direct axis sub-tran. reactance Xd"%	-ve. equ. reactance X2%.	Zero equ. reac. X0%	Inertia Const. H.
1.	2	3.	4.	5.	6.	7.	8.	9.
1.	Ramganga (3x66.67 MVA)	9Nos.	99	35.20	25.30	25.85	9.90	2.260
2.	Yamuna I (3x19+3x12.5)	6Nos.	207.30	65.88	43.30	42.39	24.08	1.713
3.	Yamuna II (4x63+4x31)	8Nos.	47.94	16.00	12.68	13.03	5.32	5.828
4.	Yamuna IV (3x11.9+3x14.5)	6Nos.	197.59	98.95	65.67	61.22	24.2	1.272
5.	Yamuna I&IV (Completed)	12Nos.	101.17	38.74	26.10	25.05	12.07	2.829
6.	Harduaganj III, IV,V (2x62.5+4x63.2)	6Nos.	96.58	10.68	7.46	8.20	3.34	3.394

TABLE -III

DATA OF TRANSFORMERS

Sl. No.	Substation	Rating of each in MVA	Nos.	Rated voltage at No load in KV			Connections.			Unit values on 200 MVA Base.		
				LV	Tap	HV	LV	HV	Tertiary	-ve. sequ. of each Trans. X_1	-ve. sequ. of each X_2	Zero sequ. of each Xo
1.	2.	3.	4.	a.	5.	b.	6.	7.	8.	9.	10.	11
1.	Harduaganj	63	6	10.5		242	Δ	Y⏚		0.35	0.058	0.049
2.	Muradnagar	100	2	13.2		220	Δ	Y⏚	‖Δ	0.160	0.080	0.068
3.	Roorkee	100	2	132		220	Y⏚	Y⏚	‖Δ	0.160	0.080	0.068
4.	Yamuna I	12.50 20.00	3 3	11 11		132 132	Δ	Y⏚		2.00 1.25	0.667 0.417	0.567 0.354
											0.257	0.218
5.	Yamuna II	69.3 34.1	4 4	11 11		250 250	Δ Δ	Y⏚ Y⏚		0.376 0.765	0.094 0.191	0.080 0.162
										0.252	0.063	0.054
6.	Yamuna IV	2x11.8+ 2x14+ 2x14.45									0.476	0.405
7.	Yamuna I&IV.	3x12.5+ 3x20+ 3x11.8									0.188	0.160
8.	Ramganga	69.3	3	11		132	Δ	Y⏚		0.361	0.361	0.307
9.	Moradabad	100	2	132		220	Y⏚	Y⏚	‖Δ	0.16	0.16	0.136

CHAPTER - II.

LOAD CHARACTERISTICS AND TYPES OF LOADS

CHAPTER 2.

LOAD CHARACTERISTICS AND TYPES OF LOADS:

2.1 LOAD BEHAVIOUR :

Load flow, stability studies and load surveys are periodically carried out, and load trends are considered at various points in power system at intervals by system planners so that future power demands can be met conveniently for the worst practicable conditions. At the detailed load levels of planning. By considering various aspects, such as demand factor, diversity factors, efficiency and power factors of equipment the active and reactive power demands can be ascertained for a particular time and for the worst conditions. Owing to lack of adequate information and convienient methods of assessment induction motor loads have previously been represented for power system transient and dynamic stability studies in various ways such as by /1/.

(a) Constant shunt impedence at system nominal frequency, giving active and reactive powers directly proportional to the square of the terminal voltage.

(b) Constant current sinks, giving active and reactive powers directly proportional to the terminal voltage.

(c) Non linear loads.

All of these representations treat the loads as static and independent of frequency, but they are, in fact, dynamic and frequency dependent.

Induction motors contribute significantly to power system loads, their input active and reactive power depending upon the instantaneous magnitudes of the terminal voltage and operating frequency. In the past, the change in instantaneous speed of of synchronous m/c under disturbed conditions has been neglected, as it has been considered insignificant. However, during electro mechanical oscillations on power systems, the instantaneous frequency does change, and changes in system loads have been previously taken into account, for example, by a system damping coefficient of 2./2/. Further, the system frequency is a very powerful parameter available for adjustment by the power system controller, but information regarding load variations with instantaneous frequency is not readily available.

In the kind of disturbance with which most stability studies are concerned, loads are subjected to two kinds of voltage change :

i) Abrupt changes caused by switching, chiefly by the application and removal of a short circuit, and ii) Slow changes caused by angular sunga. For slow chnages of voltage, loads can be considered to be in steady state, varying with the voltage. For fast changes in voltage there are transients and these are difficult to represent accuratly.

3.2 TYPES OF LOADS :

An Electrical power system supplies a large number of consumers, whose demands make up a complicated system of loads. The load of an alternating current system may in general be classified into following types:-

(i) Lighting and heating load:- Filament lamps and element heaters.
(ii) Synchronous motor load.
(iii) Synchronous convertor load.
(iv) Induction motor load.
(v) Discharge lamps.
(vi) Mercury arc rectifiers.
(vii) Arc furnaces.
(viii) Electric welders.

2.21 LIGHTING AND HEATING LOAD:

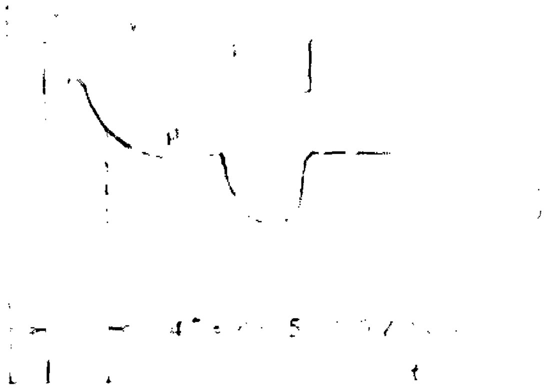
The active power consumed by the lighting load is independent of frequency and varies with voltage approximately as $V^{1.6}$. Such load consumes no reactive power. For the analysis of transient conditions the transient characteristics of this type of load can be taken to be identical with its steady-State characteristics. The lighting load can therefore be represented by a single characteristic P=f(V), shown in fig.(2.1) which also shows the corresponding change of the effective resistance. Fig.(2.2) shows the variation of P when the voltage varies rapidly.

2.22 SYNCHRONOUS MOTOR LOADS:

Assuming a constant shaft load and neglecting the losses, the power input to a synchronous motor remains fixed, independent of the voltage. The reactive power, on the other hand, will change when the voltage changes depending upon the excitation. Usually it will be found that the reactive power will change the voltage drops. In some cases a maximum point on the curve may be reached, where after the reactive power will begin to change in

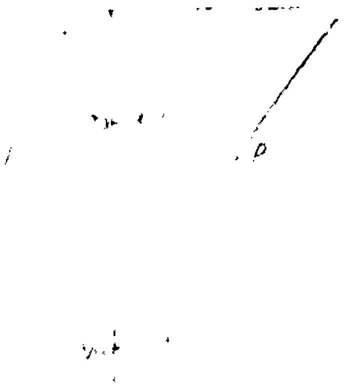
[illegible] LOAD RESISTANCE [illegible]
[illegible] REACTANCE [illegible]

FIG 2.1



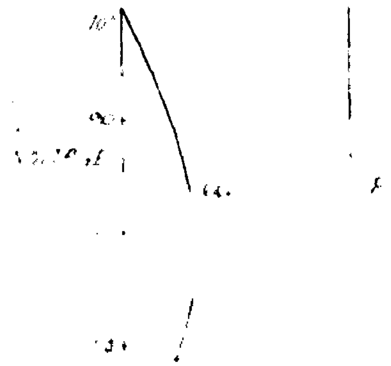
POWER [illegible] A LIGHTLY
LOADED SYSTEM WHEN CHANGED [illegible]

FIG 2.2



ACTIVE & REACTIVE POWER

FIG 2.3



CHARACTERISTICS OF SYNCHRONOUS [illegible]
OPERATING AT CONSTANT [illegible]

FIG 2.4

a lagging direction. Whether or not this will happen depends upon the amount of the voltage drops upon the design of the motor and the excitation at which it operates. The exact reactive power characteristic is then obtained from a performance chart ~~of~~ by reading off values of reactive power at constant field current and at constant power-over the desired range of terminal voltages. It may of course, also be calculated from the proper calculations.

Assuming a non salient pole m/c and neglecting resistance and other losses, the power and reactive power are given by

$$P = \frac{V\,E_a}{X}\sin\delta$$

$$Q = \frac{V\,E_a}{X}\left(\cos\delta - \frac{V}{E_a}\right)$$

The value of cos δ needed for the calculation of reactive power is obtained from equ.

$$\cos\delta = \sqrt{1-\sin^2\delta} = \sqrt{1-\left(\frac{PX}{V\,E_a}\right)^2}$$

$$\therefore Q = \sqrt{\left(\frac{V\,E_a}{X}\right)^2 - P^2} - \frac{V^2}{X}$$

This equation gives, as seen, the reactive power in terms of the constant active power, the terminal voltage and the synchronous reactance. The characteristics of a synchronous motor operating at constant shaft load are as indicated in fig(2.4)

2.23 SYNCHRONOUS CONVERTER LOAD:

The load on the converter may be either direct current lighting or direct current power. Neglecting losses, the input to the converter in the former case varies as the 4th. power of the voltage, while in the latter case it may be assumed constant

Hence the relative magnitude of the two types of load must be known. Knowing the power input, the reactive power is obtained from the performance chart/or calculated.

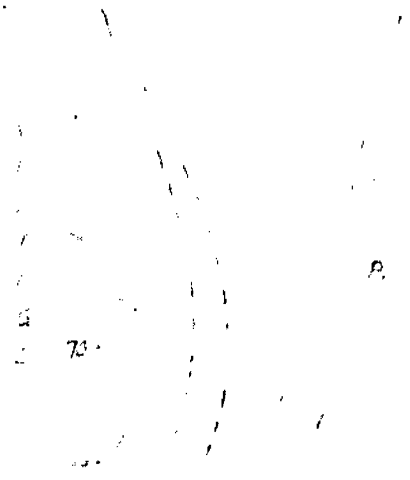
If the converter supplies direct current power only, its input characteristic versus voltage becomes as those of the synchronous motor discussed above. If on the other hand, it also carries direct current lighting, it is evident that the power input will drop off some what when the voltage drops. In fig.(2.5) are indicated characteristic of a synchronous convertor for various types of loading on the d.c.side.

2.84 A SYNCHRONOUS OR INDUCTION MOTOR LOADS :

The steady state and transient characteristics of asynchronous loads are different. The difference arises because these are induced currents when the slip changes rapidly. Fig.(2.6) shows a three dimensional diagram of the torque characteristics, and fig.(2.7) shows a family of curves which are more convinient for practical design.

If the time rate of change of slip is not too large, the transient characteristics of an induction motor for changing conditions of operation e.g. for a variable supply voltage, can be derived from a family of its steady state characteristics.

When considering the steady state characteristics of an induction motor, the problem is simplified if the stator losses are not included, but are either lumped with the line losses or combined with those of the rotor (with $r2=R_2/S$).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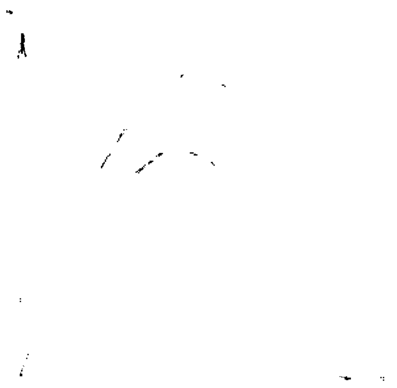

[illegible]

[illegible]

If the magnetising losses are also neglected, the induction motor may be represented by the simplified equivallent circuit shown in fig(2.8);

The active power taken by the motor and the torque developed are determined under these condition by the mechanical torque demanded by the driven mechanism, i.e. by its charactrics T mech. = f(s). The changes of P & T depend upon the characteristic of the supply and of the driven mechanisms.

