STABILITY STUDIES ON A POWER SYSTEM INCLUDING SOME FUTURE EXPANSION PROGRAMMES

BY

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ABSTRACT

In this work transient stability study of eastern grid of Bangladesh Power Development Board with some future expansion programmes has been done by digital computer. Stability study of this part of electrical network of country's only power authority was not done within the last one decade. So it was considered highly important to study system stability in case of faults originating in the heavily loaded sections of the network.

A load flow solution with maximum loading condition was done first to get the conditions prior to disturbance in the network. Gauss-Seidel iterative method was used for load flow solution and developed a computer programme for this. Machine to Machine admittances for different circuit conditions were calculated then digitally by eliminating one node at a time and also developed a computer programme. Loads were represented as fixed admittances to ground in this study. The swing equation was solved by Step by Step and Runge-Kutta fourth order approximation methods. Computer programme for both Step by Step and Runge-Kutta fourth order approximation methods were developed. Transient stability was examined for 3-phase faults in different sections of the network with clearing time of 0.15, 0.2 and 0.3 second. The entire study was performed on IBM 360 digital computer. The computer programmes develpped may be easily used by the power authority of the country for their any future load flow or transient stability study.

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CHAPTER - 1

INTRODUCTION

Introduction

It is an established fact that electrical energy has a vital role in the rapid growth of modern industrial complexes and civilization as a whole. The increased need and higher demands of electrical energy are forcing the power companies and authorities to install new power stations and create new transmission facilities rapidly. The locations of power stations are again dictated by economic reasons and often may be away from load centres, but are likely to be near fuel centres, compelling the power companies to construct long transmission lines for transfer of load and as a result power system networks are becoming larger and at the same time more and more complex. Presently, customers specially with automated industries and vital installations are demanding stable supply with increased service reliability. To ensure higher service reliability to customers, power companies are planning their expansion policy with much care and vigorous study of the networks. These includes mainly load-flow studies, fault level studies and transient stability studies. Load flow study provides a knowledge of the voltage levels throughout the system, and enables the loading and utilization of circuits for different generation and load conditions, while transient stability studies provide information related to the capability of a power system to remain in synchronisim during major disturbances resulting from either the loss of generating or transmission facilities, sudden or sustained load changes, or momentary faults. Specifically, transient stability studies provide the changes in the voltages, currents, powers, speeds and torques of the machines of the power system, as well as the changes in system voltages and power flows, during and immediately following a disturbance. So in order to provide the reliability required by the dependence on continuous electric service, it is necessary that power systems be designed to be stable under any conceivable disturbances.

In early stages a.c. network analyzer was used for transient stability studies to obtain the operating performance of the power network during a disturbance and the step by step calculations of swing equations were performed manually. Later on, the use of digital computer made it easier and time saving for studying system performance during transient stability studies.

In transient stability study usually a load-flow is done to determine the system conditions prior to the disturbance. Transient stability analysis is performed by combining a solution of the algebraic equations describing the network with a numerical solution of the differential equation describing operating characteristics of synchronous and induction machines. Presently, many digital computer programmes for the solution of stability problems are available with provision of inclusion of detailed representation of machines and loads i.e. governnor response, exciter characteristics, damping, transient saliency, flux linkage variation caused by armature current, saturation, static impedance or admittance to ground, constant current at fixed power factor, constant real and reactive power etc. Improvements in the various methods are continually being made to minimize computation time and storage requirement in the computer and there by to minimize the cost of analysis and study.

In this work transient stability problem of Eastern grid of Bangladesh power Development Board has been studied. In pre-liberation period twice power-flow and stability studies of the primary grid system were done. The first[1] one was done by Director Planning, power of the then East Pakistan Water and Power Development Authority, on Mitsubishi A.C. net work analyzer in April, 1963 with very preliminary expansion schemes. The latest study of stability problem of the primary networks of the then power development authority was done by Fichtner[2] in 1967 in connection with the selection of site and design characteristics of Ashuganj power station. Fichtner's study included the then planning schemes upto the year 1985. But unfortunately, the year by year planning & construction schedule taken by Fichtner in its study has deviated too much from actual programmes. Fichtner's study report is no longer a representation of present or future networks of the country. After the war of liberation 1971, no systematic stability analysis of eastern grid was done, Several incidents of major grid failures were experienced by Power Development Board during the last few years and without going into detail stability analysis presently power development board has introduced automatic load shedding schemes during faults in order to save the grid from failure. So with a view to give better understanding of stability problem and procedure and means for calculation of transient stability to the country's only power authority, it was decided to investigate the stability problem of Eastern grid with some immediate future expansion schemes.

The new projects which are considered in this study are Sikalbaha 60 MW and Kaptai third unit of 40 MW stations, 132 KV loop around Dacca city as proposed by Ewe Bank and Partners[3] to ensure steady power supply in the capital, and Ghorasal-Tongi 132 KV double circuit. Radial feeders were not considered in this study.

A load-flow programme was developed for calculating system conditions prior to faults. This pogramme can also be used for carrying out load-flow studies for systematic system expansion and planning. A computer programme for determining machine to machine admittances for various circuit condition was also developed and lastely, swing-equation was solved by step-by-step and Runge-Kutta 4th order approximation methods. In this study mechanical power input and voltage behind transient reactance of machines were held fixed. Transient stabilities for maximum loading condition were examined by assuming 3-phase faults in heavily loaded section of the networks and clearing the fault by simultaneous opening of the breakers from the faulted buses in o.3 second and to see the worst case the line was not reclosed.

Interruption reports from the period Jan., 1976 to Jan, 1977 of eastern grid of power system of Bangladesh Power Development Board were examined by the author to sort out the types of faults occured in the system. Total number of faults actually happened was 51 during the above period. Detail breakdown of different types of faults are as follows:

Type of faults	Number	percentage
Single line to ground	29	56.86%
Line to line	6	11.76%
Two line to ground	9	17.65%
Three phase	7	13.72%

All the previous study of stability on the system of Bangladesh power development board were carried out by assuming 3-phase fault. Though the usual practice in stability study is to assume 2 L-G fault, but to make the results of this study comparable with previous stability studies 3-phase fault is considered in the study.

Percentage of different types of faults shows that number of 2 L-G and 3-phase faults are almost equal and as a result it was decided to carry out transient stability study by assuming 3-phase.fault.

This study will be valid upto 1985 if East-grid and West-grid interconnector is not constructed within this period.

The computer programmes developed for using with locally available IBM 360 computer, are easy and comprehensive. These programmes may be used easily by the engineers of Bangladesh power Development Board for analyzing its future system and preparing planning schemes in a systematic way. The results of transient stability studies are discussed in Chapter-6.

CHAPTER - 2

LITERATURE REVIEW

Literature Review:

The problem of system stability had its beginning when synchronous machines were first operated in parallel. It was early recognized that the amount of power that can be transferred from one synchronous machine to another is limited. This amount of load is known as the stability limit and when it is exceeded, the machine acting as a generator 'over speeds' and the machine acting as a motor 'stalls'.

As power systems developed, it was found with certain machines, particularly with certain systems connected through high-reactance tie lines, that it was difficult to maintain synchronism under normal conditions and that the systems had to be seperated in the event of faults or loss of excitation. Various emergency conditions occasionally made it necessary to operate machines and lines at the highest practicable load; under these conditions stability limits were estimated from experience.

The early analytical work on system stability was directed to the determination of the power limits of synchronous machines under two conditions: first the pull-out of a synchronous motor or generator from an infinite bus; and second, the pull-out or stability limit for two identical machines one acting as a generator and the other acting as a motor. However, the principal developments in system stability did not come about as an extension of synchronous machine theory, but as the result of the study of long distance transmission systems.

The modern view of the stability problem dates from the 1924 winter convention of the American Institute of Electrical Engineers when the results of the first laboratory tests[4] on miniature systems proportioned to simulate a power system having a long transmission line was presented. Another important step was taken in 1925 when the first field tests[5,6] on stability were made on the system of the Pacific Gas and electric company. Much additional practical information[7] on the problem was obtained by transient recording apparatus, first installed on the system of the Southern California Edison Company. During the ten year period from 1924 to 1933, the theory of system stability was carefully investigated. During this work there were proposed many new methods of improving stability of systems. Since that time considerable experience has been obtained with methods of analyzing stability and with new methods of improving stability.

Rapid opening of circuit breakers on faulted lines has been recognized for many years as one of the most effective ways of improving power system stability. But later on it was pointed out that rapid opening followed by rapid reclosing[8] gave further improvement in stability if the fault were transitory. In early stages, power engineers used to solve swing equation by hands. W.B. Boast and J.D. Rector[9] developed a method for obtaining directly on calibrated d.c. cathode ray oscilloscopes the swing curves for power systems during disturbance conditions. G.A. Bekey and F.W. Scholt[10] developed a method for direct determination of swing curves by the interconnection of a network analyzer with a differential analyzer. E.O. Norinder[11] developed a rational method for solving swing equation based on the ordinary step by step method and matched to ordinary office calculator.

For proper design[12] of power system, stability studies are very much needed. Transient stability considerations may determine the maximum economically usable conductor sizes[13] for bulk power transmission lines. Stability study also gives the power station operating guides[14] indicating loading restrictions.

Development of Digital computer made the power system analysis very easy and much less time consuming. Since its invention various methods and ways have been developed for transient stability study. J.L. Gaggbard, Jr. and J.E. Rowe[15] developed an easy method for solving stability equations of an electric power system using Digital Computer. Solution of transient stability problem employing Runge-Kutta 4th order approximation method[16] by digital computer was also developed.

One of the major problems encountered when an extensive power system is to be represented on an a.c. network analyzer is that of developing proper equivalents for those portions of the power system which are not to be represented in detail either because of limitations of the analyzer or because of a desire for simplification of the over all system. W.T. Brown and W.J. Cloues[17] developed a method for finding new equivalent which can be used interchangeably for both load-flow and stability studies on a.c. network analyzer. The growing complexity of the networks tremendously increases the difficulties of performing stability investigation. High computer memory is required for detailed representation of modern complicated power networks, which intern increases the time and cost of study. This problem can be handled by finding proper stability equivalents[18] to represent portions of the network beyond the area of immediate interest.

G.W. Stagg, A.F. Gabrielle, D.R. Morre and J.F. Hohenstein[19] developed a method and a computer programme for solving transient stability problem by the nodal iterative method for the solution of system voltages and currents and Gills variations of the Runge-Kutta procedure for the solution of the differential equations describing synchronous and induction machine behaviour, with a high speed digital computer. M.S. Dyrkacz and D.G. Lewis[20] also developed digital computer programming for the solution of transient stability by nodal iterative method.

M.S. Dyrkacz, c.c. Young and F.J. Maginniss[21] presented several new and important improvements and refinements in the application of digital computing techniques to transient stability analysis. The effect of transient saliency, exciter response and speed governing action were included in the computer programmes.

H.H. Happ, C.E. Person and c.c. Young[22] developed matrix computational methods for solving power system stability problems with the inclusion of transient saliency, variable impedance type loads, voltage regulator effect and governor response. They also developed a digital computer programme and discussed the convergence characteristics of the major computational loops of the algorithm employed.

H.E. Lokay and R.L. Bolger[23] presented increasingly detailed turbine generator representation on calculated system stability limits. They developed a new digital computer programme which permitted the representation of transient saliency, flux linkage variation caused by armature current, saturation, machine and system damping, the speed governor system and the excitation system and compared the new method with the previous computational methods.

B.J. Gevay and W.H. Schippel[24] studied the transient stability of an isolated radial power system by digital computer. They kept the load constant but its division was varied among three load components, namely, synchronous motors, induction motors and static load.