To simplify matters it is assumed that the mechanical torque T mech. is independent of the slip. All the equations are hence forth expressed in per unit quantities. Hence for steady conditions, neglecting losses

P Mech. = T mech. and

Pel = P mech. = P = $3I^2 \frac{R2}{s}$ = Constt.

Hence $s = 3\frac{I^2}{P} R2$ or $s \propto I^2$

The equivalent circuit of fig.(2.8) shows that the reactive power Q taken by the motor consists of two components, Qu the magnetising power associated with the magnetising current Iu and Qs associated with the stator and rotor leakage. Hence with the above assumptions:

$Qu = \frac{V^2}{Xu}$, $Qs = 3I^2 xs$ and

$Q = Qu + Qs$

When saturation occurs the value of X/u decreases and the relation between Qu and V departs appreciably from a square law.

The relation between the supply voltage and the slip is readily obtained from the equivalent circuit of fig. (2.8).

$$P = 3I^2\frac{R2}{S} = \frac{V^2}{\left(\frac{R_2}{S}\right)^2 + X_m^2} \times \frac{R_2}{S} = \frac{V^2 R_2 S}{R2 + (S X_m)^2}$$

$$\frac{V^2 R S}{R_r^2 + (S x_m)^2}$$

Fig. (2.9) gives a family of curves showing this relation for various values of the voltage V. The relation between S and V, for a given value P, is also shown in fig. Since $Q = 3I^2 x_m$ and [illegible] I^2 S for a constant mechanical torque, the relation QS=f(V) has the same shape as the relation S=f(V) as shown in fig.(2.10).

The curves show that, for any given value of the mechanical load P mech, the motor has a critical slip Scr and critical voltage VCr. The maximum power P max. which the motor can develop is then exactly equal to the mechanical power demand d, and operation at a lower voltage is not possible, because the electrical power would then be less than the mechanical power.

The critical slip and critical power are determined mathematically by differentiating the expression for P in equation with respect to S equating to zero.

$$\frac{dP}{dS} = V^2 R_2 \frac{R_2^2 - (S x_m)^2}{(R_2^2 + (S x_m)^2)^2} = 0$$

$$\text{Hence} \quad S_{cr} = \frac{R_2}{X_m}.$$

$$P\ \text{max.} = \frac{V^2}{2X_m}.$$

Fig.(2.10) shows the curve of $Q_\mu = f(V)$, the curve of QS=f(V) and the curve of total reactive power $Q = Q_\mu + Q_S = (f(V))$. The point $Q = Q_{cr}$, $V = V_{cr}$, at which $dQ/dV = -\infty$, or $dV/dQ = 0$, corresponds to operation at the point 4 on fig.(2.9).

It may be noted that, if the slip is less than the critical value, dP/dS is always positive and the motor operationis stable. Any accidental change of the slip, or of the rotor angle, brings about an imbalance between the electrical accelerating torque and the mechanical breaking torque causing the rotor to return to the origineal condition of operation. It can be easily seen that this occurs at point 1,2,3, of fig(2.9).

On the other hand, at points 5,6,7, the value of dP/dS is negative and the operation is unstable since a small change of slip increases the imbalance between the electrical and mechanical torques and leads to a further increase in slip. The point 4 is of particular interest, because it lies at the boundary between stable and unstable operation.

2.24.1 STEADY STATE LOAD CHARACTERISTICS :

The total load characteristics for both active and reactive power can be obtained by adding together the lighting load, the motor load and the power losses in the cables and transformers. Typical characteristics for an induction motor are shown in fig.(2.11)(a) and for a composite load in fig.(2.11)(b). These show that for typical loads at normal voltage, the slope dP/dV varies between 0.5 and 0.75 and the slope dQ/dV varies between 1.5 and 2.5.

The composite load supplies by a power system can, for calculation purposes be represented

(a) (b)

[illegible]

either by an equivalent circuit which includes lighting and induction motor loads or by characteristics derived from an equivalent circuit. The characteristics can then be further simplified, as shown in fig.(2.12). It is assumed that active power P and the reactive power Q are related to the voltage. In fig.(2.12)(b), both P & Q are assumed to vary as the square of the voltage. With the latter assumption the equivalent impedence ZL of the total load may be represented either by a parallel or a series equivalent circuit. For the parallel

$$R_L = \frac{V^2}{P_L} , X_2 = \frac{V^2}{Q_L}$$

For the series circuit

$$Z = R_L \pm jx_L , -\frac{V^2}{S} = \frac{V^2}{S} (\text{Cos}.\emptyset \; a\pm \sin\emptyset)$$

Where S is the total complex power supplied to the load and S is its modulus.

These simplifications have a certain range of Practical application. The simplest assumtion, that the power is independent of the voltage, is appropriate for steady state conditions. Such calculations start by assuming the power derived at various points in the nett work to be independent of the voltage. The assumption is justified if the voltage at the customers terminals is maintained constant; independently of any variation of the voltage of the high voltage transmission line. The customer's voltage would be held constant by [illegible] changes in transformer taps or by using static or synchronous condensors.

It is obvious that the characteristics P=Const. and Q= Constt. are not applicable to transient conditions. The use of approximate steady state characteristics; taking the tangents (Δ_1+K_1V) and $(-\Delta_2+K_2V)$ as in fig.(2.11) (a), gives good results for transient conditions only if the voltage variations are small. Otherwise the error is likely to be considerabl~~y~~e.

The power taken by a composite load also varies with frequency. As already mentioned an ordinary lighting load is independent of frequency, although this is not true for gas discharge lamps, for which power consumed decreases by 0.5-0.8 percent, if the frequency increases by 1%. However, in general the manner of variation of power with frequency for a composite load is determined almost entirely by its induction motor component.

If the output torque T mech at the motor shaft is constt. the active power P taken by the motor is proportional to the frequency P=WT fig.(2.13).

For an induction motor with normal design constants, a drop in frequency causes ~~and~~ a drop in slip, as shown in fig.(2.14) according to

$$T=\frac{V^2R_2S}{\left\{R_2^2+\left(\frac{W}{W0}SX0\right)^2\right\}W}.$$

or very approximately, $S\propto f$, if T is constant.

The relative power taken by the motor also varies with the frequency. The determine the manner of variation it is necessary to consider separately the frequency characteristics of its two components QS and Q^U.

Taking $S=3\frac{I^2R2}{WT}$ and $QS=3I^2\frac{X0}{W0}V$, It follows that $I^2 \propto Us$ and $Q_s \propto V^2 s \propto Fs^2$.

This Qs decreases when the frequency falls and increases with frequency rise.

The other component of the reactive power Qu increases with decreasing frequency, since

$$Qu = \frac{V^2}{\frac{Xu0}{UC}V} \propto 1/f$$

For a normal induction motor the variation of the total reactive power Q=Qs+Qu is determined mainly by the first component when the change of frequency is small, but the second component is important when there is a considerable rise of frequency (fig.2.15).

fig.(2.16 gives frequency characteristics for a typical load. They show that at nominal voltage (V=1) and at nominal frequency the value of the slope dQ/df is about -0.8 to 1.2, while that of the slope dP/dQ is about 1.7 to 2.5.

Hitherto it has been assumed that the variations of voltage and frequency are independent of each other. In practice, however, frequency changes are often accompanied by voltage changes. A variation of frequency is usually caused by an imbalance between the electrical output of the prime movers. The change of frequency, as shown above, changes reactive power taken by the load and the active and reactive power losses in the nett work, and hence causes a change of voltage. A decrease of frequency generally causes a decrease of voltage. The curves in fig.(2.17) show how the active and reactive power components change when the frequency and voltage vary simultaneously.

Assuming a given value of the shaft torque T mech., the curves show that, for a frequency below normal, the maximum electrical torque and the critical slip increases, while the operating slip decreases. Thus a decrease of frequency affects the motor operation in a similar manner to an increase of voltage. Consequently, if the frequency is below normal, a larger drop of voltage can be tolerated without danger of losing stability. In other words, the critical voltage is lower, if the frequency is below normal.

This effect is illustrated in fig.(~~D~~ 2.17) (b) which shows the displacement of the characteristics Q=f(V) due to a change of frequency and the corresponding shift ofthe point at which dQ/dV=   .Thus the lowering of the frequency and the consequent decreases of power demand (fig. 2.16) and of the critical voltage can be regarded as desirable properties, which tend to improve the stability of a heavily loaded system operating below normal voltage. However, this kind of operation is not acceptable, except in quite abnormal conditions.

2.5 DISCHARGE LAMPS :

These have higher colour temperature, high luminous ~~flask~~ flux per watt and longer life thanfilament lamps, and accordingly have become increasingly popular. All discharge lamps, require a stabilising ballast which may be a resistance, inductance or capacitance, but the most common is the inductive ballast. The ballasts have core losses which depend on the instantaneous frequency and flux density when the voltage is held constant, an increase in instantaneous frequency gives a reduction in magnetic flux density in the iron cores; in this way the increase in core losses due to frequency changes alone is approximately off set by reduction in core losses due to flux density changes.

Fig.(2.18) shows an equivalent circuit for a discharge lamp. The effective resistance of the lampcircuit upon the instantaneous current. Fig.(2.19) indicates the active and reactive power inputs to a typical combination of discharge lamps against frequency; the results indicate 1.02% reduction in active power and 1.15% reduction in reactive power when the operating frequency rises by 1% in the absence of shunt compensation. Operating power factor varies from 0.5 to 0.55; consequently shunt capacitors are usually employed to improve these values to between 0.8 to 0.9; either individually or in groups.In the presence of shunt capacitors the active power remains unaffected, but the rate of fall of reactive power with frequency is increased as shown in fig.(2.20)/1/.

2.26 MURCURY ARC RECTIFIES :

In the last decade, the mercuryarc rectifier has been used extensively for d.c.transmission links, and, investigating these systems for stability under disturbed conditions, it has been represented in detail. In studies on industrial applications, however, mercury arc rectifiers have been represented simply by shunt impedance independent of frequency; it is necessary here to consider frequency dependent representation. Fig.(2.21) indicates an equivalent circuit of a mercury-arc rectifier in which the plasma resistance is a very small part of the total resistance of the circuit and the total effective resistance of the circuit can be treated as constant. The inductive reactance is frequency dependent and its variation with instantaneous frequency will effect the active and reactive power in puts.

By controlling the firing angle, the mercury arc rectifier can be operated either for constant voltage out put or ~~cor~~ constant current output (as in electro chemical processes). Fig.(2.22) indicates active and reactive power in puts to a mercury arc rectifier when supplying a constant direct load current. The active power reduction with rise in frequency is small for this constant resistance inductive load, and is of the order of 0.5% for 1% increase in frequency, reactive power reduction is 1% for 1% increase in frequency /14

2.27 ARC FURNACES :

The arc has a falling voltage/current characteristic, as shown in fig.(2.23) and is consequently unsuitable for a constnt voltage supply. For satisfactory operation, a stabili~~ty~~sing series resistance or react~~ive~~ance i~~n~~s essential and in general, transmission voltage with high leakage reactance usually supplemented by series reactors, are employed. Long electric arcs in air have also been observed with slightly rising voltage/current characteristics, but usually the characteristic is falling. The total react~~ive~~ance in the circuit depends upon the instantaneous frequency. Fig.(2.24) indicates an equivalent circuit for an arc furnace. The arc resistance is current dependent and falls when the current rises, resulting in a reduced arc voltage, as shown in fig.(2.23).

Considering the voltage drop across the total effective resistance of the circuit (A to B), the fall in arc voltage due to rise in current is approximately compensated for by the increased voltage drops due to the resistances of the main transformer, buffer reactor, furnace transformer, leads and electrode. In this way, the voltage drop across the effective resistance of the circuit becomes approximately constant, indicating that $R \propto 1/I$, an the input active power is directly proportional to the furnace current. From the characteristics, of arc furnace, it is observed that the total in put active power to an arc furnace is directly proportional to the arc current over the working range.

An arc furnace load varies violently during the whole of its operation, except during refining. The violent change in active and reactive power drawn from a power system causes violent voltage fluctuations and results in lamp flicker. In order to investigate the effects of arc furnaces in a power system, a comprehensive survey of arc furnace installations was carried out with the object of reducing objectionable buffer reactors and synchronous compensators, and later, series capacitors. The inclusion of buffer reactors is simple and cheap, but affects the over all power factors. As the inductive reactance is frequency dependent, the input active and reactive power are inversely proportional to the instantaneous frequency. Fig.(2.25) indicates active & reactive power inputs to a 45 ton arc furnace with and without buffer reactor. The synchronous compensator, if installed, will provide the entire reactive power for the arc furnace at full load and roughly 50% of that absorbed in the buffer reactor. In this situation, the synchronous compensators should be treated dynamically for stability studies of the power system as a whole.

2.28 ELECTRIC WELDERS:

For both arc welding and resistance welding, the electrodes are supplied by special high leakage reactance transformers and usually operate at 0.2-0.3 power factor. In this case, the power drawn by a welder will be either full on or off, and this causes violent fluctuations in active and reactive power inputs and causes lamp flicker; For this purpose, series capacitors are used owing to their instantaneous response. The presence of series capacitors in welder circuits aggravates the variation in active and reactive power inputs when the instantaneous operating frequency changes fig.(2.26) indicates the active and reactive power inputs to a 200 KVA welder with and without capacitors.

2.3 APPLICATION TO STABILITY PROBLEM :

The factors which have been discussed may be important in assessing power system stability. Necessarily information is required on the composition and type of power system loads.

The loads usually receive their power over the distribution nett work through distribution transformers. The distribution nett work is connected to the substations which in turn are supplied from the generating stations over over head or under ground transmission lines or feeders. In stability investigations, each system load can be devided with the aid of load survey into four parts:

(a)Murcury-arc rectifiers, arc furnaces and electric welders.

(b) Resistance loads.

(c) Induction-motor loads.

(d) Lighting loads.

Murcury arc rectifiers used for electrochemical purposes can be adequately represented by constant current sinks as far as the bus voltage is concerned, and by constant resistance inductive circuits for frequency-dependent considerations.

The resistance load can be represented by fixed shunt conductance, whereas the induction motor loads can be handled dynamically and frequency dependently.

From above it is observed that the effective instantaneous resistance of discharge-lamp loads and arc furnace loads varies inversely with the instantaneous value of current. Such loads are predominately affected by voltage, particularly for reactive power demands.

The usual operating power factor for discharge lamp loads is 0.5-0.55 lagging when the bus voltage falls to 50% or below under disturbed conditions, the lamp will extinguish and consequently the inductive port of the load will disappear, leaving only the capacitive part. Similarly arc furnace loads, which normally operate at 0.707-0.9 power factor, will turn off if the bus voltage falls below 75% of normal, under disturbed conditions, owing to inadiquate voltage available to maintain the arc.

Lighting loads consists mainly of discharge lamps, as pointed out above. The discharge-lamp loads and arc furnace loads need special attention in stability studies because of possible inadequate voltage. They can be represented by an inductive circuit having current dependent resistance and instantaneous frequency dependent reactance.

In stability investigations it is inpracticable to include all individual loads properly in the analysis and still it is important to introduce at least the approximate effect of the load action.

2.4 DEVELOPMENT OF LOAD CHARACTERISTIC OF SYSTEM CONSIDERED:

As already mentioned that ~~the~~ we have chosen the Western U.P.Grid as our working system with Muradnagar load. Voltage and frequency dependent and all other loads considered as constant impedence.

The total load fed from Muradnagar is of the order of 184 MW at 0.9 P.F. as has been considered in the load flow studies on nett work ~~analyser~~ analyser at Banglore carried out by U.P.State Electricity Board in September, 1967. There are four major Generating Stations namely, Ramganga, Yamuna Stage I, Yamuna Stage II and Harduaganj in the Grid. The Eastern U.P.Grid has been truncated at Mainpuri, taking it to be as infinite bus for our system.

The various loads, for the purpose of analysis have been taken into following proportions;

	%	Active MW.	%	Reactive MVAR.	P.F.
1. Light load	10%	18.4	-	-	100%
2. Discharge lamps.	15%	27.6	15%	7.8	
3. Furnace load	10%	18.4	10%	5.2	
4. Electric welders	5%	9.2	5%	2.6	
5. Induction motor.	60%	110.4	70%	36.4	
Total:		184.0		52.0	

2.42 DYNAMIC AND FREQUENCY DEPENDENCE CHARACTERISTICS:

As is already said, the loads in the system are frequency dependent also, except for the light loads. This effect is very much marked in case of induction motor. Full load slip of induction motors normally varies from 5.5 to 1%; inertia factor varies from 0.1 to 0.3 and magnetising current varies from 50 to 20 % of the full load current, for general purpose induction motors, over a range of 1 to 1000 H.P.

It has been verified in practice that the inertia factor contribution of loads such as drilling, grinding, milling and spinning machines, fans, lathes, pumps, compressors etc. is quite significant, and at least equal to that of the driving motor. Installations with the exceptionally high inertia factor such a-s ward leonard- Illgner speed control large motors falls under the category of important induction motors and should be considered seperately.

Comparatively little is known about the behavious of loads for changing frequency. Some work has been done by Mr.M.Y.Akhtar and the characteristics of various loads with reference to frequency have been plotted and Published /1/,/2/. To study the dynamic and frequency dependent ~~behaviour~~ behaviour of induction motors and other loads, a frequency range of 50 ± 2.5 C/S has been selected. The 2.5 C/S change has been distributed over 18 intervals each of 0.05 secs. as shown in fig.(2.27) below; the low of variation closely correspo-nds to the ~~sining~~ swing curves of synchronous m/c under disturbed conditions, [illegible]

The curves plotted by Sri Akhtar have been made use of to plot the composite load characteristic of our system; as noted in the table below and shown in fig.(2.28).

Frequency f	Active power P	Reactive power. Q
48	192.75	54.18
49	187.98	52.98
50	184.00	52.00
51	186.21	51.70
52	186.98	51.46

As will be seen from the characteristics, the active power first decreases as the frequency increases upto 50 and then it again starts increasing while the reactive power decreases. For simplifying the further analysis the characteristics are being assumed to approximate straight line. As we see from the characteristics;

$$\frac{\Delta P}{\Delta f} = \frac{184.0-192.75}{50-48} \qquad (2.1)$$

$48 < f < 50$ $= -\frac{8.75}{2} = -4.375$

i.e. $\frac{\Delta P}{\Delta f} = K31 = -4.375$

$48 < f < 50$

and $\frac{\Delta P}{\Delta f} = \frac{186.98 - 184.0}{52-50} = \frac{2.98}{2} = 1.49$

$50 < f < 52$

i.e. $\frac{\Delta P}{\Delta f} = K32 = 1.49$ - (2.2)

$50 < f < 52$

Similarly

$\frac{\Delta Q}{\Delta f} = K4 = \frac{51.46 - 54.18}{52-48} = -\frac{2.72}{4}$

$48 < f < 52$ $= -0.68$ (2.3)

2.43 LOAD VOLTAGE CHARACTERISTICS :

The response of nearly all loads to voltage changes can be represented by some combination of constant impedance, constant current and constant MVA devices. Actually, the constant current model is unnecessary as it is nearly equivalent to 50 per-cent constant impedance load combined with 50 percent constant MVA load.

The constant MVA type load representation from the system stability point of view because of its effect in amplifying voltage oscillations; a drop in voltage will cause an increase in load current resulting in a further voltage drop. Conversely, constant impedance loads have a decided damping effect on voltage oscillations.

Individual loads may be viewed as being devided into two classes, static and rotating. The static class consists of heating and lighting equipment will generally exhibit a constant near unity power factor. The different characteristics of static loads tend to compensate each other, resulting in a composite effect of constant impedence load.

The rotating class of loads consists of synchronous motors and induction motors driving equipment with a variety of torque speed characteristics. Motors will normally be constant MVA devices for moderate voltage changes, although the power factor may vary widely.

Recognising the need for a factual basis for load representation, the southern california Edison company organised a field testing program in 1965 and 1966 /3/. The selected tests consisted of gradual and rapid voltage changes on 66 KV buses in three 220/66 KV stations; each having more than one half the connected substation load in a single category.

Tests were carried out at selected hours and days of the week during the general periods of summer peak, winter peak and spring minimum to enable evaluation of load response for the usual conditions assumed in stability studies.

To measure the load and voltage changes a portable test instrumentation board was constructed and moved to each test site, voltage and current signals from stations metering transformers were fed into a metering unit to establish initial conditions and to veryfy test connections. A phase shifting transformer was used to seperate watt and var reading. From the metering unit, current and voltage were fed into a Hall effect four channel transducer equipped with suppressed Zero capability. DC signals from the transducer were amplified to drive a light beam oscillograph recorder and these oscillographs from the test recorder were replotted on sealed paper for analysis.

According to H.A.Peterson, University of Wisconsin, Madison, the experimental results are interperated in terms of the three often used ways of load simulation , constant MVA, constant current, and constant impedence/4/. Any one of these three is particular case of the more general per unit relation ship $P=V^n$. For example, if $n=0$, the load is one of constant current, and if $n=2$, the load is one of constant impedence. Other neon integer values of n, including values greater than 2, could be used if experimental results, so dictate. It has further been given in the paper that any composite load can be represented by a single V^n term where

$$n=Q_1N_1+a_2N_2+a_3N_3$$

a_1, Q_2 , a_3 being the fractional loads, to and N1,N2,N3 are the corresponding exponents; the value of which being given as

$N1 = 1.36$ for pure residential loads.
$N2 = 0.264$ for commercial industrial loads.
$N3 = 0.353$ for agriculmral type loads.

In our case we have only 2 tyepes of major loads i.e. residential and industrial being taken as 25% & 75% respectively. Thus we will have

$n=0.25 \times (1.36) + 0.75 \times (0.26)$

$=0.34 + 0.195$

$=0.435$

we will thus have

$P = P_{normal} V^n$

$Q = Q_{normal} V^n$

i.e. $P = \frac{184}{200} V^{0.435}$

$= 0.92 V^{0.435}$ (in P.U.)

$Q = \frac{52}{200} V^{0.435}$ (in P.U.)

$= 0.26 V^{0.435}$

giving thereby

$\frac{\Delta P}{\Delta V} = nK1 V^{n-1}$ $n=0.435$

or $\Delta P = nK1 V^{n-1} \Delta V$ (2.4) $K1=0.92$

and $\Delta Q = nK2 V^{n-1} \Delta V$ (2.5) $K2=0.26$

Thus with the help of equation (2.1),(2.2),(2.3), (2.4) and (2.5) give the change in power due to change in frequency and voltage in an interval. We can have the power equation as, at any instant

~~[illegible]~~

$$\left.\begin{aligned} P_{\substack{now \\ 48<f<50}} &= nK1V^{n-1} \Delta V + K31 \Delta f + P_{old} \\ P_{\substack{now \\ 50<f<52}} &= nK1V^{n-1} \Delta V + K32 \Delta f + P_{old} \end{aligned}\right\} \quad (2.6)$$

$$Q_{\substack{now \\ 48<f<52}} = nK2V^{n-1} \Delta V + K4 \Delta f + Q_{old} \quad (2.7)$$

depending upon the change in voltage and frequency range the value of power at regular time intervals can be worked out with the help of equ.(2.6) and (2.7). These equations shall be made use of at the time of plotting the swing curves in chapter 3, when the system is considered as dynamic and frequency dependent. ~~is considere~~. The values of n,K1,K31,K32, K2 and K4 will have the values as worked out in this section.

CHAPTER - III.

STABILITY STUDIES

CHAPTER- III.

STABILITY STUDIES

3.1 TRANSIENT STABILITY STUDIES WITH CONSTANT IMPEDENCE LOADS :

In the first phase of our study of the stability of the system, all the loads including that at Muradnagar have been treated as constant impedence loads and the effect of change in frequency on the load has not been considered. In the following section detailed procedure of the stability study is outlined.