G.A. Jones[25] applied Bang-Bang excitation scheduling to a synchronous generator returning from load rejection. Such control increases the generator's degree of transient stability and terminates its mechanical oscillations. They developed the criterion for control from observations of generators response to return from load rejection and pulse variation in the excitation.

J.M. Undrill[26] developed a method for Dynamic stability calculations for an arbitrary number of interconnected synchronous machines by the application of standard multivariable control theory.

The papers referred to in the preceeding paragraphs indicate the evolution and scope of the theoretical and numerical analysis of the transient stability problem of electrical networks in biref. They are a sampling of the more important contributions in this field.

In the present work, an attempt has been made to study transient stability of the eastern grid of Bangladesh Power Development Board with some expansion schemes in the near future and in particular to develop a comprehensive computer programmes which may be used by the system planners in future study.

CHAPTER - 3

LOAD FLOW STUDY

3.1 Introduction

3.2 Derivation of the Nodal Equations

3.3 Formation of bus admittance matrix

3.4 Gauss-seidel iterative method of solution

3.5 Description of the test system

3.6 Computer programme

3.7 Results

3.1 Introduction:

Load flow calculations provide power flows and voltages for a specified power system subject to the regulating capability of generators, condensers, and tap changing under load transformers as well as specified net interchange between individual operating systems. This information is essential for the continuous evaluation of the current performance of a power system and for analyzing the effectivenss of alternative plans for system expansion to meet increased load demand. The aim of the author for performing load flow study was to determine system conditions prior to the disturbance, i.e. fault in the system, required for transient stability study.

The load flow problem consists of the calculation of power flows and voltages of a net work for specified terminal or bus conditions. A single phase representation is adequate since power systems are usually balanced. Associated with each bus are four quantities: the real and reactive power, the voltage magnitude and the phase angle. Three types of buses are represented in the load flow calculation and at a bus, two of the four quantities are specified. It is necessary to select one bus, called the slack bus, to provide the additional real and reactive power to supply the transmission losses, since these are unknown until the final solution is obtained. At this bus the voltage magnitude and phase angle are specified. The remaining buses of the system are designated either as voltage controlled buses or load buses. The real power and voltage magnitude are specified at a voltage controlled bus. The real and reactive powers are specified at a load bus.

X Network connections are described by using code numbers assigned to each bus. These numbers specify the terminals of transmission lines and transformers.

The two primary considerations in the development of an effective engineering computer programme are:

1. the formulation of a mathematical description of the problem.

2. the application of a numerical method for a solution. The analysis of the problem must also consider the interelation between these two factors.

The mathematical formulation of the load flow problem results in a system of algebraic nonlinear equations. These equations can be established by using either the bus or loop frame of xreference. The co-efficients of the equations depend on the selection of the independent variables, i.e. voltages or currents. Thus, either the admittance or impedance network matrices can be used. The author uses bus admittance matrix for the mathematical formulation of the load flow problem.

The solution of the algebraic equations describing the power system are based on an iterative technique because of their non-linearity. The solution must satisfy Kirchhoff's Laws, i.e. the algebraic sum of all flows at a bus must equal zero, and the algebraic sum of all voltages in a loop must equal zero. One or the other of these laws is used as a test for convergence of the solution in the iterative computational method. The author uses Gauss-Seidel iterative method for the numerical solution of algebraic equations describing the power system for load flow problem.

3.2 Derivation of the Nodal Equations:[27]

The real and reactive power at any bus P is given by:

$$P_p - jQ_p = E_p^{*} I_p \qquad (3.2.1)$$

where P_p is the real power at the bus P, Q_p is the reactive power at the bus P, E_p and I_p are the voltage and current at the said bus, and E_p^{*} is the complex conjugate of E_p.

The current at the bus P can also be expressed in terms of admittances and voltages of the adjacent buses ~~af~~ q as given by:

$$I_p = \sum_{q=1}^{n} Y_{pq} E_q$$

~~ar~~

or

$$I_p = Y_{pp} E_p + \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq} E_q \qquad (3.2.2)$$

where Y_{pq} = Mutual admittance between bus p and q

and Y_{pp} = Self admittance of bus p.

Equation (3.2.2) can be rewritten as:

$$E_p = \frac{1}{Y_{pp}} \left(I_p - \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq} E_q \right) \tag{3.2.3}$$

Combining equations (3.2.1) and (3.2.3)

$$E_p = \frac{1}{Y_{pp}} \left(\frac{P_p - jQ_p}{E_p^*} - \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq} E_q \right)$$

Substituting the real and imaginary components of the admittances and expanding different terms, the above expression becomes.

$$E_p = \frac{ARL(p)+jAIL(p)}{E_p^*} - \sum_{\substack{q=1 \\ q \neq p}}^{n} (BZR(p,q) + BZI(p,q)) E_q$$

where, $ARL(p) = (P_p AZR(p,p) - Q_p AZI(p,p))/(AZR(p,p)**2+AZI(p,p)**2)$

$AIL(p)=(-P_p AZI(p,p)-Q_p AZR(p,p))/(AZR(p,p)**2+AZI(p,p)**2)$

$BZR(p,q)=(AZR(p,q)AZR(p,p)+AZI(p,q)AZI(p,p))/(AZR(p,p)**2+AZR(p,p)**2)$

$BZI(p,q)=(AZI(p,q)AZR(p,p)-AZR(p,q)AZI(p,p))/AZR(p,p)**2+AZI(p,p)**2)$

Substituting the real and imaginary component of voltage.

$$ER(p)=(ARL(p)ER(p)-AIL(p)*EI(p))/(ER(p)**2+EI(p)**2)$$

$$- \sum_{\substack{q=1 \\ q \neq p}}^{n} (BZR(p,q)ER(q)-BZI(p,q)EI(q)) \tag{3.2.4}$$

$$EI(p)=(AIL(p)ER(p)+ARL(p)EI(p))/(ER(p)**2+EI(p)**2) - \sum_{\substack{q=1\\q\neq p}}^{n} (BZI(p,q)ER(q)+BZR(p,q)EI(q)) \quad (3.2.5)$$

where ER(p) and EI(p) are respectively the real and imaginary components of the voltage at bus p.

The above equations are solved by Gauss-seidel iterative method. The line flows are calculated as follows:

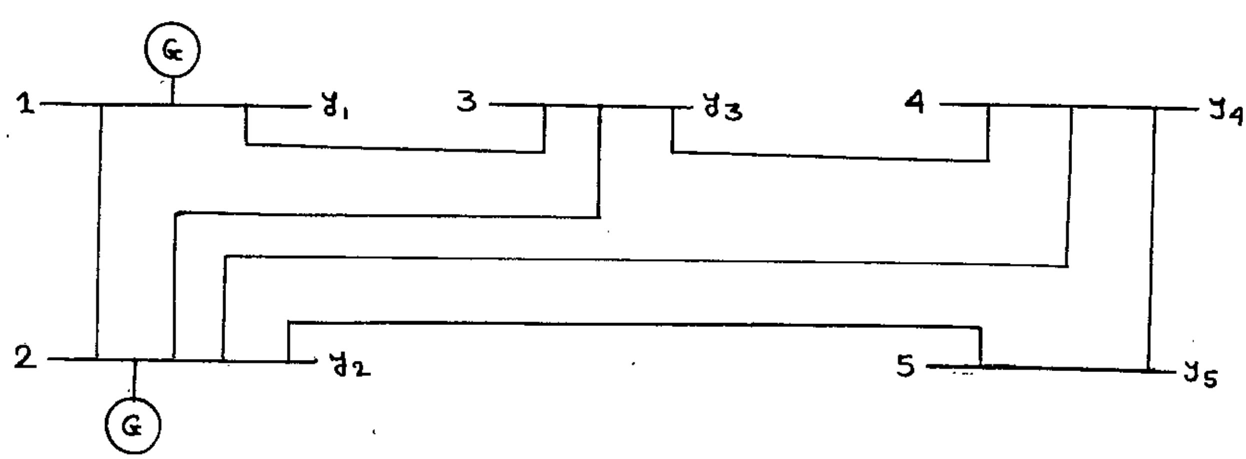
$$P_{pq}-jQ_{pq} = E_p^{*} (E_p-E_q)y_{pq}+E_p^{*} E_p \frac{y'_{pq}}{2} \quad (3.2.6)$$

where, y_{pq} = line admittance

y'_{pq} = total line charging admittance.

3.3 Formation of Bus Admittance Matrix:

Let us consider a simple system to illustrate the method of formation of bus admittance matrix.



Hene, y_1, y_2 etc. indicates total line charging admittance to ground at the bus indicated by the subscript.

Let y_{pq}, indicate admittance of lines connecting bus p and q.

No mutual coupling in the representation of the system is considered. Then, the diagonal element of the bus admittance matrix for bus 1 is

$$Y_{11} = y_{12} + y_{13} + y_1$$

and off diagonal element is

$$Y_{12} = -y_{12}$$

In general, the diagonal element and off diagonal element of bus admittance matrix are given by

$$Y_{pp} = \sum_{q=1}^{n} y_{pq} + y_p \qquad (3.3.1)$$

$$Y_{pq} = Y_{qp} = - y_{pq} \qquad (3.3.2)$$

3.4 <u>Gauss-Seidel Iterative Method of Solution:</u>

The power network equations are solved easily by Gauss-Seidel iterative method with small error. This method can easily be programmed for a computer.

To illustrate the method, let us consider the case of three equations in three unknowns.

$$a_{11}x_1 + a_{12}x_2 + a_{13}x_3 = b_1 \tag{3.4.1}$$

$$a_{21}x_1 + a_{22}x_2 + a_{23}x_3 = b_2 \tag{3.4.2}$$

$$a_{31}x_1 + a_{32}x_2 + a_{33}x_3 = b_3 \tag{3.4.3}$$

Let $a_{11} \neq 0$, $a_{22} \neq 0$, $a_{33} \neq 0$ and rewritting the equations as:

$$x_1 = \frac{1}{a_{11}} (b_1 - a_{12}x_2 - a_{13}x_3) \tag{3.4.4}$$

$$x_2 = \frac{1}{a_{22}} (b_2 - a_{21}x_1 - a_{23}x_3) \tag{3.4.5}$$

$$x_3 = \frac{1}{a_{33}} (b_3 - a_{31}x_1 - a_{32}x_2) \tag{3.4.6}$$

We now take any first approximation to the solution; call $x_1^{(o)}$, $x_2^{(o)}$ and $x_3^{(o)}$. We solve (3.4.4) for a new approximation to x_1:

$$x_1^{(1)} = \frac{1}{a_{11}} (b_1 - a_{12}x_2^{(o)} - a_{13}x_3^{(o)})$$

using the new value of x_1, together with $x_3^{(o)}$, we solve (3.4.5) for x_2:

$$x_2^{(1)} = \frac{1}{a_{22}} (b_2 - a_{21}x_1^{(1)} - a_{23}x_3^{(o)})$$

Finally we use the newly computed values of x_1 and x_2 in (3.4.6) to find a new value of x_3:

$$x_3^{(1)} = \frac{1}{a_{33}} (b_3 - a_{31}x_1^{(1)} - a_{32}x_2^{(1)})$$

This completes one iteration. We now start all over by replacing $x_1^{(o)}$, $x_2^{(o)}$ and $x_3^{(o)}$ by $x_1^{(1)}$, $x_2^{(1)}$ and $x_3^{(1)}$ and another approximation. In general the Kth approximation is given by.

$$x_1^{(k)} = \frac{1}{a_{11}} (b_1 - a_{12} x_2^{(k-1)} - a_{13}x_3^{(k-1)}) \qquad (3.4.7)$$

$$x_2^{(k)} = \frac{1}{a_{22}} (b_2 - a_{21}x_1^{(k)} - a_{23}x_3^{(k-1)}) \qquad (3.4.8)$$

$$x_3^{(k)} = \frac{1}{a_{33}} (b_3 - a_{31}x_1^{(k)} - a_{32}x_2^{(k)}) \qquad (3.4.9)$$

Extending now equations (3.4.7) to (3.4.9) to n equations in n unknowns, the Kth approximation to x_i is

$$x_i^{(k)} = \frac{1}{a_{ii}} (b_i - a_{i1}x_1^{(k)} - \cdots\cdots a_{i,i-1}x_{i-1}^{(k)} - a_{i,i+1}x_{i+1}^{(k-1)}$$

$$- \cdots\cdots a_{in}x_n^{(k-1)}) \qquad i = 1,2 \cdots\cdots n \qquad (3.4.10)$$

The process is iterated until all $x_i^{(k)}$ are sufficiently close to $x_i^{(k-1)}$. A typical way of determining closeness is to let

$$M^{(k)} = \text{Max} \left| x_i^{(k)} - x_i^{(k-1)} \right|$$

where the maximum is taken over all i. Then if $M^{(k)} \leq \epsilon$

where, ϵ is some predetermined small positive number usually called the tolerence limit, the iterration is stopped.

When the number of equations is large the Gauss-Seidel iterative process converges slowly requiring large number of iterations to satisfy the specified tolerance. To overcome this the value obtained from equation (3.4.7) is not used in the immediate calculation, but is modified in the way.

$$x_{1(\text{accelerated})}^{(k)} = x_1^{(k-1)} + \alpha \left| x_1^{(k)} - x_1^{(k-1)} \right|$$

where, α is the acceleration factor.

3.5 Description of the system:

System choosen for this study is the eastern-grid of Bangladesh power development board with the exception of a few radial feeders and with the inclusion of some immediate future expansion schemes. Diagram of the test system is given in Fig. 3.1. Future expansion schemes includes addition of both 132 KV lines and generating stations.

Kaptai Hydro electric project will be reinforced with another 50 MW unit bringing total capacity of the plant to 130 MW. Constructional work of this project has already been taken up and is expected to be in operation around 1980.

A new power-station of 60 MW capacity at Sikalbaha near Chittagong was planned earlier and presently its constructional work is going on. This generating station is expected to be in operation within 1980.

Future 132 KV lines considered in this study are

1. Ghorasal-Tongi 132 KV double circuit
2. Madanhat-Sikalbaha 132 KV double circuit
3. Shiddirganj-Postagola 132 KV single circuit
4. Postagola-Mirpur 132 KV single circuit
5. Mirpur-Tongi 132 KV single circuit.

Constructional works of some of these lines have already been taken up and it is expected that all these lines will be constructed as well as in in operation by 1980.

In the figure 3.1 new expansion schemes are shown with dotted lines.

3.6 Computer Programme:

A computer programme in FORTRAN IV Language employing Gauss-Seidel iterative method for load flow study was developed for running in the IBM 360 computer. At the time of working, facility of High FORTRAN language was not available in the computer and as a result programme developed was in basic FORTRAN-IV.

~~The~~

The programme starts with the input data reading of the total number of buses in the system, value of tolerance limit to be reached, maximum number of iteration to be allowed, values of acceleration factors to be used with real and reactive components of the voltages.

Next, resistance, reactance and admittance to ground of lines connecting buses are read in matrix form. The system connecting lines are read next. This is in the form of NxN matrix having elements, either zero or one. One,represents a connecting line between two buses and zero,represents no connection. Next input data are the real and reactive power generated, real and reactive parts of load.

Some voltage equation parameters are calculated before the iteration loop starts. Next the iterative part of the programme starts. Voltage magnitude of swing bus is then specified and then initial voltages of all other buses are assumed. The real and reactive components of voltages are solved seperately. Then the changes in bus voltages from the previous iteration are calculated. The bus voltages, are then replaced by the bus voltage in the previous iteration plus the changes in bus voltage multiplied by an acceleration factor. The real and reactive components of voltages are then tested against a predetermined precision index called tolerance. If the change is not within this tolerence the iteration count is advanced by one and the iterative portion is repeated again. If the changes of real and reactive parts of voltages does not satisfy the tolerance test within maximum limit of iteration number, then the Gauss-Seidel will not converge.

If the voltages are within tolerance, the number of iterations required, real and reactive parts of voltage along with bus numbers are printed.

Then the line flows are calculated. Real and reactive power flows along with bus numbers connected by the line are printed.

Next, voltage magnitude and angle associated with it are calculated and printed.

The detailed programme is given in the Appendix-A.

3.7 Results:

The computer programme described in the last section has been used to solve automatic load flow solution of the major parts of Eastern grid power network of Bangladesh power development Board. Figure (3.1) shows the single line diagram of the system. The system choosen contains near future projects of power stations and transmission lines. Load flow study was performed with 14 buses. Shahjibazar bus designated as bus no.1 was considered as swing bus and its voltage magnitude was held constant at 1.3/ 0 p.u. Bus numbers 2,3,4,12 & 14 are generator buses and the rest are load buses.

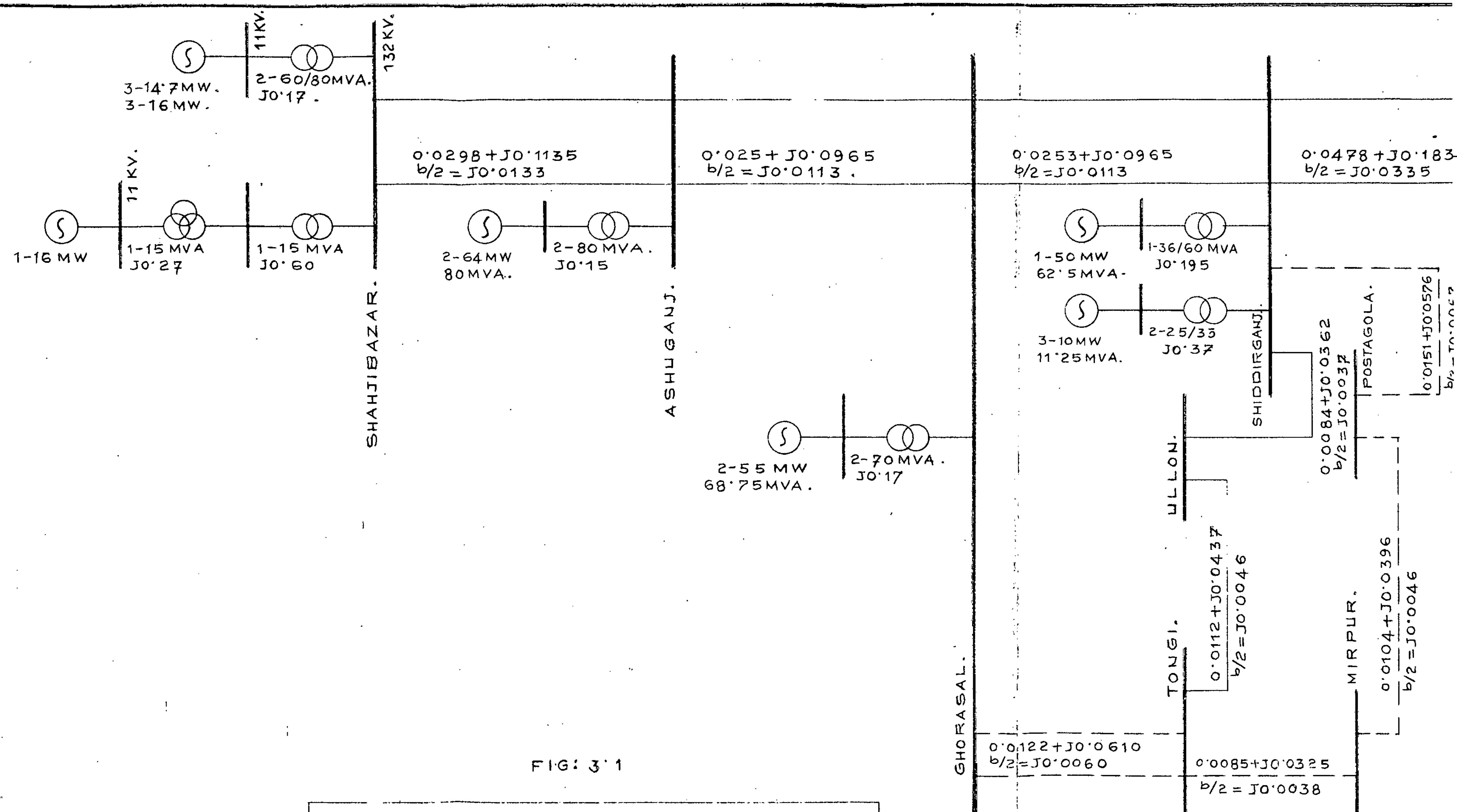
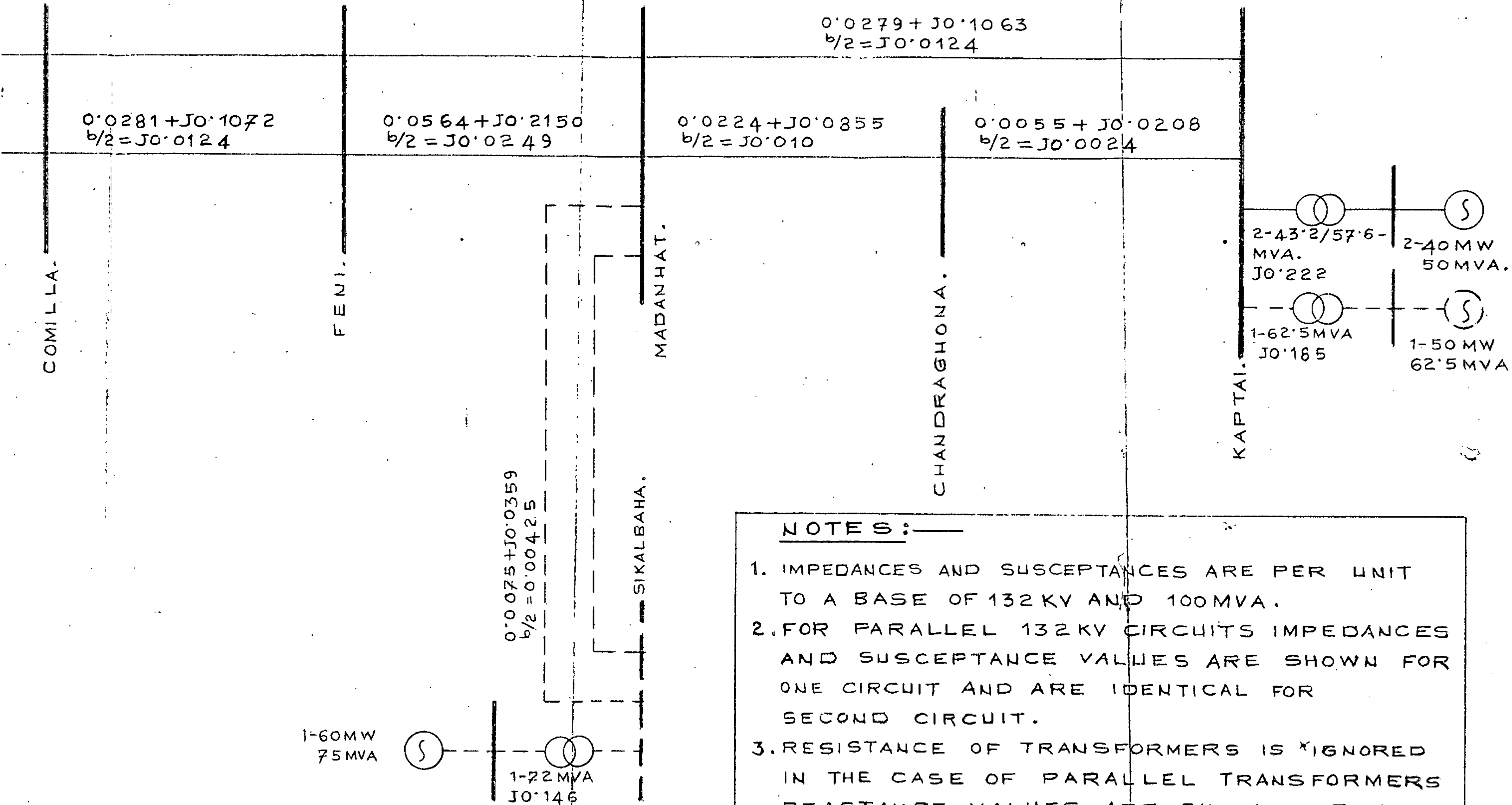


FIG: 3·1

IMPEDANCE DIAGRAM FOR TEST SYSTEM.