Refering to the single line diagram shown in fig. (1.1) of the system, a 3 phase fault is considered to occur on the line between Roorkee and Muradnagar. Though a 3 phase fault is not as common, as a single line to ground fault, it creates a severer disturbance so that the results of the study are conservative. The procedure given need only minor modifications to deal with unbalanced faults.

*/INITIAL 3.11 /ADMITANCE MATRIX FORMATION:

The system is shown in fig.(1.1). The various admitances between the nodes have been worked out based on the data shown in table 1 of chapter I and the power flow details shown in fig.(1.2).

The generators are represented by the voltage behind transient reactance in series with the transient reactance.

~~Since~~ Such a representation though not strictly correct is sufficiently accurate for multimachine stability studies.

The generator E.M.F. have also been shown in the diagram.

The infinite bus voltage has been taken as the reference phasor and the relative angle value of the other generator E.M.F. will therefore be as follows:

(i) Bg.Yamuna Stage I & IV. $=1.093 (37.3^0$
(ii) Bg.Yamuna Stage II $=1.102 (39^0$
(iii) Bg.Ramganga $=1.0718 (35^0$
(iv) Bg.Harduaganj $=1.1 (27.5^0$
(v) Bg.Mainpuri $=1.025 (0^0$

The inertia factor, power delivered by each generating station is shown in fig.(1.1).

As will be seen from the fig.(1.1), there are 15 nodes; the driving point and transfer admittance of nodes has been worked out, considering a 3ϕ fault on the 220 KV Roorkee-Muradnagar line and are listed in Appendix-I. When the fault is cleared, it is evident that only the driving point and transfer admittance values of bus 6 and 10 will change and these values will be as follows:

(i) One clearing the fault
$Y6,6 = 1.737-j29.80$
$Y10,10=7.136-j14.992$
$Y6,10=Y10,6=0-j0$

(ii) On reclosing the breaker at both ends:
$Y6,6=2.403-j\ 33.26$
$Y10,10=7.602-j\ 19.452$
$Y6,10=Y10,6=0.666-j\ 3.46$

The above values have been taken into account at the proper place of calculating the swing curve points.

Now we can have the node current equation, by Kirchof's first law as

$$I_n = Y_{n,1} E_1 + Y_{n2} E_2 + \dots Y_{n,n} E_n \qquad (3.1)$$

where In is the current going out from any node n of the system, $E_1, E_2, E_3 \text{---} E_n$ are the nodal voltages at any instant and $Y_{n,1}, Y_{n,2} \text{---} Y_{nn}$ being the transfer and driving point admitance of the nth node.

Equation (3.1) is a complex equation and can be Re-written separately for its real and imaginary components as follows:

if $E_n = E_n + jE_n'$, $I_n = I_n + jI'_n$ and $Y_{ij} = g_{ij} - jb_{ij}$

then

$$I_n = g_{n,1} E_1 + b_{2,1} E_1' + g_{n,2} E_2 + b_{n,2} E_2' + \text{---} g_{n,n} E_n + b_{n,n} E_n' \qquad (3.2)$$

and

$$I_n' = b_{n,1} E_1 + g_{n,1} E_1' - b_{n,2} E_2 + g_{n,2} E_2' + b_{n,n} E_n + g_{n,n} E_n' \text{ --- } \qquad (3.3)$$

With the help of equation (3.2) and (3.3) we can write the matrix equation for the system as

$$\begin{bmatrix} I_1 \\ I_1' \\ I_2 \\ I_2' \\ \text{---} \\ \text{---} \\ \text{---} \\ I_n \\ I_n' \end{bmatrix} = \begin{bmatrix} g_{1,1} & b_{1,1} & g_{1,2} & b_{1,2} & \text{---} & g_{1,n} & b_{1,n} \\ -b_{1,1} & g_{1,1} & -b_{1,2} & g_{1,2} & \text{---} & -b_{1,n} & g_{1,n} \\ g_{2,1} & b_{2,1} & g_{2,2} & b_{2,2} & \text{---} & g_{2,n} & b_{2,n} \\ -b_{2,1} & g_{2,1} & -b_{2,2} & g_{2,2} & \text{---} & b_{,2n} & g_{2,n} \\ \text{---} & \text{---} & \text{---} & \text{---} & & \text{---} & \text{---} \\ \text{---} & \text{---} & \text{---} & \text{---} & & \text{---} & \text{---} \\ \text{---} & \text{---} & \text{---} & \text{---} & & \text{---} & \text{---} \\ g_{n,1} & b_{n,1} & g_{n,2} & b_{n,2} & \text{---} & g_{n,n} & b_{n,n} \\ -b_{n,1} & g_{n,1} & -b_{n,2} & g_{n,2} & \text{---} & -b_{n,n} & g_{n,n} \end{bmatrix} \begin{bmatrix} E_1 \\ E_1' \\ E_2 \\ E_2' \\ \text{---} \\ \text{---} \\ \text{---} \\ E_n \\ E_n' \end{bmatrix}$$

We have got 15 ~~centre~~ nodes in our system, so by

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resolving real and imaginary port of the currents, we shall have a 30x30 matrix as above.

Bus no. 1,2,3,4,5 and 6 are of importance for us as we have to plot the swing curves for generating units at bus 1,2,3,4;5th.being the infinite bus and 6th the load bus. We shall therefore first reduce our nett works of fig.(1.1) confinned to these 6 nodes and all others being eleminated.

3.11.1 NODE ELEMINATION BY MATRIX ALGEBRA-/7/.

The nodes at which current does not entre or leave the nett work can be eleminated. The standard node equations in matrix notation are expressed as

$$\begin{bmatrix} I \end{bmatrix} = \begin{bmatrix} Y \end{bmatrix} \begin{bmatrix} V \end{bmatrix} \quad \text{---} \qquad (3.5)$$

Where I and V are column matrics and Y is a symmetrical square matrix. The colymn matrices must be so arranged that elements associated with nodes to be eleminated are in the lower rows of the matrices. Elements of the square admitance matrix are located correspondingly. The column matrices are partitioned so that the elements associated with nodes to be eleminated are separated from the other elements. The admitance matrix is partitioned so that elements idantified only with nodes to be eleminated are separated from the other elements by horizontal and vertical lines. When partitioned according to these rules, the equation (3.5) becomes

$$\begin{bmatrix} IA \\ IX \end{bmatrix} = \begin{bmatrix} K & L \\ L & M \end{bmatrix} \begin{bmatrix} VA \\ VX \end{bmatrix}, \quad \text{---} \quad (3.6)$$

Where IX is the Sub-matrix composed of the currents entering the nodes to be eleminated and VX is the sub-matrix composed of the voltages of these nodes. Of course, every element in IX is Zero, for the nodes could not be eleminated otherwise. The self and mutual admitances composing K are those identified only with nodes to be retained. M is composed of self and mutual admitances identified only with nodes' to be eleminated. L and its transpose Lt are composed only those mutual admitance common to a node to be retained and to one to be eleminated.

Performing the mutliplication indicatd in equation $^{n}{}_{3.6}$, gives

$$IA = KVA + LVx \quad \text{---} \quad (3.7)$$

and

$$Ix = LtVA + MVx \quad \text{---} \quad (3.8)$$

Since all elements of Ix are Zero, subtracting $Lt.V_A$ from both sid s of equation n (3.8) and multiplying both sides by M^{-1} yeild

$$-M^{-1}LtV_A = Vx \quad \text{---} \quad (3.9)$$

This expression for Vx substituted in equ.n (3.7) gives

$$IA = KV_A - LM^{-1}LtV_A \quad \text{---} \quad (3.10)$$

Which is a node equation having the admitance matrix

$$Y = K - LM^{-1}Lt \quad \ldots. \quad (3.11)$$

This admitancematrix enables us to construct the circuit with the unwanted nodes eleminated, and same principle will now be made use of to our problem to reduce the system by eleminating the unwanted nodes as mentioned herein above.

3.11.2 REDUCTION OF SYSTEM ADMITANCE MATRIX :

As has been mentioned above, we have 15 nodes in our system, giving a 30x30 admitance matrix. We shall first eleminate all the nodes except for 1,2,3,4,5 and 6. The admitance matrix, based on the principle described in section 3.11.1 can be written and devided as follows:

&

$$\begin{bmatrix} I_1\\ I_2\\ I_3\\ I_4\\ I_5\\ I_6\\ I_7\\ I_8\\ -\\ -\\ -\\ I_{15}\end{bmatrix} = \left[\begin{array}{ccc|ccc} Y_{1,1} & \cdots & Y_{1,6} & Y_{1,7} & \cdots & Y_{1,15}\\ \vdots & A & \vdots & \vdots & C & \vdots\\ Y_{6,1} & \cdots & Y_{6,6} & Y_{6,7} & \cdots & Y_{6,15}\\ \hline Y_{7,1} & \cdots & Y_{7,6} & Y_{7,7} & \cdots & Y_{7,15}\\ \vdots & Ct & \vdots & \vdots & B & \vdots\\ Y_{15,1} & \cdots & Y_{15,6} & Y_{15,7} & \cdots & Y_{15,15}\end{array}\right] \begin{bmatrix} E_1\\ -\\ -\\ -\\ -\\ Vm\\ E_7\\ -\\ -\\ -\\ E_{15}\end{bmatrix}$$

Where I_1, I_2, I_3 -- I_6 are the current entering or leaving nodes to be retained and I_7, I_8---I_{15} are currents leaving or entering the nodes to be eleminated which are Zero. The E_1, E_2, E_3--E_{15} are the node voltages, Vm being the voltage of bus no. 6 at the load terminals; the admitance matrix has been arranged on the same principle.

With the names given to various partitioned matrices as shown above, we will have the admitance matrix for the retained nodes as

$$\underset{12x12}{\begin{bmatrix} Y \end{bmatrix}} = \underset{12x12}{\begin{bmatrix} A & C \end{bmatrix}} \underset{12x18}{\begin{bmatrix} B \end{bmatrix}^{-1}} \underset{18x18}{\begin{bmatrix} 0 \end{bmatrix}^{t}} \; 18x12 \quad \text{—— (3.12)}$$

Based on equation^n (3.12) we can write the admitance matrix for the 6 nodes as

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} = \begin{bmatrix} \\ \\ Y \\ \\ \\ \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \\ E_5 \\ Vm \end{bmatrix}, \quad \text{— (3.13)}$$

Since we know the value of load admitance at bus no. 6, the above can further be simplified for the generator voltage and currents as follows

$$\begin{bmatrix} I \\ I_6 \end{bmatrix} = \begin{bmatrix} Y_1 & Y_2 \\ Y_{2t} & Y_3 \end{bmatrix} \begin{bmatrix} E \\ Vm \end{bmatrix} \quad \text{—— (3.14)}$$

Where I and E are the generator currents and E.M.F!S and Y_1, Y_2, Y_3 V_{2t} are the admitance matrizes obtained from partitioning the Y Matrix on the principle as described in section 3.11.1 above.

Performing the multiplication indicated in equ.^{n} 3.14 gives

$$I = Y1E + Y_2Vm. \quad \text{——} \quad (3.15)$$

$$I_6 = Y_2^tE + Y_3Vm = -YmVm \quad \text{——} \quad (3.16)$$

From equ.n(3.16), we have

$$Vm = \begin{bmatrix} -Ym-Y_3 \end{bmatrix}^{-1} Y_2^t E \quad \text{—— (3.17)}$$

Substituting the value of Vm from equ.n(3.17) to equ.n(3.15), we get

$$I = Y_1 E + Y_2 \left[- Ym - Y_3 \right]^{-1} Y_2^t \; E$$

$$= \left[Y_1 - Y_2 \left[Ym + Y_3 \right]^{-1} Y_2^t \right] E$$

i.e. $I = RE$

Where $R = Y_1 - Y_2 \left[Ym + Y_3 \right]^{-1} Y_2^t$ --- (3.18)

Thus equation (3.18) gives a matrix R which relates only the generator voltages and currents and may be used to obtain the swing curves of the generating units. A detailed degital computer programme to obtain the R matrix from the original 30x30 matrix and to plot the swing curve there from has been developed in the following section and discussed further.