NOTES:—

1. IMPEDANCES AND SUSCEPTANCES ARE PER UNIT TO A BASE OF 132 KV AND 100 MVA.
2. FOR PARALLEL 132 KV CIRCUITS IMPEDANCES AND SUSCEPTANCE VALUES ARE SHOWN FOR ONE CIRCUIT AND ARE IDENTICAL FOR SECOND CIRCUIT.
3. RESISTANCE OF TRANSFORMERS IS IGNORED IN THE CASE OF PARALLEL TRANSFORMERS REACTANCE VALUES ARE SHOWN FOR ONE TRANSFORMER AND ARE IDENTICAL FOR THE OTHER PARALLELED TRANSFORMERS.

ITER= 98

REAL VOLTAGE	IMG VOLTAGE	BUS CODE
1.0299997	C.0	1
1.0716238	C.0106042	2
1.0674429	-C.0098372	3
1.0646505	-0.0225581	4
1.0484257	-C.0330430	5
1.0430536	-C.0338630	6
1.0339718	-0.0420411	7
1.038600C	-C.0402385	8
1.1112261	-C.0070553	9
1.1399536	C.0087901	10
1.1939945	C.0472310	11
1.1942768	0.0473443	12
1.2317228	C.0806522	13
1.2422619	C.0901486	14

CALCULATION OF LINE FLOWS

REAL POWER	IMG POWER	BUS CODE	
-0.370554	-0.6928	1	2
0.378686	0.6647	2	1
0.448386	-0.0457	2	3
-0.446176	C.0025	3	2
0.278727	-0.C394	3	4
C.978738	C.6364	3	6
-0.277866	-0.C087	4	3
0.405832	0.3723	4	5
0.431741	0.3538	4	8
-0.311189	-0.5328	4	9
-0.403562	-0.3708	5	4
0.C53118	0.1096	5	6
-C.971347	-0.6262	6	3
-0.052955	-0.1190	6	5
C.323788	0.1941	6	7
-0.322663	-C.1980	7	6
-0.077845	-0.1034	7	8
-0.427520	-0.3525	8	4
0.077998	0.C941	8	7
C.317629	C.3987	9	4
-0.456180	-0.5050	9	10
0.461090	0.4609	10	9
-C.518678	-0.5049	10	11
0.528719	0.4073	11	10
-C.010322	-0.C291	11	12
-0.550936	-C.4153	11	13
-0.568740	-C.4297	11	14
C.010323	0.C049	12	11
0.558220	C.4136	13	11
-0.650752	-C.4925	13	14
C.578376	C.4294	14	11
0.653144	0.4942	14	13

CALCULATION OF BUS VOLTAGE AND ANGLE

1		2		3		4		5		6		7	
1.029999	0.0	1.071675	0.57	1.067488	-0.53	1.064888	-1.21	1.048944	-1.81	1.043602	-1.86	1.034825	-2.33
1.039378	-2.22	1.111248	-0.36	1.139987	0.44	1.194927	2.27	1.195214	2.27	1.234360	3.75	1.245527	4.15
8		9		10		11		12		13		14	

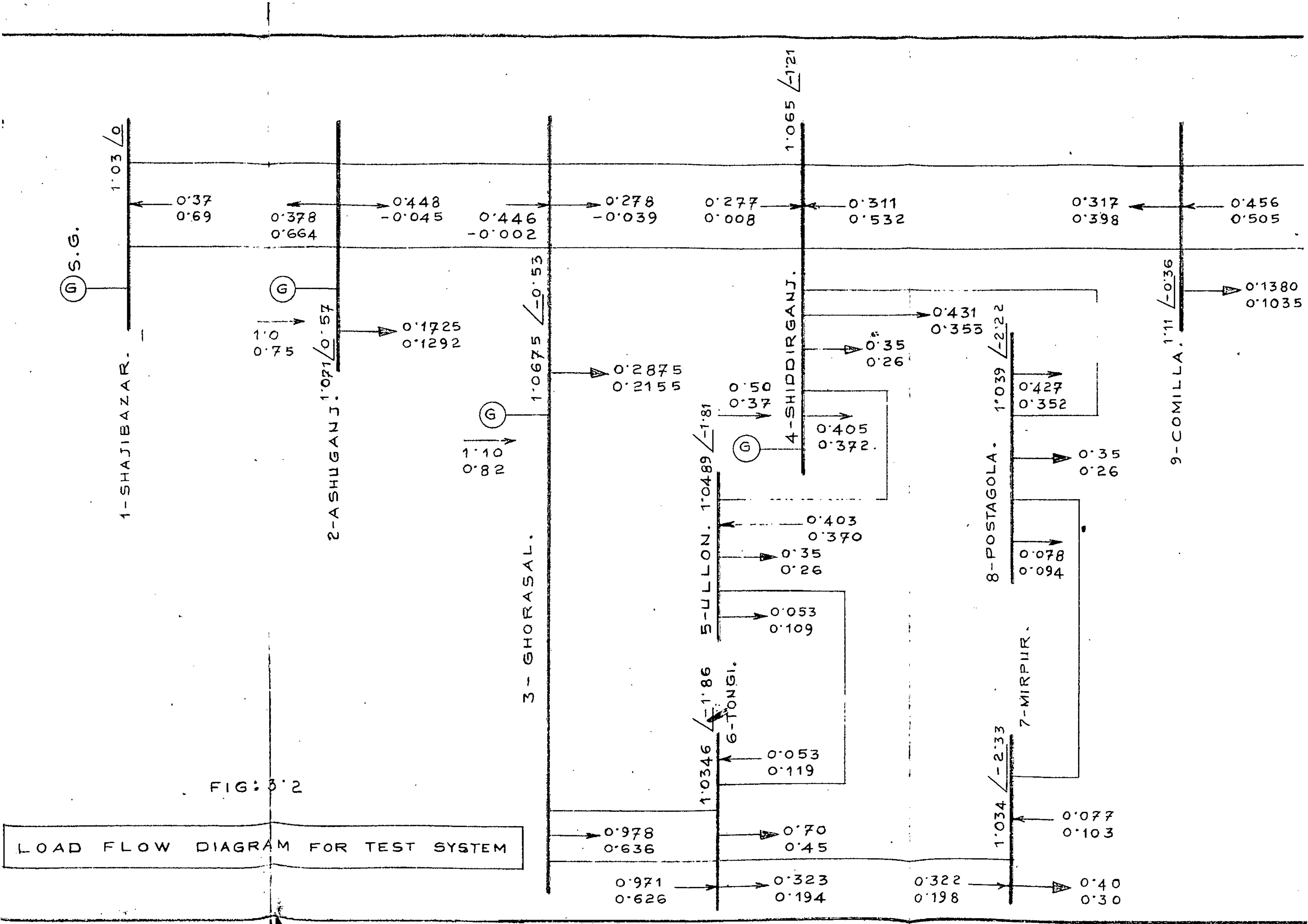
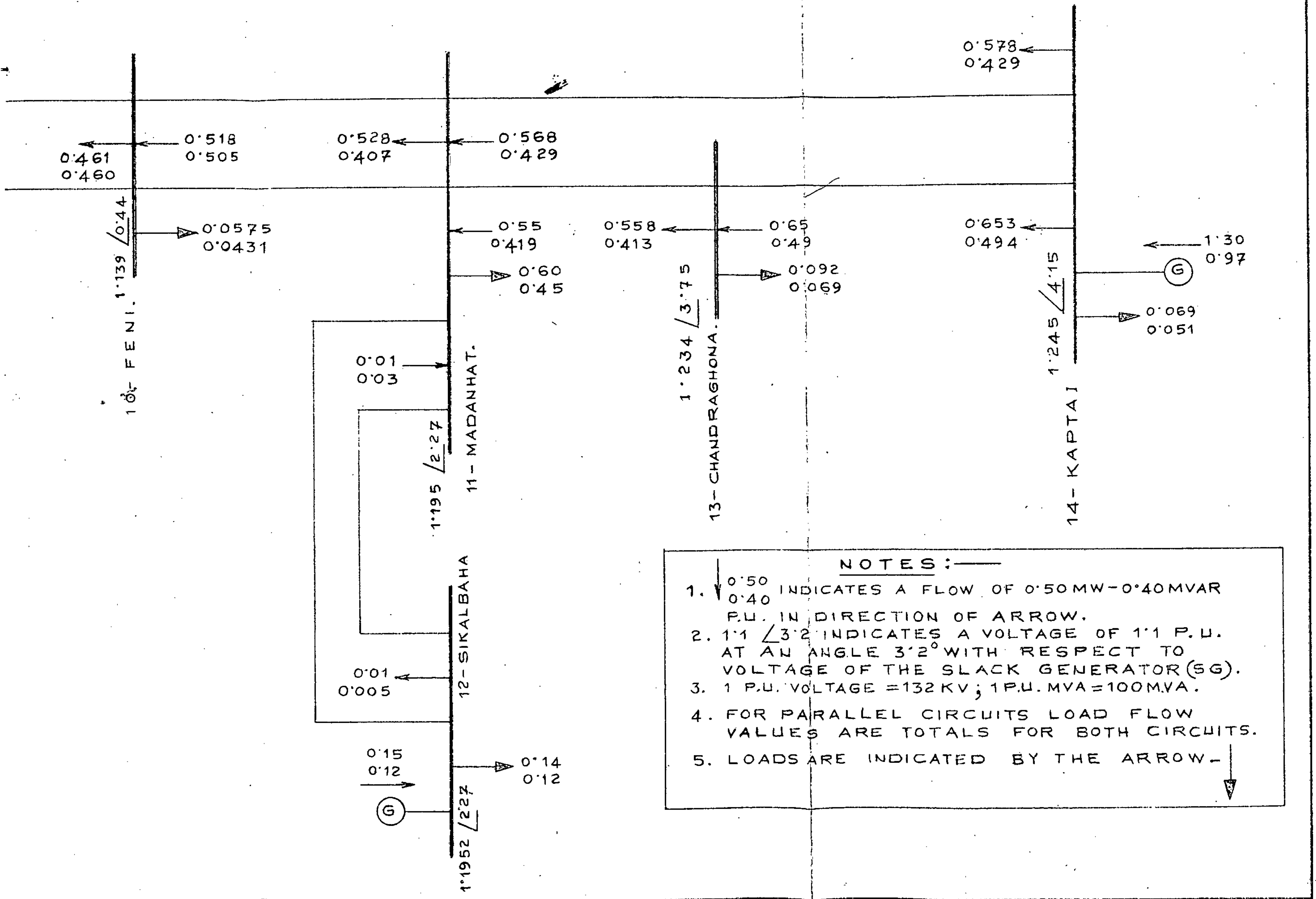


FIG: 3·2

LOAD FLOW DIAGRAM FOR TEST SYSTEM



NOTES:—

1. ↓ 0·50 / 0·40 INDICATES A FLOW OF 0·50 MW - 0·40 MVAR P.U. IN DIRECTION OF ARROW.
2. 1·1 ∠3·2 INDICATES A VOLTAGE OF 1·1 P.U. AT AN ANGLE 3·2° WITH RESPECT TO VOLTAGE OF THE SLACK GENERATOR (SG).
3. 1 P.U. VOLTAGE = 132 KV ; 1 P.U. MVA = 100 MVA.
4. FOR PARALLEL CIRCUITS LOAD FLOW VALUES ARE TOTALS FOR BOTH CIRCUITS.
5. LOADS ARE INDICATED BY THE ARROW –

CHAPTER - 4

VOLTAGE BACK OF TRANSIENT REACTANCE OF MACHINES

4.1 Calculation of voltage back of transient reactance of machines

4.2 Computer Programme

4.3 Results

4.1 Calculation of Voltage Back of Transient Reactance of Machines:

Once the system conditions prior to disturbance are obtained from load flow study, the next step for transient stability study is to calculate voltage back of transient reactance of machines.

Machine currents are calculated as follows:

$$I_{ti} = \frac{P_{ti} - jQ_{ti}}{E_{ti}^{*}} \quad , i = 1,2, \ldots . m \qquad (4.1.1)$$

where m is the number of machines and P_{ti} and the Q_{ti} are the scheduled or calculated machine real and reactive terminal powers. The calculated power for the machine at the slack bus and the terminal voltages are obtained from the initial load flow solution.

When the machine i is represented by a voltage source of constant magnitude back of transient reactance, the voltage is obtained from

$$E_{i(0)} = E_{ti} + jx_i' I_{ti} \quad \ldots . \qquad (4.1.2)$$

combining equations (4.1.1) and (4.1.2) and substituting real and imaginary parts of voltages, we obtain

ETR = ER + (VG*ER - WG*EI)* x/(ER**2 + EI ** 2)   (4.1.3)

ETI = EI + (WG*ER + VG* EI)* x/(ER**2 + EI ** 2)   (4.1.4)

where, ETR and ETI are the real and imaginary parts of voltage back of transient reactance of machines; ER and EI are real and imaginary parts of terminal voltage; WG and VG are real and imaginary power of machines.

Internal voltage angle is calculated from

$$\delta = \tan^{-1}(ETI/ETR) \qquad (4.1.5)$$

4.2 Computer Programme:

A simple computer programme was developed by the author to calculate voltage back of transient reactance of machines and internal voltage angle employing equations (4.1.3), (4.1.4) and (4.1.5).

Input data for this programme are number of machines, real and imaginary terminal voltages of machines, transient reactances of machines and real and imaginary powers of machines.

First real and imaginary parts of voltage back of transient reactance and then magnitude of the voltage and voltage angles are calculated.

Detailed computer programme for calculation of voltage back of transient reactance of machines is given in Appendix-B.

4.3 Results:

Terminal voltages and power outputs of machines of all buses except swing bus are obtained from load flow study. Power output of swing bus (Shajibazar 132 KV) is obtained after assinging load at that bus and then equating with line flows. Real and imaginary powers at swing bus were calculated to be as

P = 13 MW and   Q = 29 MVAR

Computer prints magnitude of voltage back of transient reactance and voltage angles with name of the machines. Time taken by the computer for this programme was noted as 1 minute 18 seconds computer print outs containing the results is given on page 32.

COMPUTATION OF VOLTAGEBACK CF TRANSIENT REACTANCE OF MACHINE

	SHAHJIBAZAR	AHSHU GANJ	GHORA SAL	SHIDDIRGANJ	SIKAL BAHA	KAPTAIHYDRO
VOLTAGE	0.99546	1.17493	1.19950	1.12073	1.24337	1.39647
ANGLE	0.89429	6.83621	7.24817	2.48540	4.96610	11.79144

CHAPTER - 5

CALCULATION OF MACHINE TO MACHINE ADMITTANCES

5.1 Introduction

5.2 Network Reduction Process

5.3 Calculation of Driving point and transfer Admittance constants

5.4 Computer Programme

5.5 Results

5.1. Introduction:

Once the load flow study and voltages behind transient reactance of machines are calculated the next step before proceeding with the solution of swing equation for transient stability study is to determine machine to machine admittances during fault and after clearance of fault. Impedance diagram of test system for transient stability study is shown in Fig. (5.1). Machine data are also given in Table (5.2). In all six generators of eastern grid were considered in the study. More than one machine at a particular bus were combined together to a equivalent machine. For identical machines inertia constant of equivalent machine was taken as the sum of the inertia constants of individual machine. Impedance of the equivalent machine was calculated in usual way of paralleling the impedances of the individual machines. Loads in different buses were expressed as equivalent admittances to ground. Line charging admittances were also taken into account. A computer programme was developed to determine machine to machine admittances during a 3-phase fault and after the clearance of the fault.

5.2. Network Reduction Process:[29]

Before entering into a detailed discussion of the network reduction process, as given in this section, it would be better to mention the preliminary data requirements for this calculation. On an impedance diagram of the system giving a single line representation of the positive sequence network, all important lines and equivalent load branches to ground should be indicated as well as the generator transient reactances and the fictitious nodes behind these reactances.

To illustrate the process of network reduction let us take the network diagram of Fig. (5.4) as an example. The various nodes are classified as generator nodes, fault nodes and load nodes. The classifications are defined as follows:

Generator nodes are those factitious nodes, numbered 1 through 4 in Fig. (5.4), at which the voltage behind transient reactance exists. Fault nodes numbered 5 and 6 are the terminal nodes of the line which is to be faulted. More generally, the terminal nodes for all lines which may be faulted are included in this classification. All other nodes, numbered 7 through 10, are referred to as load nodes, even though in some cases there may be no load connected. It may be noted that the generator nodes have been numbered consecutively as a group, then the fault nodes, and finally the remaining load nodes. The reason for this ordered numbering will soon become apparent.

The goal of the network reduction process is an equivalent network containing only buses 1 through 4 of Fig. (5.4). The form of the equivalent network will be as shown in Fig. (5.5) with the possibility that any of the mutual admittances might be zero. It must be recognized that more than one set of admittance constants for Fig. (5.5) will ordinarily be needed. This is due to the fact that the network conditions change with the occurrence of a fault and its subsequent clearance. It is important to note that all of the network changes corresponding to different conditions can be made on a partially reduced network, if that partially reduced network contains buses 5 and 6. It is apparent that a computational saving can be obtained by eliminating once the buses marked L in Fig. 5.4 , then eliminating as many times as required the buses marked F, namely 5 and 6.

The nodal equations for the system of Fig. 5.4 are represented by the matrix equation

$$EY = I \qquad \ldots \qquad (5.2.1)$$

where, E stands for a vector whose elements are complex voltages at the 10 system buses, Y stands for a 10x10 matrix of self and mutual admittances, and I is a vector whose elements are the complex shunt currents at each of the 10 buses. If we expand equation (5.2.1) for the system of Fig. 5.4 , we get the expanded equation as follows:

$$\begin{array}{cccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 \\ \hline y_{11} & & & & & & -y_{17} & & & \\ \hline & y_{22} & & & & & & -y_{28} & & \\ \hline & & y_{33} & & & -y_{36} & & & & \\ \hline & & & y_{44} & & & & & & -y_{410} \\ \hline & & & & y_{55} & -y_{56} & -y_{57} & & & \\ \hline & & -y_{63} & & -y_{65} & y_{66} & & & & -y_{610} \\ \hline -y_{71} & & & & -y_{75} & & y_{77} & -y_{78} & & \\ \hline & -y_{82} & & & & & -y_{87} & y_{88} & -y_{89} & \\ \hline & & & & & & & -y_{98} & y_{99} & -y_{910} \\ \hline & & & -y_{104} & & -y_{106} & & & -y_{109} & y_{1010} \\ \hline \end{array} \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \\ e_5 \\ e_6 \\ e_7 \\ e_8 \\ e_9 \\ e_{10} \end{bmatrix} = \begin{bmatrix} i_1 \\ i_2 \\ i_3 \\ i_4 \\ i_5 \\ i_6 \\ i_7 \\ i_8 \\ i_9 \\ i_{10} \end{bmatrix}$$

.....(5.2.2)

Since buses 5 through 10 are ultimately to be eliminated, the shunt currents 5 through 10 may be substituted for by using the relations

$$i_k = - e_k y_k \qquad k = 5, \ldots 10 \qquad (5.2.3)$$

$$y_k \doteq \frac{p_k - j\, Q_k}{e_k^{\,2}} \qquad (5.2.4)$$

This merely follows the customary procedure of replacing loads by constant admittance branches where magawatt and mega-var values are unchanged for normal bus voltages. The result of substituting equations (5.2.3) into (5.2.2) results in

$$\begin{array}{cccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 \end{array}$$

$$\begin{bmatrix} y_{11} & & & & & & -y_{17} & & & \\ & y_{22} & & & & & & -y_{28} & & \\ & & y_{33} & & & -y_{36} & & & & \\ & & & y_{44} & & & & & & -y_{410} \\ & & & & y_{55}+y_5 & -y_{56} & -y_{57} & & & \\ & & -y_{63} & & -y_{65} & y_{66}+y_6 & & & & -y_{610} \\ -y_{71} & & & & -y_{75} & & y_{77}+y_7 & -y_{78} & & \\ & -y_{82} & & & & & -y_{87} & y_{88}+y_8 & -y_{89} & \\ & & & & & & & -y_{98} & y_{99}+y_9 & -y_{910} \\ & & & -y_{104} & & -y_{106} & & & -y_{109} & y_{1010}+y_{10} \end{bmatrix} \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \\ e_5 \\ e_6 \\ e_7 \\ e_8 \\ e_9 \\ e_{10} \end{bmatrix} = \begin{bmatrix} i_1 \\ i_2 \\ i_3 \\ i_4 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

...... (5.2.5)

Here the method of eliminating one bus at a time, that is, the matrix co-efficients is reduced by one column and row at a time is adopted. By way of illustrations, consider again the equations for the network of Fig. 5.4 which have been written as equation (5.2.5). The last equation of (5.2.5) may be written

$$-y_{10,4}e_4 - y_{10,6}e_6 - y_{10,9}e_9 + (y_{10,10}+y_{10})e_{10} = 0 \qquad (5.2.6)$$

solving for e_{10} in equation (5.2.6), we obtain

$$e_{10} = \frac{y_{10,4}}{y_{10,10}+y_{10}} e_4 + \frac{y_{10,6}}{y_{10,10}+y_{10}} e_6 + \frac{y_{10,9}}{y_{10,10}+y_{10}} e_9 \qquad (5.2.7)$$

If node 10 is to be eliminated, e_{10} must be removed from the fourth, sixth and nineth equations of equation (5.2.5) by substitution. The terms which the substitution add to equation (4) of equation (5.2.5) are

$$-\frac{y_{4,10}y_{10,4}}{y_{10,10}+y_{10}} e_4 \; ; \; -\frac{y_{4,10}y_{10,6}}{y_{10,10}+y_{10}} e_6 \; ; \; -\frac{y_{4,10}y_{10,9}}{y_{10,10}+y_{10}} e_9$$

(5.2.8)

Similar expressions will be added to the sixth and nineth equations. Altogether, the elimination of node 10 requires the entry of nine new co-efficients in the first 9 equations of equation (5.2.5). Since the array of coefficients is symmetrical, there are just six distinctly different new coefficients to be added to the first 9 equations. This is important from the computing stand point. This process of node elimination is, of course, closely related to the problem of star mesh conversion.

A rule may now be developed in terms of the subscripts which may be programmed for the computer so that the computer may automatically obtain the new coefficients when a node has been deleted.