3.12 PLOTTING OF SWING CURVE :

For the purpose of plotting the swing curves of the m/c of four generating units, the 3φ fault has been considered on the 220 KV Roorkee-Muradnagar line. The system, in the initial conditions has been considered to be stable and the m/c torque angle deviations have been calculated by the step by step method taking the time interval of 0.01 sec., The fault has been allowed to persist from 0.0 to 0.1 sec. and then it is cleared after 0.1 sec. alowing the line to remain open upto 0.6 sec., when it is desired to reclose the breakers at both the ends. The time angle relations have been shown in table 4 and the swing curves have been plotted and shown in fig.(3.1). The detailed computor programme starting from the reduction of admitance matrix, upto getting the torque angles for each machine, alongwith the corresponding data and results as obtained from the computor are given on appendix II and III for time interval from 0.0 to 0.1 sec. and 0.1 to 0.6 sec. respectively.

3.22.1 APPROACH TO THE COMPUTOR PROGRAMME AND FLOW CHART:

The following approach for framing the computor programme may be used.

1. The initial value of $E_1, E_2, E_3, E_4, E_5 P_1, P_2, P_3, P_4, H_1, H_2, H_3, H_4, D_1, D_2, D_3, D_4, D_5$ are known.
2. Frame the system admitance matrix in the manner as discussed in section 3.11.1 for fault on condition.
3. Solve equation (3.12) to get (Y) matrix.
4. Simplify further to solve equ.(3.18) to get I R Z matrix.
5. Calculate driving point and transfer admitances and admitance angle of the remaining 5 nodes.
6. Find the relative torque angles of various units as $D_{12}=D_1-D_2, D_{13}=D_1-D_3$ etc.
7. Find the load torque TA_1, TA_2, TA_3 and TA_4.
8. Find change in torque angle DD_1, DD_2, DD_3 and DD_4.
9. Find the new values of torque angle of each unit as

   $D_1 = D_1 + DD_1$

   $D_2 = D_2 + DD_2$

   $D_3 = D_3 + DD_3$

   $D_4 = D_4 + DD_4$
10. Runch the values of D_1, D_2, D_3 and D_4
11. Test for time of period.
12. Go to step (6) and repeat with time interval $\Delta t=0.01$ upto 0.1 sec. when the fault is cleared.

13. After the computations have occured upto 0.1 sec, modify the admitance matrix of the system at step (3) for fault cleared condition by changing the respective elements and repeat upto step (10) for the period from 0.1 to 0.6 sec. with $\triangle t = 0.01$ sec.
14. With the values of D_1, D_2, D_3 and D_4 available at the end of each interval, $\triangle t = 0.01$ sec. upto 0.6 sec., the swing curve for each m/c group can be plotted.

FLOW CHART: As shown in Fig.(3.2).

3.13 COMMENTS :

As is observed from the swing curves plotted in fig.(3.1), the system happens to be unstable if the fault is allowed to persist for a period of 0.1 sec. i.e. for 5 cycles.

This suggests the use of faster operating breakers i.e. operating within 2.5 to 3 cycles should be employed. However here it may be mentioned that the effect of voltage regulators, grounding, Damper windings and speed governers has not been taken into account while carrying out the above studies. Firstly because of the lack of information about the system and secondly, these detailed studies are beyond the scope of this thises. These factors should invariably be considered while designing a system from transient stability point of view as they have their definite effect on the stability limit of the system.

3.2 TRANSIENT STABILITY STUDIES WITH DYNAMIC-

which is detrimental to stability as it promotes acc tion of the generalers.

It is further necessary to consider the system to be dynomic and frequency dependent ~~dynomic~~. As for example system is so designed to remain stable under steady transient conditions, considering the system loads a constant impedence loads, the system would work out instable when the loads are considered to be dynomic frequency dependent, as given above.

There is lack of information available for the composite load charactristics of the system. Althoug power system Engineers~~ing~~ have been concerned with th effects ~~to~~ of load charactristics, on system stability at least 40 years and many studies have been made on subject, few electric utilities have made adequate t to determine their own load characteristcs. Under-st the Electric utilities are reluctant to subject thei customers to very many planned distrubances for the of anslysing transient behaviour and not utilities w make such tests. However instrumentation and automat recorders are now available which may make it feasib for utilities to obtain load characteristics without tests. By installing such equipment at impportant bus whenevera system disturbance occures, pertinent data be recorded, In time, sufficient load data might be ed to detemine the load characteristcs, although sep of voltage and frequency effects may be often diffic If such attempts to record the actual load character are made, and considered in stability studies, it wi d to more accurate and conservative results, without the present studies may be said to be optimistic. The system designed with all such considerations taken i account shall be more reliable.

13. After the computations have occured upto 0.1 sec, modify the admitance matrix of the system at step (3) for fault cleared condition by changing the respective elements and repeat upto step (10) for the period from 0.1 to 0.6 sec. with $\triangle t=0.01$ sec.
14. With the values of D_1, D_2, D_3 and D_4 available at the end of each interval, $\triangle t=0.01$ sec. upto 0.6 sec., the swing curve for each m/c group can be plotted.

<u>FLOW CHART:</u> As shown in Fig.(3.2).

3.13 COMMENTS :

As is observed from the swing curves plotted in fig.(3.1), the system happens to be unstable if the fault is allowed to persist for a period of 0.1 sec. i.e. for 5 cycles.

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3.2 TRANSIENT STABILITY STUDIES WITH DYNAMIC-

CHARACTERISTIC OF LOADS:

For power system planning and operation under normal and emergency conditions, voltage dependent and frequency dependent behaviour of loads should be studied, becasue voltage and frequency are the powerful parameters available for control /8/. An effort has been made to develop the procedume for studeing the transient stability of a multimachine system taking the load at Muradnagar to be dynamic and frequency dependent. The load characteristic with ref. to and frequency and voltage of the composite load has already been developed in section 2.42 and 2.43 of chapter II. It is now proposed to develop the procedure for obtaining the swing curve in the following section with load being dynamic and frequency dependent,utilising composit load characteristic as shown by equation 2.6 and 2.7 in chapter II.

3.21 DEVELOPMENT OF THE PROCEDURE FOR PLOTTING SWING CURVE WITH LOAD AS DYNAMIC AND FREQUENCY DEPENDENT :

The detailed procedure for plotting the swing curve under steady state i.e.taking the load as constant impedance has already been given in section 3.12.1. above. For the purpose of present study the effect of change in voltage and frequency has further been considered to evaluate the value of load admitance Ym in each interval of 0.01 sec. and then by using this new value of Ym the R Matrix may be worked out each time and then the calculations for obtaining the swing curve in the similar method can be performed. The following approach is proposed:

i) The initial value of load admitance Ym is known.

ii) The generator E.M.S., E_1, E_2, E_3, E_4 and E_5 are known and are said to be constant during and after the fault. The initial values $P_1, P_2, P_3, P_4, D_1, D_2, D_3, D_4$ and D_5 of each m/c group are known.

iii) The admitance matrix with fault on condition may be written for the complete ~~[illegible]~~ system as is done in section 3.12.1. The same canbe modified for fault cleared conditions by changing the respective element.

iv) Reduce the admitance matrix to 6x6 by matrix operation as suggested by equ.n (3.12) of section 3.11.2.

v) Equation (3.17) of section 3.11.2. may be written as

$$Vm = \left[Ym + Y_3 \right]^{-1} Y_2^t E$$

$$= \frac{Y_2^t}{\left[Ym + Y_3 \right]} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \\ E_5 \end{bmatrix}$$

This gives the value of Vm immediately after the fault.

vi) Consider the frequency to remain constant in the first interval of $\triangle t = 0.01$ sec.

vii) With due consideration of step(Vii) above and with the help of equation (4) and (5) of section 2.43 of chapter II, we can get the change in active and reactive power taken by the load due to the change in voltage V, in the first interval i.e..

$$\triangle P = nK_1 Vm^{n-1} \times \triangle Vm$$

$\triangle Q = nK_2 V_m^{n-1} x \triangle V_m$

K_1, K_2 & n are known

Where values as defined in the above section and
$\triangle V_m$ = Vm before fault -Vm after fault.

ix) We can now have the new values of active and reactive power taken by the load just after the fault, the before fault values of power being known.

x) From the new values of P and Q we can find the respective value of Ym as follows:

$$Y_m = \frac{(P^2+Q^2)^{\frac{1}{2}}}{V_m^2} \frac{\angle \tan^{-1}\frac{Q}{P}}{\angle 2\theta}$$

Where θ being the phase angle of Vm.

xi) Got to step (vi) and iterate and test until Vm converges within a predetermined index say 1 part in 1000. If test is satisfied proceed as follows:

xii) Proceed to reduce the (6x6) matrix to 5x5 by matrix operation as suggested by equation (3.18) of secton 3.11.2.

xiii) Calculate driving point and transfer admitances and admitance angles of the remaining 5 nodes.

xiv) Find the relative torque angle of various units DD_1, DD_2 etc.

xv) Find the load torque TA_1, TA_2, TA_3 and TA_4 of each unit.

xvi) Find change in torque angle DD_1, DD_2, DD_3 and DD_4.

xvii) Find the new values of torque angle of the E.M.F. of each unit as

$D_1 = D_1 + DD_1$
$D_2 = D_2 + DD_2$
$D_3 = D_3 + DD_3$
$D_4 = D_4 + DD_4$

xviii) Punch the values of D_1, D_2, D_3 and D_4.

xix) Test for time period.

xx) Go to step (iv) and calculate the new value of Vm with changed values of the phase angles of E.M.F.S., E_1, E_2, E_3 and E_4.

xxi) At the end of (xx) the step we know the value Vm and phase angle θ at the end of previous interval.

$\therefore \triangle\theta = \theta_{new} - \theta_{old}$ radius.
giving there by change in frequency as
$\triangle f = \frac{\triangle\theta}{\triangle t}$ $\triangle t = 0.01$ sec.

xxii) We can now get the new value of fraquency as
$F_{new} = F_{old} + \triangle f$

xxiii) Calculate the new values of active and reactive power with the help ofequation (2.6) and (2.7) of chapter 2:43 i.e.

$P_{new} = nK_1 Vm^{n-1} \triangle Vm + K31 \triangle f + P_{old}$.
$48 < f < 50$

$P_{new} = nK_1 Vm^{n-1} \triangle Vm + K32 \triangle f + P_{old}$
$50 < f < 52$

$Q_{new} = nK_2 Vm^{n-1} \triangle Vm + K_4 \triangle f + Q_{old}$.
$48 < f < 52$

xxiv) Go to step (X) and calculate the value of Ym.

xxv) Repeat the calculations from step (xii) with time interval $\triangle f = 0.01$ sec.

xxvi) After the computations have occured upto 0.01 sec. modify the admitance matrix of the system at step (iii) for fault cleared condition by changing the respective elements and repeat upto step (xxv) for the period from 0.01 to 0.6 sec. with

$\Delta t = 0.01$ sec.

xxvii) With the values of D_1, D_2, D_3 and D_4 available at the end of each interval $\Delta t = 0.01$ sec upto 0.6 sec., the swing curve for each m/c group can be plotted.

3.22 PLOT CHART: As shown in fig.(3.3)

TABLE - 4

SWING CURVE OF THE MACHINE'S CONSIDERING THE LOAD AS CONSTANT IMPEDANCE:

Time interval T=0.01 sec. The fault cleared at 0.1 sec.