This rule may be demonstrated as follows:

Suppose that it is desired to eliminate node k from a network and that there are three off diagonal terms, which are associated with it in the co-efficient matrix.

a) Designate the off-diagonal terms as $-Y_{k1}$, $-Y_{k3}$, $-Y_{k4}$

b) Designate the diagonal term as Y_{kk}

c) Form: Y_{k1}/Y_{kk}, Y_{k3}/Y_{kk}, Y_{k4}/Y_{kk}

d) The three terms in (a) when multiplied by each of the three terms of (c) will give the changes which must be added to the original co-efficients to produce the new desired terms.
To be specific

$$Y_{11\text{ new}} = Y_{11\text{ old}} - (Y_{k1})(Y_{k1}/Y_{kk})$$

$$Y_{13\text{ new}} = Y_{13\text{ old}} - (Y_{k1})(Y_{k3}/Y_{kk})$$

$$Y_{14\text{ new}} = Y_{14\text{ old}} - (Y_{k1})(Y_{k4}/Y_{kk})$$

$$Y_{33\text{ new}} = Y_{33\text{ old}} - (Y_{k3})(Y_{k3}/Y_{kk})$$

$$Y_{34\text{ new}} = Y_{34\text{ old}} - (Y_{k3})(Y_{k4}/Y_{kk})$$

$$Y_{44\text{ new}} = Y_{44\text{ old}} - (Y_{k4})(Y_{k4}/Y_{kk})$$

It is now apparent that to reduce a new network it is necessary to know the subscripts of the non-zero coefficients of the admittance matrix, what the values of these coefficients are, where they are located in the memory, and what nodes are to be deleted. Of course it is convenient to have the nodes ordered to, so that the nodes which are to be deleted are grouped together. It is a convenience to be able to delete the last node, and then the next to last etc.

5.3. Calculation of Driving Point and Transfer Admittance Constants:[30]

Calculation of two sets of driving point and transfer admittance constant is required; one with fault on and the other after clearance of fault by simultaneous opening of breakers from bus 5 and 6. In the preceeding section principle of network reduction is given. Once all the load buses are removed, then the circuit conditions are applied for determining driving point and transfer admittances. When all load buses are removed, then the equation (5.2.5) takes the form

$$\left[\begin{array}{c|c} Y_{GG} & Y_{GF} \\ \hline Y_{FG} & Y_{FF} \end{array}\right] \left[\begin{array}{c} E_G \\ \hline E_F \end{array}\right] = \left[\begin{array}{c} i_G \\ \hline 0 \end{array}\right] \qquad (5.3.1)$$

With the breakers at bus 5 and 6 closed and fault on, the value of e_6 for a 3-phase fault is zero and the fault current i_{F6} is unknown.

The equation,

$$Y_{FG}\ E_G + Y_{FF}\ E_F = 0$$

may be reritten as

$$y'_{51}e_1 + y'_{52}e_2 + y'_{53}e_3 + y'_{54}e_4 + y'_{55}e_5 = 0 \qquad (5.3.2)$$

$$y'_{61}e_1 + y'_{62}e_2 + y'_{63}e_3 + y'_{64}e_4 + y'_{65}e_5 = I_{F6} \qquad (5.3.3)$$

The subscripts used with the admittance constants of equations (5.3.2) and (5.3.3) serve to differentiate between these elements and those of equation (5.2.5) before the elimination of load buses.

The problem of reducing the network now becomes one of just determining e_5 from equation (5.3.2) and substituting this value in equation (5.3.1). From equation (5.3.2).

$$e_5 = -\frac{1}{y'_{55}}(y'_{51}e_1 + y'_{52}e_2 + y'_{53}e_3 + y'_{54}e_4)$$

which upon substitution into equation (5.3.1) gives the result as

$$Y_{GG}\ E_G + Y_{GF}\begin{bmatrix} -(y_{55})^{-1} & 0 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} y'_{51} & y'_{52} & y'_{53} & y'_{54} \\ 0 & 0 & 0 & 0 \end{bmatrix} E_G = I_G$$

... (5.3.4)

which can finally written as

$$Y^{1}_{GG}\ E_G = I_G \quad .. \qquad (5.3.5)$$

The equation (5.3.5) gives the required driving point and transfer admittances during fault.

The following procedure is applied for determing driving point and transfer admittances after the clearance of fault. The clearance of fault means disconnection of line between faulted buses i.e 5 and 6 by the simultaneous opening of circuit breakers. This change is brought in by changing the parameters of the matrix Y_{FF}, which is the matrix for fault buses of equation (5.3.1). The change in the matrix for faulted buses i.e Y_{FF} is brought about by sub-tracting the admittance of the faulted line from the mutual admittances between nodes 5 and 6 and from the self admittances of nodes 5 and 6. Let Y_{FF} after these changes becomes Y'_{FF} and the equation (5.3.1) now becomes

$$\begin{bmatrix} Y_{GG} & Y_{GF} \\ \hline Y_{FG} & Y'_{FF} \end{bmatrix} \begin{bmatrix} E_G \\ \hline E_F \end{bmatrix} = \begin{bmatrix} i_G \\ \hline 0 \end{bmatrix} \qquad (5.3.6)$$

Now the required driving point and transfer admittances are calculated by first removing node 6 and then node 5, application of the principle given in the preceeding section. Finally, the equation (5.3.6) will become after elimination of node 5 & 6

$$Y^2_{GG}\, E_G = I_G \qquad (5.3.7)$$

Y^1_{GG} and Y^2_{GG} from equations (5.3.5) and (5.3.7) indicates the machine to machine admittances for condition 1 and 2 i.e. with the fault on and fault cleared.

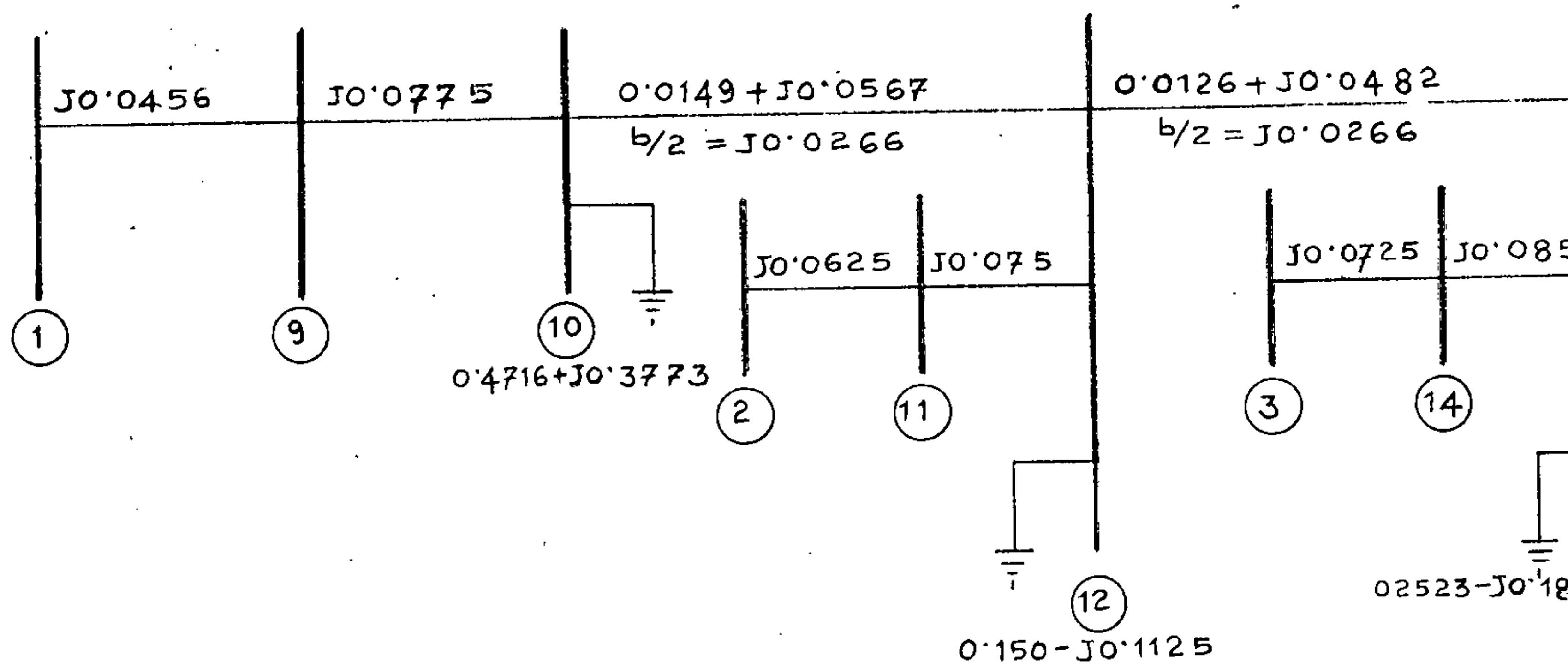
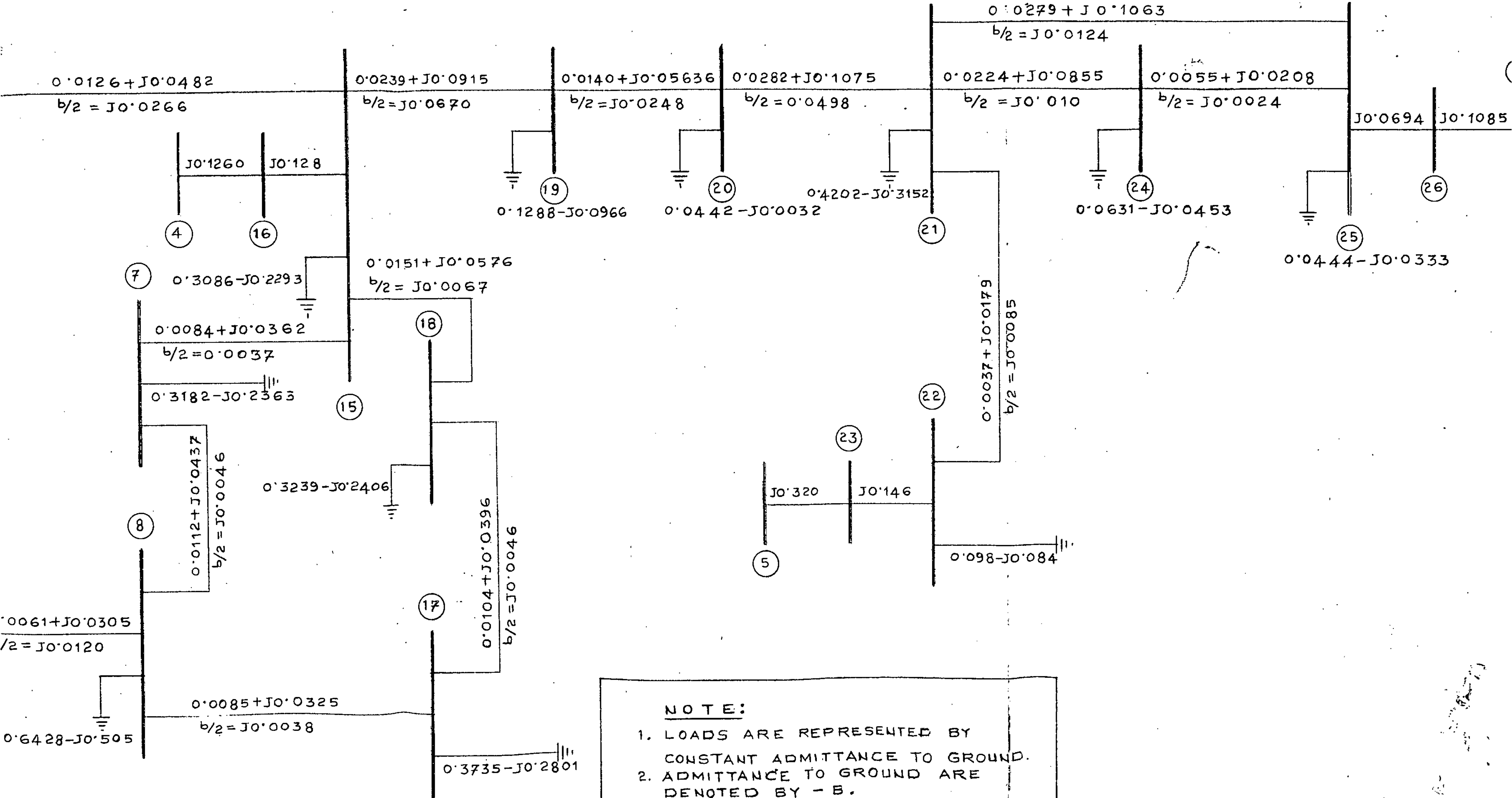


FIG: 5·1

IMPEDANCE DIAGRAM OF TEST SYSTEM FOR TRANSIENT STABILITY STUDY.



NOTE:

1. LOADS ARE REPRESENTED BY CONSTANT ADMITTANCE TO GROUND.
2. ADMITTANCE TO GROUND ARE DENOTED BY - B.

STATION.	OUT PUT (MVA)	VOLTAGE (K.V.)	SPEED (R.P.M.)	P.F.	IMPEDANCE.							2H-CONSTANT (KWS/KVA)
					% X''_d	% X'_d	% X_d	% X''_q	% X_q	% X_2	% X_0	
KAPTAI	2 X 50	11	107	0·8	18·0	30	113	21·0	53·5	19·5	7·0	8·18
	1 X 62·5	11	107	0·8	18·0	30	113	21·0	53	19	7·0	8·0.
SIKALBAHA.	1 X 75	11	3000	0·8	16	24	230	16	210	16	8·0	9·7
SHIDDHIRGANJ	3 X 11·25	11	3000	0·8	15	22	120	15	115	12	4	8·8
	1 X 62·5	11·5	3000	0·8	17·5	29	127	17·5	121	17·5	6	9·2
GHORASAL.	2 X 69	10·5	3000	0·8	14	20	151	20	151	17	6·7	12·68
ASHUGANJ.	2 X 80	11	3000	0·8	12·5	20	233	12·5	221	12·5	8·0	9·8
SHAHJIBAZAR.	4 X 20	11	3000	0·8	11	16·6	152	10·5	185	12	4·5	20·0
	3 X 19·625	11	3000	0·8	14	18	195	14·5	185	14·4	4·2	20

TABLE FOR GENERATOR DATA.

NOTE:
VALUES OF IMPEDANCES AND
H - CONSTANT ARE ON NATURAL MVA.

TABLE : 5·2

TABLE FOR LOAD DATA

Name of Substation	Load	
	MW	MVAR
Shajibazar	50	40
Ashuganj	17.25	12.92
Ghorasal	28.75	21.55
Shiddirganj	35	26
Ullon	35	26
Tongi	70	50
Mirpur	40	30
Postagola	35	26
Comilla	13.8	10.35
Feni	5.75	4.31
Madanhat	60	45
Sikalbaha	14	12
Chandraghona	9.2	6.9
Kaptai	6.9	5.1

Table 5.3

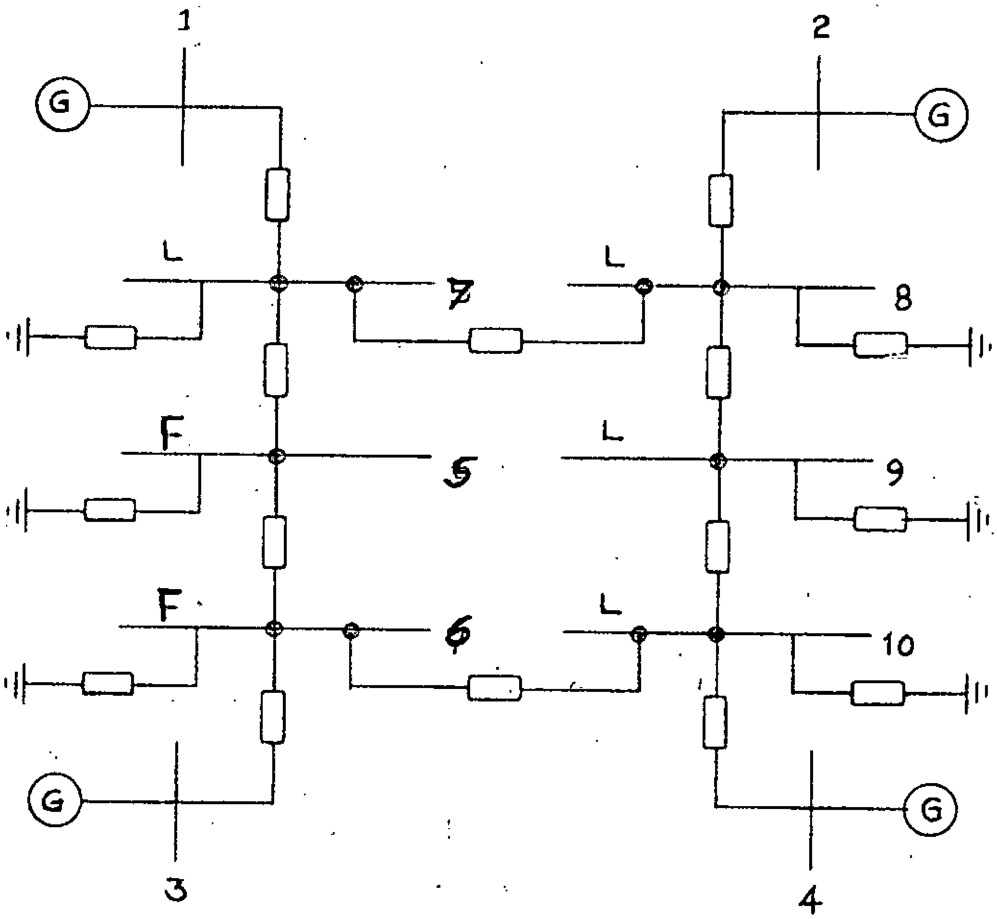


FIG: 5·4

DIAGRAM OF SYSTEM TAKEN AS AN EXAMPLE.

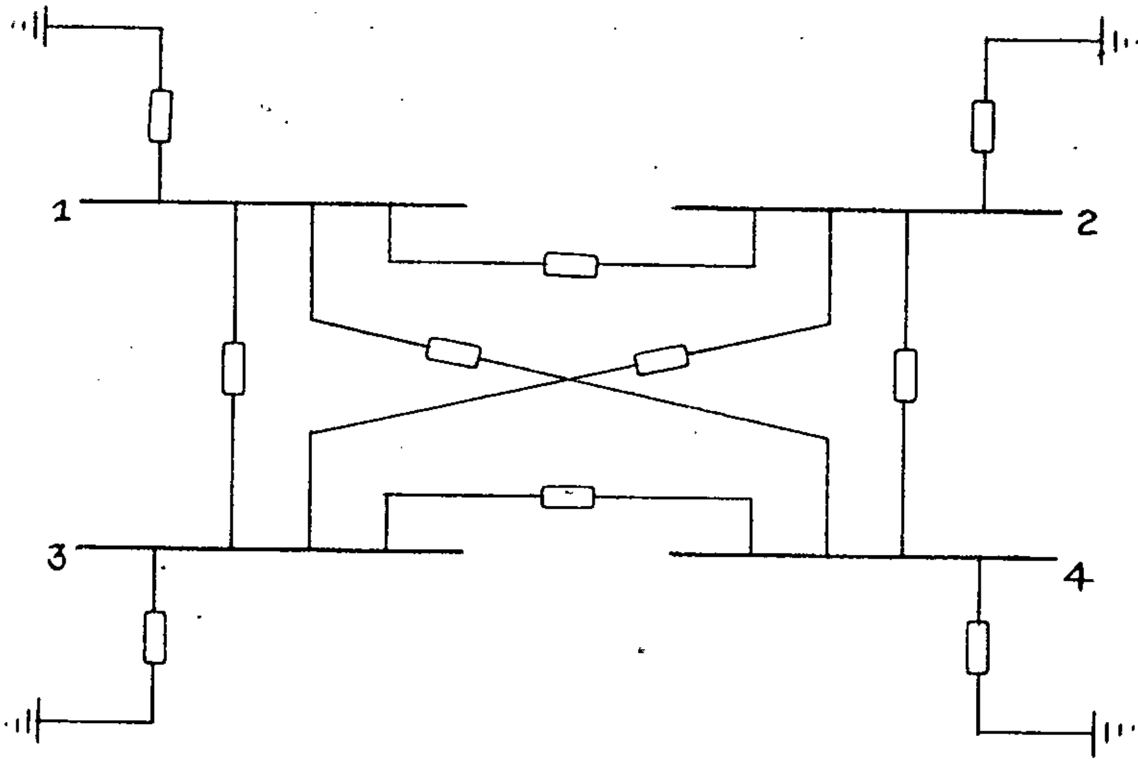


FIG: 5·5

REDUCED DIAGRAM OF EXAMPLE SYSTEM.

5.4 Computer Programme:

The author has developed a computer programme in FORTRAN-IV language for calculation of driving point and transfer admittances of machines during a 3-phase fault and after its clearance.

The input data required for this programme are resistances and reactances of different connecting branches of the network, number of buses, line connecting matrices, line charging admittances of buses and load equivalent admittances to ground. Buses are also designated as per discussion of section (5.2) of this Chapter.

With above inputs computer first forms bus admittance matrix and then starts eliminating one node at a time by the principle outlined in section (5.2) of this chapter. Network reduction process is carried out through a sub-routine in the main programme. All the load buses are eliminated in this way. Now for simulating a 3-phase fault the reduced matrix, containing only generator and fault nodes are modified according to equations (5.3.4) and in this way machine to machine admittances during fault is calculated.

Next step of the programme is to calculate machine to machine admittances after the clearance of the fault. The use of reduced matrix, containing only the generator and fault nodes is again made to calculate the required admittances. Changes are made in the reduced matrix according to equation (5.3.6). Then again the network reduction process are carried out till the fault nodes are eliminated. The resulting the elements of the resulting matrix having only the generator nodes gives the required admittances after the fault is cleared.

If the fault location is changed, then the previous faulted bus numbers are assigned to the new faulted buses. This needs a few simple statements to accomodate this change. The position of the elements of the line parameter matrices are changed according to new faulted buses. Computer prints out the real and imaginary parts of the admittances and also their magnitudes. The programme is very simple and the detail programming is given in Appendix-C.

5.5 Results:

Three pairs of driving point and transfer admittances were calculated by the computer for three different fault locations. 3-phase fault was considered at 1) Ullon-Tongi line, 2) Kaptai-Madanhat line and 3) Shahjibazar 11 KV-132 KV buses, (which indicates a faults in bus-barss). For each fault location computer prints out admittances during and after fault cleared in 6x6 matrix (as the number of machine was six) with captions as machine to machine admittance during fault and machine to machine admittance fault cleared respectively. Real and imaginary parts of the admittances as well as their magnitude were also printed.

Machine to machine admittances for a 3-phase fault in Ullon-Tongi line as calculated and printed by the computer is given on page 50.

Machine to machine admittances for a 3-phase fault in Kaptai-Madanhat line as calculated and printed by the computer is given on page 51.

Machine to machine admittances for a 3-phase fault in Shahjibazar buses as calculated and printed by the computer is given on page 52.