Sl. No.	Time in sec.	Torque angle in radians at the begining of Interval			
		Yamuna Stage II	Yamuna stage I & IV	Ramganga	Harduaganj
1.	0.0	0.682	0.652	0.576	0.48
2.	0.01	0.6533	0.8538	0.4913	0.5016
3.	0.02	0.7369	1.0042	0.3377	0.5166
4.	0.03	0.9311	0.9332	0.4856	0.4842
5.	0.04	1.0015	1.1295	0.7609	0.4711
6.	0.05	1.0993	1.3951	0.9631	0.5252
7.	0.06	1.3770	1.4241	0.9776	0.5639
8.	0.07	1.5685	1.6381	0.9749	0.5133
9.	0.08	1.6274	1.9416	1.1027	0.4525
10.	0.09	1.7606	1.8769	1.3099	0.4920
11.	0.10	1.8290	1.8595	1.4496	0.5740
12.	0.11	1.6994	2.1044	1.7503	0.5241
13.	0.12	2.0455	2.0027	1.9111	0.4072
14.	0.13	2.0824	1.8922	1.9192	0.4158
15.	0.14	2.5407	2.6789	2.2317	0.5335
16.	0.15	2.4947	2.3414	2.7426	0.5422

17.	0.16	3.0710	3.1016	2.8793	0.4025
18.	0.17	3.1781	2.8926	3.1748	0.3460
19.	0.18	3.6582	3.7386	3.8004	0.4653
20.	0.19	3.8793	3.5404	4.3388	0.4889
21.	0.20	4.5700	4.5953	4.6843	0.3573
22.	0.21	5.1021	5.3770	5.4468	0.3437
23.	0.22	5.8752	6.1045	6.2791	0.5207
24.	0.23	6.9313	7.0008	6.7579	0.6399
25.	0.24	7.8834	8.3195	7.8225	0.4764
26.	0.25	9.2011	9.0873	8.9602	0.3260
27.	0.26	10.1191	10.7280	10.3373	0.4034
28.	0.27	11.5721	11.2628	12.0183	0.5088
29.	0.28	12.6504	13.1867	13.0184	0.5141
30.	0.29	14.3844	14.4719	13.7137	0.4952
31.	0.30	15.7562	15.9213	18.4778	0.4142
32.	0.31	16.9742	17.3777	17.7778	0.4116
33.	0.32	18.7192	18.5913	19.2655	0.4116
34.	0.33	20.4619	20.9930	19.6294	0.6087
35.	0.34	22.1898	22.2583	21.4678	0.4980
36.	0.35	23.3840	23.5740	24.3566	0.3604
37.	0.36	27.9364	25.2916	25.9295	0.3499
38.	0.37	27.1172	27.1108	25.5677	0.6912
39.	0.38	28.4770	29.0426	26.9386	0.5771
40.	0.39	29.4418	29.5498	29.3300	0.3253
41.	0.40	30.2080	30.2249	32.5311	0.3205
42.	0.41	30.0788	31.5399	32.8861	0.7833
43.	0.42	32.2370	32.3294	30.2227	0.9046
44.	0.43	32.8313	32.9644	29.1849	0.2057
45.	0.44	33.4786	34.0875	26.5006	- 0.2343
46.	0.45	34.4976	33.7948	24.6561	0.5514
47.	0.46	33.9239	34.4591	22.3796	0.9422
48.	0.47	34.6009	34.7513	18.5580	0.4897
49.	0.48	35.2559	35.3987	12.5426	- 0.2096
50.	0.49	35.0069	36.4011	4.3782	0.3347

51.	0.50	36.7160	36.4078	- 2.7442	1.0583
52.	0.51	36.1649	36.9852	- 8.4029	0.9648
53.	0.52	35.7198	35.6042	- 12.4581	0.0720
54.	0.53	35.1325	35.2016	- 19.0836	- 0.0469
55.	0.54	34.5109	35.3524	- 26.9935	0.7338
56.	0.55	34.6473	33.8680	- 37.0671	1.0094
57.	0.56	33.1225	33.8471	- 45.6566	0.2409
58.	0.57	31.9904	33.0522	- 55.6902	- 0.3832
59.	0.58	31.7562	30.2408	- 65.9531	0.4431
60.	0.59	29.8320	28.9771	- 77.2675	1.4197
61.	0.60	26.5444	30.0583	- 88.1766	0.9909
62.	0.61	21.3783	31.3560	- 98.2089	- 0.4143

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CHAPTER - IV.

DISCUSSION AND CONCLUSION.

CHAPTER - IV

4.1 DISCUSSION :

It will be observed from Fig.(3.1) that the system happens to be unstable for a 3 phase fault on Roorkee-Muradnagar line. From the studies carried out on frequency dependent passive loads usually met in practice, the results indicate the presence of negative damping due to the rise in active power when the instantaneous frequency falls under disturbed condition./1/

The frequency dependent load imposes extra load owing to reduced available voltage and reduced operating frequency, there by promoting deceleration of machines and consequent increased instability.

In general, in the presence of shunt and series compensation (used to improve power factor, reduce lamp flicker, and to improve voltage regulation), the active power is affected mainly by the series compensation and falls at an increased rate when operating frequency rises, thereby offering more negative damping. The behaviour of the reactive power is determined mainly by the compensation. In the case of series compensation, the nature of behaviour of the reactive power with instantaneous frequency does not change because the series compensation is never more than 100%, but the shunt compensation by reactors aggravates the situation because the rate of change of reactive power becomes positive, which reduces the system voltages, thus increasing the negative damping offered by the active power.

For power system studies, lighting and arc-furnace loads can be represented by a current dependent resistance and frequency dependent reactance circuits, mercury arc rectifiers can be represented by a constant current sink for voltage dependence and by a constant resistance inductive circuit for frequency dependence in stability studies.

If this is done, a more accurate assessment of the system is possible, and the magnitude of the effects so included can be practically significant.

4.2 CONCLUSIONS:

The transient stability study of the Eastern U.P.Grid has been carried out with load to be constant impedance in first instance and dynamic and frequency dependent in the 2nd. instance.

With knowledge of load composition obtained from load surveys, each load in the power system can be divided approximately into components such as

i) Dynamic loads involving induction motors.
ii) Passive frequency dependent loads.
iii) Pure resistance loads.

In particular, the characteristics of voltage and frequency dependent loads should be employed in assessing the required power system margins of stability under steady state and disturbed conditions, as well as for emergency control, and can give significantly different results from those obtained when frequency and voltage dependence is ignored.

The consideration of effect of change in voltage on the load for designing a system from stability point of view is of very much importance. A dip in voltage may cause shedding of loads such as discharge lamps, mercury arc rectifiers, etc. which are provided with under voltage release, which is detrimental to stability as it promotes acceleration of the generators. It is, therefore, of interest to a planner while designing a system for optimum stability under steady state as well as under transient state that the effect of voltage dip causing thereby the possible load shedding should be considered and taken into account.

It is further necessary to consider the system loads, particularly induction motors, Industrial and Agricultural loads to be dynamic and frequency dependent. As for example, if a system is so designed to remain stable under steady or transient conditions, considering the system loads as constant impedance loads, the system would work out to be unstable when the loads are considered to be dynamic and frequency dependent.

There is lack of information available for the composite load characteristics of the system. Although power system Engineers have been concerned with the effects of load characteristics on system stability for at least 40 years and many studies have been made on the subject, few electric utilities have made adequate tests to determine their own load characteristics.[17] Understandably, the Electric utilities are reluctant to subject their customers to very many planned disturbances for the purpose of analysing transient behaviour and not all utilities will make such tests. However instrumentation and automatic recorders are now available which may make it possible for utilities to obtain load characteristics without tests. By installing such equipment at important buses, whenever a system disturbance occurs, pertinent data can be recorded. In time, sufficient load data might be obtained to determine the load characteristics, although sepration of voltage and frequency effects may be often difficult. If such attempts to record the actual load characteristics are made, and considered in stability studies, it will lead to more accurate and conservative results, without which the present studies may be said to be optimistic. The system designed with all such considerations taken into account shall be more reliable.

APPENDICES

APPENDIX - I

DRIVING POINT ADMITTANCE :

Y1,1 = 0-j 6.25
Y2,2 = 0-j 2.58
Y3,3 = 0-j 2.84
Y4,4 = 0-j 9.42
Y5,5 = 3.79-j 17.95
Y6,6 = 3.069-j 36.72
Y7,7 = 1.704-j 15.02
Y8,8 = 1.949-j 8.94485
Y9,9 = 3.16-j 17.11
Y10,10 = 8.468-j 22.912
Y11,11 = 3.923-j 9.769
Y12,12 =18.0835-j 37.852
Y13,13 = 7.77-j 21.69
Y14,14 = 7.953-j 15.425
Y15,15 = 5.4885-j 47.465

TRANSFER ADMITTANCE :

Y1,7 = Y7,1 = 0-j 10.21
Y2,9 = Y9,2 = 0-j 5.36
Y3,13 = Y13,3 = 0-j 5.61
~~Y3,1~~ = ~~Y5,15~~ = ~~0-j 0~~
Y4,15 = Y15,4 = 0-j 12.28
Y5,15 = Y15,5 = 3.79-j 17.95
Y6,15 = Y15,6 = 0-j 22.4
Y6,10 = Y10,6 = 0-j 0
Y6,8 = Y8,6 = 1.15-j 5.9
Y6,14 = Y14,6 = 0.587-j 1.5
Y7,10 = Y10,7 = 1.15-j 5.9
Y7,8 = Y8,7 = 0.054-j 2.87
Y7,9 = Y9,7 = 0-j6.25
Y9,11 = Y11,9 = 3.16-j 8.08

$Y_{10,11} = Y_{11,10} = 0.642 - j\ 1.635$

$Y_{10,12} = Y_{12,10} = 4.49 - j\ 8.22$

$Y_{12.13} = Y_{13,12} = 7.77 - j18.92$

$Y_{12,14} = Y_{14,12} = 5.66 - j\ 10.58$

$Y_{14,15} = Y_{15,14} = 0.746 - j\ 4.08$

All other values of transfer admitances beihg Zero, and has not been written above.

APPENDIX - II

COMPUTER PROGRAMME FOR SWING CURVE FOR PERIOD 0 to 0.1 SEC.

```
CC,     STABILITY STUDY OF WESTERN U.P.GRID BY R.A.BANSAL
        DIMENSION A(12,12),C(12,18),CT(18,12),B(18,18),Y(12,12)
        DIMENSION Y2(10,2),Y2T(2,10),Y1(10,10),YM(2,2),Y3(2,2),R(1
        DIMENSION C1(18,12),C2(12,12),Y2TT(2,10),R1(10,10)
        READ1,NAROW,NACOL
        READ1,NCROW,NCCOL
        READ1,NSIZE
        READ1,NYMRO,NYMCO
        READ10,E1,E2,E3,E4,E5,P1,P2,P3,P4,H1,H3,H4,H2,D1,D2,
              D3,D4,D5,D, DT
        READ2,((A(I,J),J=1,NACOL),I=1,NAROW)
        READ2,((C(I,J),J=1,NCCOL),I=1,NCROW)
        READ2,((B(M,N),N=1,NSIZE),M=1,NSIZE)
        READ2,((YM(I,J),J=1,NYMCO),I=1,NYMRO)
      1 FORMAT(2I2)
      2 FORMAT(6F10.3)
     10 FORMAT(4F10.4)
     21 FORMAT(37H ANGLE AT THE BEGINING OF INTERVAL TT/5F10.4,
        4X, I2)
        DD1=0.
        DD2=0.
        DD3=0.
        DD4=0.
        TT=0.
        N=1
        AK1=180.*F*(DT**2)/H1
        AK2=180.*F*(DT**2)/H2
        AK3=180.*F*(DT**2)/H3
        AK4=180.*F*(DT**2)/H4
    105 DO3I=1,NCCOL
        DO3J=1,NCROW
C       TRANSPOSITION OF C AS CT
```

```
    3  CT(I,J)=C(J,I)
       CALL INVERT(B,18,18)
C      MULTIPLICATION OF BINVERT AND CT
       CALL MLTATC( 18,18,12,B,18,C1,18)
C      MULTIPLICATION OF C AND C1
       CALL MLTATC (12,18,12,C,12,C1,18,C2,12 )
C      DIFFERENCE OF A AND C2
       DO8I=1,NAROW
       DO8J=1,NACOL
    8  Y(I,J)=A(I,J)-C2(I,J)
       PUNCH2,((Y(I,J),J=1,12),1=1,12)
C      R=Y1-Y2*(YM+Y3)INVERT*Y2T
       DO9I=1,10
       DO9J=11,12
    9  Y2(I,J-10)=Y(I,J)
       DO11=1,10
       DO11J=1,10
   11  Y1(I,J)=Y(I,J)
       DO12I=11,12
       DO12J=11,12
   12  Y3(I-10,J-10)=Y(I,J)
       DO13I=1,2
       DO13J=1,10
   13  Y2T(I,J)=Y2(J,I)
C      ADDITION OF MATRIX YM AND Y3
C      LET YM=YM+Y3
       DO14I=1,NYMRO
       DO14J=1,NYMCO
   14  YM(I,J)=YM(I,J)+Y3(I,J)
C      INVERSION OF MATRIX YM
       CALL INVERT (YM,2,2)
C      MULTIPLICATION OF YM INVERT AN D Y2T
       CALL MLTATC(2,2,10,YM,2,Y2T,2,Y2TT,2)
C      MULTIPLICATION OF Y2 AND Y2TT
```

Contd....

```
      CALL MLTATC(10,2,10,Y2,10,Y2TT,2,R1,10)
C     OBTAIN REQUIRED VALUE OF R
      DO19I=1,10
      DO19J=1,10
   10 R(I,J)=Y1(I,J)-R1(I,J)
      PUNCH2,((R(I,J),J=1,10),I=1,10)
      I=1
      J=1+1
      Y11=SQRTF(R(I,I)**2+R(I,J)**2)
      ALP11=1.57-ATANF(-R(I,J)/R(I,I))
      I=I+2
      J=I+1
      Y22=SQRTF(R(I,I)**2+R(I,J)**2)
      ALP22=1.57-ATANF(-R(I,J)/R(I,J))
      I=I+2
      J=I+1
      Y33=SQRTF(R(I,I)**2+R(I,J)**2)
      ALP33=1.57-ATANF(-R(I,J)/R(I,I)
      I=I+2
      J=I+1
      Y44=SQRTF(R(I,I)**2+R(I,J)**2)
      ALP44=1.57-ATANF(-R(I,J)/R(I,I))
      I=1
      J=3
      K=J+1
      Y12=DQRTF(R(I,J)**2+R(I,K)**2)
      ALP12=1.57-ATANF(-R(I,K)/R(I,J))
      J=5
      K=J+1
      Y13=SQRTF(R(I,J)**2+R(I,K)**2)
      ALP13=1.57-ATANF(-R(I,K)/R(I,J))
      J=7
      K=J+1
      Y14=SQRTF(R(I,J)**2+R(I,K)**2)
```

Contd....

```
      ALP14= 1.57-ATANF(-R(I,K)/R(I,J))
      J=9
      K=J+1
      Y15=SQRTF(R(I,J)**2+R(I,K)**2)
      ALP15=1.57-ATANF(-R(I,K)/R(I,J))
      I=3
      J=5
      K=J+1
      Y23=SQRTF(R(I,J)**2+R(I,K)**2)
      ALP23=1.57-ATANF(-R(I,K)/R(I,J))
      J=7
      K=J+1
      Y24=SQRTF(R(I,J)**2+R(I,K)**2)
      ALP24=1.57-ATANF(-R(I,K)/R(I,J))
      J=9
      K=J+1
      Y25=SQRTF(R(I,J)**2+R(I,K)**2)
      ALP25=1.57-ATANF(-R(I,K)/R(I,J))
      I=5
      J=7
      K=J+1
      Y34=SQRTF(R(I,J)**2+R(I,K)**2)
      ALP34=1.57-ATANF(-R(I,K)/R(I,J))
      J=9
      K=J+1
      Y35=SQRTF(R(I,J)**2+R(I,K)**2)
      ALP35=1.57-ATANF(-R(I,K)/R(I,J))
      I=7
      J=9
      K=J+1
      Y45=SQRTF(R(I,J)**2+R(I,K)**2)
      ALP45=1.57-ATANF(-R(I,K)/R(I,J))
   25 D12=D1-D2
```

Contd....

```
      D13=D1-D3
      D14=D1-D4
      D15=D1-D5
      D23=D2-D3
      D24=D2-D4
      D25=D2-D5
      D34=D3-D4
      D35=D3-D5
      D45=D4-D5
      DMMY1=E1*E2*Y12*SINF(D12-ALP12)+E1*E3*Y13*SINF
      (D13-ALP13)
      DMMY2=E1*E4*Y14*SINF(D14-ALP14)+E1*E5*Y15*SINF
      (D15-ALP15)
      TA1=PI-(E1*E1*Y11*SINF(ALP11)+DMMY1+DMMY2)
      DMMY1=-E1*E2*Y12*SINF(D12+ALP12)+E2*E3*Y23*SINF
      (D23-ALP23)
      DMMY2=E2*E4*Y24*SINF(D24-ALP24)+E2*E5*Y25*SINF
      (D25-ALP25)
      TA2=P2-(E2*E2*Y22*SINF(ALP22)+DMMY1+DMMY2)
      DMMY1=-E1*E3*Y13*SINF(D13+ALP13)-E2*E3*Y23*SINF
      (D23+ALP23)
      DMMY2=E3*E4*Y34*SINF(D34-ALP34)+E3*E5*Y35*SINF
      (D35-ALP35)
      TA3=P3-(E3*E3*Y33*SINF(ALP33)+DMMY1+DMMY2)
      DMMY1=E4*E1*Y14*SINF(D14+ALP14)-E2*E4*Y24*SINF
      (D24+ALP24)
      DMMY2=-E3*E4*Y38*SINF(D34+ALP34)+E4*E5*Y45*SINF
      (D45-ALP45)
      TA4=P4-(E4*E4*Y44*SINF(ALP44)+DMMY1+DMMY2)
      PUNCH10,TA1,TA2,TA3,TA4
      TT=TT+.01
      IF(TT-.01)22,22,23
22    X1=(AK1*TA1)/2.
      X2=(AK2*TA2)/2.
      X3=(AK3*TA3)/2.
      X4=(AK4*TA4)/2.
```

Contd...

```
      GOTO24
23    X1=AK1*TA1
      X2=AK2*TA2
      X3=AK2*TA3
      X4=AK4*TA4
24    DD1=DD1+X1
      DD2=DD2+X2
      DD3=DD3+X3
      DD4=DD4+X4
      D1=D1+DD1
      D2=D2+DD2
      D3=D3+DD3
      D4=D4+DD4
      PUNCH21,D1,D2,D3,D4,TT,N
      N=N+1
      IF(TT-.1)25,25,26
26    STOP END
```

DATA FOR IBM.PROGRAMME AT APPENDIX-II.

```
 1212
 1218
 18
 0202
 1.102     1.093    1.0718     1.1
 1.025     1.15     0.43        .35
 1.425     5.829    2.889      2.26
 3.394      .682     .652       .576
  .48      0.       50.         .01
 0.        6.25     0.         0.        0.        0.
 0.        0.       0.         0.        0.        0.
-6.25      0.       0.         0.        0.        0.
 0.        0.       0.         0.        0.        0.
 0.        0.       0.         2.58      0.        0.
 0.        0.       0.         0.        0.        0.
 0.        0.      -2.58       0.        0.        0.
 0.        0.       0.         0.        0.        0.
 0.        0.       0.         0.        0.        2.84
 0.        0.       0.         0.        0.        0.
 0.        0.       0.         0.       -2.84      0.
 0.        0.       0.         0.        0.        0.
 0.        0.       0.         0.        0.        0.
 0.        9.42     0.         0.        0.        0.
 0.        0.       0.         0.        0.        0.
-9.42      0.       0.         0.        0.        0.
 0.        0.       0.         0.        0.        0.
 0.        9.       3.79      17.95      0.        0.
 0.        0.       0.         0.        0.        0.
 0.        0.     -17.95       3.79      0.        0.
 0.        0.       0.         0.        0.        0.
 0.        0.       0.         0.        3.069    36.72
 0.        0.       0.         0.        0.        0.
```

0.	0.	0.	0.	-36.72	3.062
0.	10.21	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
-10.21	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	5.36
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	-5.36	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	5.61	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
-5.61	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	12.28
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	-12.28	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	3.79	17.95
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	-17.95	3.79
0.	0.	1.15	5.9	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	.587	1.5	0.	22.4

```
 0.          0.      -5.9       1.15    0.        0.
 0.          0.       0.        0.      0.        0.
 0.          0.      -1.15       .587 -22.4       0.
 1.704      15.02      .554     2.87    0.        6.25
 1.15        5.9      0.        0.      0.        0.
 0.          0.       0.        0.      0.        0.
-15.02       1.704   -2.87       .554  -6.25      0.
-5.9         1.15     0.        0.      0.        0.
 0.          0.       0.        0.      0.        0.
  .554       2.87     1.949     8.948   0.        0.
 0.          0.       0.        0.      0.        0.
 0.          0.       0.        0.      0.        0.
 -2.87        .554   -8.948     0.949   0.        0.
 0.          0.       0.        0.      0.        0.
 0.          0.       0.        0.      0.        0.
 0.          6.25     0.        0.      3.16     17.11
 0.          0.       3.16      8.08    0.        0.
 0.          0.       0.        0.      0.        0.
 -6.25       0.       0.        0.    -17.11      3.16
 0.          0.      -8.08      3.16    0.        0.
 0.          0.       0.        0.      0.        0.
 1.15        5.9      0.        0.      0.        0.
 8.468      22.962     .642     1.635   4.49      8.22
 0.          0.       0.        0.      0.        0.
 -5.9        1.15     0.        0.      0.        0.
 -22.962     8.468   -1.635     0.642  -8.22      4.49
 0.          0.       0.        0.      0.        0.
 0.          0.       0.        0.      3.16      8.08
  .642       1.635    3.923     9.789   0.        0.
 0.          0.       0.        0.      0.        0.
 0.          0.       0.        0.     -8.08      3.16
 -1.635       .642   -9.789     3.923   0.        0.
 0.          0.       0.        0.      0.        0.
 0.          0.       0.        0.      0.        0.
```

```
4.49      8.22     0.         0.       18.083    37.852
7.77      18.92    5.66       10.58    0.        0.
0.        0.       0.         0.       0.        0.
-8.22     4.49     0.         0.       -37.852   18.083
-18.92    7.77     -10.58     5.66     0.        0.
0.        0.       0.         0.       0.        0.
0.        0.       0.         0.       7.77      18.92
7.77      21.69    0.         0.       0.        0.
0.        0.       0.         0.       0.        0.
0.        0.       0.         0.       -18.92    7.77
-21.69    7.77     0.         0.       0.        0.
0.        0.       0.         0.       0.        0.
0.        0.       0.         0.       5.66      10.58
0.        0.       7.953      15.425   .794      4.08
0.        0.       0.         0.       0.        0.
0.        0.       0.         0.       -10.58    5.66
0.        0.       -15.425    7.953    -4.08     .794
0.        0.       0.         0.       0.        0.
0.        0.       0.         0.       0.        0.
0.        0.       .794       4.08     5.488     47.464
0.        0.       0.         0.       0.        0.
0.        0.       0.         0.       0.        0.
0.        0.       -4.08      .794     -47.464   5.488
9.15      2.57     -2.57      9.15
```

APPENDIX -III

PROGRAMME FOR SWING CURVE FOR PERIOD FROM 0.1 to 0.6 Sec.

```
CC          STABILITY STUDY OF WESTER-N U.P GRID BY R.A.BAN-SAL.
            DIMENSION A(12,12),C(12,18),CT(18,12),B(18,18),
                      Y(12,12)
            DIMENSION Y2(10,2),Y2T(2,10),Y1(10,10)YM(2,2),
                      Y3(2,2),R(10,10)
            DIMENSION C1(18,12),C2(12,12),Y2TT(2,10)R1(10,10)
            READ1,NAROW,NACOL
            READ1,NCROW,NCCOL
            READ1,NSIZE
            READ1,NYMRO,NYMCO
            READ10,E1,E2,E3,E4,E5,P1,P2,P3,P4,H1,H2,H3,H4,D1,
                   D2,D3,D4,D5,F,DT
            READ2,((A(I,J),J=1,NACOL),I=1,NAROW)
            READ2,((C(I,J),J=1,NCCOL),I=1,NCROW)
            READ2,((B(M,N),N=1,NSIZE),M=1(NSIZE)
            READ2,((YM(I,J),J=1,NYMCO),I=1,NYMRO)
            READ10,DD1,DD2,DD3,DD4,T1,T2,T3,T4,TT
            READ1,N
      1     FORMAT(2I2)
      2     FORMAT(6F10.3)
     10     FORMAT(4F10.4)
     21     FORMAT(37H ANGLE AT THE BEGINING OF INTERVAL TT/
                   5F10.4,4X,I2)
            DD1=0.0684
            DD2=-0.0394
            DD3= 0.1597
            DD4= 0.0820
            TT=0.1
            N =11
            T1=-0.8720
            T2=0.7755
            T3=-0.4386
            T4=-0.3441
```

```
          AK1=180.*P*(DT**2)/H1
          AK2=180.*P*(DT**2)/H2
          AK3=180.*P*(DT**2)/H3
          AK4=180.*P*(DT**2)/H4
      105 DO3I=1,NCCOL
          DO3J=1,NCROW
C         TRANSPOSITION OF C AS CT
        3 CT(I,J)=C(J,I)
          CALL INVERT(B,18,18)
C         MULTIPLICATION OF BINVERT AND CT
          CALL MLTATC(18,18,12,B,18,CT,18,C1,18)
C         MULTIPLICATION OF C AND C1
          CALL MLTATC(12,18,12,C,12,C1,18,C2,12)
C         DIFFERENCE OF A AND C2
          DO8I=1,NAROW
          DO8J=1,NACOL
        8 Y(I,J)=A(I,J)-C2(I,J)
          PUNCH2,((Y(I,J),J=1,12),I=1,12)
C         R=Y1-Y2*(YM+Y3)INVERT*Y2T
          DO9I=1,10
          DO9J=11,12
        9 Y2(I,J-10)=Y(I,J)
          DO11I=1,10
          DO11J=1,10
       11 Y1(I,J)=Y(I,J)
         DO12I=11,12
          DO12J=11,12
       12 Y3(I-10,J-10)=Y(I,J)
          DO13I=1,2
          DO13J=1,10
       13 Y2T(I,J)=Y2(J,I)
C         ADDITION OF MATRIX YM AND Y3
C         LET YM=YM+Y3
          DO14I=1,NYMRO
          DO14J=1,NYMCO
```

```
      14   YM(I,J)=YM(I,J)+Y3(I,J)
C          INVERSION OF MATRIX YM
           CALL INVERT (YM,2,2)
C          MULTIPLICATION OF YM INVERT AND Y2T
           CALL MLTATC(2,2,10,YM,2,Y2T,2,Y2TT,2)
C          MULTIPLICATION OF Y2 and Y2TT
           CALL MLTATC( 10,2,10,Y2,10,Y2TT,2,R1,10)
C          OBTAIN REQUIRED VALUE OF R
           DO19I=1,10
           DO19J=1,10
      19   R(I,J)=Y1(I,J)-R1(I,J)
           PUNCH2,((R(I,J),J=1,10),I=1,10)
           I=1
           J=I+1
           Y11=SQRTF(R(I,I)**2+R(I,J)**2)
           ALP11=1.57-ATANF(-R(I,J)/R(I,I))
           I=I+2
           J=I+1
           Y22=SQRTF(R(I,I)**2+R(I,J)**2)
           ALP22=1.57-ATANF(-R(I,J)/R(I,I))
           I=I+2
           J=I+1
           Y33=SQRTF(R(I,I)**2+R(I,J)**2)
           ALP33=1.57-ATANF(-R(I,J)/R(I,I))
           I=I+2
           J=I+1
           Y44=SQRTF(R(I,I)**2+R(I,J)**2)
           ALP44=1.57-ATANF(-R(I,J)/R(I,I))
           I=1
           J=3
           K=J+1
           Y12=SQRTF(R(I,J)**2+R(I,K)**2)
           ALP12=1.57-ATANF(-R(I,K)/R(I,J))
           J=5
           K=J+1
```

```
Y13=SQRTF(R(I,J)**2+R(I,K)**2)
ALP13=1.57-AT ANF(-R(I,K)/R(I,J))
J=7
K=J+1
Y14=SQRTF(R(I,J)**2+R(I,K)**2)
ALP14=1.57-AT ANF(-R(I,K)/R(I,J))
 J=9
 K=J+1
Y15=SQRTF(R(I,J)**2+R(I,K)**2)
ALP15=1.57-AT ANF(-R(I,K)/R(I,J))
I=3
J=5
K=J+1
Y23=SQRTF(R(I,J)**2+R(I,K)**2)
ALP23=1.57-AT ANF(-R(I,K)/R(I,J))
J=7
K=J+1
Y24=SQRTF(R(I,J)**2+R(I,K)**2)
ALP24=1.57-AT ANF(-R(I,K)/R(I,J))
J=9
K=J+1
Y25=SQRTF(R(I,J)**2+R(I,K)**2)
ALP25=1.57-AT ANF(-R(I,K)/R(I,J))
I=5
J=7
K=J+1
Y34=SQRTF(R(I,J)**2+R(I,K)**2)
ALP34=1.57-AT ANF(-R(I,K)/R(I,J))
J=9
K=J+1
Y35=SQRTF(R(I,J)**2+R(I,K)**2)
ALP35=1.57-AT ANF(-R(I,K)/R(I,J))
I=7
```

```
      J=9
      K=J+1
      Y45=SQRTF(R(I,J)**2+R(I,K)**2)
      ALP45=1.57-AT ANF(-R(I,K)/R(I,J))
      PUNCH2,Y11,Y22,Y33,Y44,Y12,Y13,Y14,Y15,Y23,Y24,
             Y25,Y34,Y35,Y45
      PUNCH2,ALP11,ALP22,ALP33,ALP44,ALP12,ALP13,ALP14,
             ALP15
      PUNCH2,ALP23,ALP24,ALP25,ALP34,ALP35,ALP45
   25 D12=D1-D2
      D13=D1-D3
      D 14=D1-D4
      D15=D1-D5
      D23=D2-D3
      D24=D2-D4
      D25=D2-D5
      D34=D3-D4
      D35=D3-D5
      D45=D4-D5
      DMMY1=E1*E2*Y12*SINF(D12-ALP12)+E1*E3*Y13*SINF
             (D13-ALP13)
      DMMY2=E1*E4*Y14*SINF(D14-ALP14)+E1*E5*Y15*SINF
            (D15-ALP15)
      TA1=P1-(E1*E1*Y11*SINF(ALP11)+DMMY1+DMMY2)
      DMMY1=-E1*E2*Y12*SINF(D12+ALP12)+E2*E3*Y23*SINF
             (D23-ALP23)
      DMMY2=E2*E4*Y24*SINF(D24-ALP24)+E2*E5*Y25*SINF
            (D25-ALP25)
      TA2=P2-(E2*E2*Y22*SINF(ALP22)+DMMY1+DMMY2)
      DMMY1=-E1*E3*Y13*SINF(D13+ALP13)-E2*E3*Y23*SINF
            (D23+ALP23)
      DMMY2=E3*E4*Y34*SINF(D34-ALP34)+E3*E5*Y35*SINF
            (D35-ALP35)
      TA3=P3-(E3*E3*Y33*SINF(ALP33)+DMMY1+DMMY2)
      DMMY1=-E4*E1*Y14*SINF(D14+ALP14)-E2*E4*Y24*SINF
            (D24+ALP24)
      DMMY2=-E3*E4*Y34*SINF(D34+ALP34)+E4*E5*Y45*SINF
            (D45-ALP45)
```

```
       TA4=P4-(E4*E4*Y44*SINF(ALP44)+DMMY1+DMMY2)
      PUNCH10,TA1,TA2,TA3,TA4
  107  TT=TT+.01
       IF(TT-.11) 108,108,23
  108  X1=AK1*(T1+TA1)/2.
       X2=AK2*(T2+TA2)/2.
       X3=AK3*(T3+TA3)/2.
       X4=AK4*(T4+TA4)/2.
       GO TO 24
  23   X1=AK1*TA1
       X2=AK2*TA2
       X3=AK9TA3
       X4=AK *TA4
  24   DD1=DD2+X1
       DD2=DD2+X2
       DD3=DD3+X3
       DD4=DD4+X4
       D1=D1+DD1
       D2=D2+DD2
       D3=D3+DD3
       D4=D4+DD4
       PUNCH21,D1,D2,D3,D4,TT,N
       N=N+1
       IF(TT-.6)25,25,26
  26   STOP
       END
```

DATA FOR IInd.PROGRAMME AT APPENDIX - III.

```
1212
1218
18
0202
1.102     1.093   1.0718    1.1
1.025     1.15     .43       .35
1.425     5.828   2.829     2.26
3.394     1.829   1.8395    1.4496
 .5740    0.      50.        .01
0.        6.25    0.        0.      0.      0.
0.        0.      0.        0.      0.      0.
-6.25     0.      0.        0.      0.      0.
0.        0.      0.        0.      0.      0.
0.        0.      0.        2.58    0.      0.
0.        0.      0.        0.      0.      0.
0.        0.      -2.58     0.      0.      0.
0.        0.      0.        0.      0.      0.
0.        0.      0.        0.      0.      2.84
0.        0.      0.        0.      0.      0.
0.        0.      0.        0.      -2.84   0.
0.        0.      0.        0.      0.      0.
0.        0.      0.        0.      0.      0.
0.        9.42    0.        0.      0.      0.
0.        0.      0.        0.      0.      0.
-9.42     0.      0.        0.      0.      0.
0.        0.      0.        0.      0.      0.
0.        0.      3.79      17.95   0.      0.
0.        0.      0.        0.      0.      0.
0.        0.      -17.95    3.79    0.      0.
0.        0.      0.        0.      0.      0.
0.        0.      0.        0.       1.737  29.8
0.        0.      0.        0.      0.      0.
0.        0.      0.        0.      -29.8    1.737
```

0.	10.21	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
-10.21	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	5.36
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0 .	0.	0.	-5.36	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	5.61	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
-5.61	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	12.28
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	-12.28	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	3.79	17.95
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	-17.95	3.79
0.	0.	1.15	5.9	0.	0.
0.	0.	0.	0.	0.	0.

0.	0.	.587	1.5	0.	22.4
0.	0.	-5.9	1.15	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	-1.15	.587	-22.4	0.
1.704	15.02	.554	2.87	0.	6.25
1.15	5.9	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
-15.02	1.704	-2.87	.554	-6.25	0.
-5.9	1.15	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
.554	2.87	1.949	8.948	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
-2.87	.554	-8.948	1.949	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	6.25	0.	0.	3.16	17.11
0.	0.	3.16	8.08	0.	0.
0.	0.	0.	0.	0.	0.
-6.25	0.	0.	0.	-17.11	3.16
0.	0.	-8.08	3.16	0.	0.
0.	0.	0.	0.	0.	0.
1.15	5.9	0.	0.	0.	0.
7.136	14.992	.642	1.635	4.49	8.22
0.	0.	0.	0.	0.	0.
-5.9	1.15	0.	0.	0.	0.
-14.992	7.136	-1.635	.642	-8.22	4.49
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	3.16	8.08
.642	1.635	3.923	9.789	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	-8.08	3.16
-1.635	.642	-9.789	3.923	0.	0.
0.	0.	0.	0.	0.	0.

0.	0.	0.	0.	0.	0.
4.49	8.22	0.	0.	18.083	37.852
7.77	18.92	5.66	10.58	0.	0.
0.	0.	0.	0.	0.	0.
-8.22	4.49	0.	0.	-37.852	18.083
-18.92	7.77	-10.58	5.66	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	7.77	18.92
7.77	21.69	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	-18.92	7.77
-21.69	7.77	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	5.66	10.58
0.	0.	7.953	15.425	.794	4.08
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	-10.58	5.66
0.	0.	-15.425	7.953	-4.08	.794
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	.794	4.08	5.488	47.464
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	-4.08	.794	-47.464	5.488
9.15	2.57	-2.57	9.15		
.0684	-.0394	.1397	.0820		
-.8720	.7755	-.4386	-.3441		
.10					
.11					

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