MACHINE TO MACHINE ADMITTANCE DURING FAULT

REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG
0.513	-4.485	0.128	1.449	0.014	0.364	0.002	0.098	-0.002	0.018	-0.008	0.036
0.128	1.449	0.299	-5.354	0.051	0.483	0.011	0.130	-0.001	0.024	-0.007	0.049
0.014	0.364	0.051	0.483	0.125	-5.664	0.030	0.184	0.001	0.035	-0.005	0.071
0.002	0.098	0.011	0.130	0.030	0.184	0.086	-3.563	0.006	0.071	-0.001	0.147
-0.002	0.018	-0.001	0.024	0.001	0.035	0.006	0.071	0.057	-1.663	0.002	0.839
-0.008	0.036	-0.007	0.049	-0.005	0.071	-0.001	0.147	0.002	0.839	0.031	-2.593

MAGNITUDE OF MACHINE TO MACHINE ADMITTANCE

4.514774	1.454831	0.364269	0.097606	0.018048	0.037298
1.454831	5.362455	0.486191	0.130275	0.024089	0.049782
0.364269	0.486191	5.665301	0.186657	0.034514	0.071327
0.097606	0.130275	0.186657	3.564211	0.070914	0.146552
0.018048	0.024089	0.034514	0.070914	1.663650	0.838935
0.037298	0.049782	0.071327	0.146552	0.838935	2.593207

MACHINE TO MACHINE ADMITTANCE FAULT CLERED/

REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG
0.472	-4.149	0.102	1.901	0.026	1.012	0.010	0.489	-0.010	0.090	-0.039	0.183
0.102	1.901	0.305	-4.751	0.125	1.345	0.057	0.651	-0.006	0.121	-0.036	0.247
0.026	1.012	0.125	1.345	0.322	-4.441	0.151	0.924	0.005	0.173	-0.025	0.357
0.010	0.489	0.057	0.651	0.151	0.924	0.183	-3.036	0.011	0.170	-0.011	0.351
-0.010	0.090	-0.006	0.121	0.005	0.173	0.011	0.170	0.055	-1.644	-0.005	0.876
-0.039	0.183	-0.036	0.247	-0.025	0.357	-0.011	0.351	-0.005	0.876	0.009	-2.518

MAGNITUDE OF MACHINE TO MACHINE ADMITTANCE

4.175991	1.903422	1.012120	0.489521	0.090516	0.187061
1.903422	4.760377	1.350883	0.653366	0.120812	0.249671
1.012120	1.350883	4.452393	0.936138	0.173098	0.357727
0.489521	0.653366	0.936138	3.041692	0.169947	0.351215
0.090516	0.120812	0.173098	0.169947	1.645355	0.876165
0.187061	0.249671	0.357727	0.351215	0.876165	2.517920

MACHINE TO MACHINE ADMITTANCE DURING FAULT

REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG
0.519	-4.529	0.131	1.390	0.012	0.279	0.003	0.083	0.002	0.034	0.003	0.066
0.131	1.390	0.298	-5.433	0.041	0.371	0.011	0.110	0.005	0.046	0.010	0.087
0.012	0.279	0.041	0.371	0.099	-5.823	0.028	0.156	0.012	0.065	0.024	0.124
0.003	0.083	0.011	0.110	0.028	0.156	0.074	-3.622	0.025	0.104	0.018	0.086
0.002	0.034	0.005	0.046	0.012	0.065	0.025	0.104	0.027	-2.029	0.011	0.051
0.003	0.066	0.010	0.087	0.024	0.124	0.018	0.086	0.011	0.051	0.034	-6.823

MAGNITUDE OF MACHINE TO MACHINE ADMITTANCE

4.558995	1.396418	0.279717	0.082721	0.034335	0.065791
1.396418	5.441047	0.373339	0.110408	0.045828	0.087812
0.279717	0.373339	5.824329	0.158192	0.065661	0.125816
0.082721	0.110408	0.158192	3.622885	0.106418	0.087934
0.034335	0.045828	0.065661	0.106418	2.028907	0.051897
0.065791	0.087812	0.125816	0.087934	0.051897	6.823161

MACHINE TO MACHINE ADMITTANCE FAULT CLERED7

REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG
0.456	-4.272	0.070	1.739	-0.037	0.784	-0.026	0.399	-0.014	0.211	-0.052	0.743
0.070	1.739	0.248	-4.964	0.020	1.047	0.001	0.533	0.001	0.282	-0.003	0.994
-0.037	0.784	0.020	1.047	0.141	-4.856	0.059	0.761	0.031	0.403	0.103	1.421
-0.026	0.399	0.001	0.533	0.059	0.761	0.099	-3.231	0.041	0.326	0.072	0.891
-0.014	0.211	0.001	0.282	0.031	0.403	0.041	0.326	0.037	-1.902	0.043	0.499
-0.052	0.743	-0.003	0.994	0.103	1.421	0.072	0.891	0.043	0.499	0.170	-5.081

MAGNITUDE OF MACHINE TO MACHINE ADMITTANCE

4.296290	1.740009	0.784532	0.399341	0.211420	0.744990
1.740009	4.969778	1.047118	0.533003	0.282183	0.994341
0.784532	1.047118	4.857605	0.763682	0.404310	1.424683
0.399341	0.533003	0.763682	3.232815	0.328088	0.894174
0.211420	0.282183	0.404310	0.328088	1.901940	0.500669
0.744990	0.994341	1.424683	0.894174	0.500669	5.083591

MACHINE TO MACHINE ADMITTANCE DURING FAULT

REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG
0.0	-8.123	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.314	-5.666	0.141	0.857	0.071	0.431	0.002	0.081	-0.012	0.167
0.0	0.0	0.141	0.857	0.334	-4.710	0.168	0.825	0.010	0.155	-0.010	0.322
0.0	0.0	0.071	0.431	0.168	0.825	0.177	-3.138	0.013	0.151	-0.005	0.313
0.0	0.0	0.002	0.081	0.010	0.155	0.013	0.151	0.056	-1.648	-0.003	0.869
0.0	0.0	-0.012	0.167	-0.010	0.322	-0.005	0.313	-0.003	0.869	0.015	-2.532

MAGNITUDE OF MACHINE TO MACHINE ADMITTANCE

8.123477	0.0	0.0	0.0	0.0	0.0
0.0	5.668280	0.868479	0.437096	0.080822	0.167028
0.0	0.868479	4.721536	0.842131	0.155716	0.321804
0.0	0.437096	0.842131	3.143295	0.151263	0.312602
0.0	0.080822	0.155716	0.151263	1.648796	0.869277
0.0	0.167028	0.321804	0.312602	0.869277	2.531642

MACHINE TO MACHINE ADMITTANCE FAULT CLERED/

REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG	REAL	IMG
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	0.491	-3.920	0.208	1.778	0.105	0.895	-0.003	0.167	-0.040	0.342
0.0	0.0	0.208	1.778	0.355	-4.222	0.179	1.071	0.006	0.201	-0.028	0.414
0.0	0.0	0.105	0.895	0.179	1.071	0.182	-3.015	0.011	0.174	-0.013	0.359
0.0	0.0	-0.003	0.167	0.006	0.201	0.011	0.174	0.055	-1.644	-0.006	0.878
0.0	0.0	-0.040	0.342	-0.028	0.414	-0.013	0.359	-0.006	0.878	0.008	-2.515

MAGNITUDE OF MACHINE TO MACHINE ADMITTANCE

0.0	0.0	0.0	0.0	0.0	0.0
0.0	3.951039	1.790534	0.901158	0.166630	0.344360
0.0	1.790534	4.236836	1.085492	0.200715	0.414801
0.0	0.901158	1.085492	3.020258	0.173828	0.359235
0.0	0.166630	0.200715	0.173828	1.644644	0.877577
0.0	0.344360	0.414801	0.359235	0.877577	2.515133

CHAPTER - 6

TRANSIENT STABILITY STUDY

6.1 Swing equation

6.2 Power angle equation

6.3 Solution of swing equation

6.4 Computer programme

6.5 Results

6.1 Swing Equation:[31]

In order to determine the angular displacement between the machines of a power system during transient conditions, it is necessary to solve the differential equation describing the motion of the machine rotors. The net torque acting on the rotor of a machine, from the laws of mechanics related to rotating bodies is

$$T = \frac{WR^2}{g}\alpha \qquad \ldots \qquad (6.1.1)$$

where, T = algebraic sum of all torques, ft-lb.

WR^2 = moment of inertia, lb-ft^2.

g = acceleration due to gravity,

α = mechanical angular acceleration rad./sec.^{2}

The electrical angle $\theta_e = \frac{P}{2}\,\theta_m$ (6.1.2)

The frequency f in cycles per second is

$$f = \frac{P}{2}\;\frac{rpm}{60} \qquad (6.1.3)$$

Then from equation (6.1.2) and (6.1.3) the electrical angle in radian is

$$\theta_e = \frac{60f}{rpm}\,\theta_m \qquad (6.1.4)$$

The electrical angular position δ, in radians, of the rotor with respect to a synchronously rotating reference axis is

$$\delta = \theta_e - w_o t$$

where, w_o = rated synchronous speed, rad/sec.

t = time, sec.

Then, the angular velocity or slip with respect to the reference axis is

$$\frac{d\delta}{dt} = \frac{d\,\Theta_e}{dt} - w_o$$

and the angular acceleration is

$$\frac{d^2\delta}{dt^2} = \frac{d^2\Theta_e}{dt^2}$$

Taking the second derivative of equation (6.1.4) and substituting,

$$\frac{d^2\delta}{dt^2} = \frac{60f}{rpm}\,\frac{d^2\Theta_m}{dt^2}$$

where, $\frac{d^2\Theta_m}{dt^2} = \alpha$

Then substituting into equation (6.1.1), the net torque is

$$T = \frac{WR^2\ rpm}{g\ \ 60f}\,\frac{d^2\delta}{dt^2}$$

It is desirable to express the torque in per unit. The base torque is defined as the torque required to develop rated power at rated speed,

$$\text{Base torque} = \frac{\text{base Kva}\left(\frac{550}{0.746}\right)}{2\,\pi\left(\frac{rpm}{60}\right)}$$

where the base torque is in ft-lbs.

Therefore, the torque in per unit is

$$T = \frac{\frac{WR^2}{g}\ \frac{2\pi}{f}\ (\frac{rpm}{60})^2\ \frac{0.746}{550}}{\text{base Kva}}\ \frac{d^2\delta}{dt^2} \qquad (6.1.5)$$

The inertia constant H of a machine is defined as the kinetic energy at rated speed in KW-sec/Kva.

The kinetic energy in ft-lbs is

$$\text{Kinetic energy} = \frac{1}{2}\ \frac{WR^2}{g}\ w_o^{\ 2}$$

where, $w_o = 2\pi\ \frac{rpm}{60}$, and rpm is the rated speed.

Therefore,

$$H = \frac{\frac{1}{2}\ \frac{WR^2}{g}\ (2\pi)^2 (\frac{rpm}{60})^2\ \frac{0.746}{550}}{\text{base Kva}}$$

Substituting in equation (6.1.5)

$$T = \frac{H}{\pi f}\ \frac{d^2\delta}{dt^2} \qquad (6.1.6)$$

The torques acting on the rotor of a generator include the mechanical input torque from the prime mover, torques due to rotational losses (friction, windage and core loss), electrical output torques, and damping torques due to prime mover, generator, and power system. The electrical and mechanical torques acting on the rotor of a motor are of opposite sign and are a result of the electrical input and mechanical load. Neglecting damping and rotational losses, the accelerating torque T_a is

$$T_a = T_m - T_e$$

where, T_m = Mechanical torque

T_e = Electrical torque

Thus equation (6.1.6) becomes

$$\frac{H}{\pi f} \quad \frac{d^2\delta}{dt^2} = T_m - T_e \qquad (6.1.7)$$

Since the torque and power in per unit are equal for small deviations in speed, equation (6.1.7) becomes

$$\frac{d^2\delta}{dt^2} = \frac{\pi f}{H} (P_m - P_e)$$

where, P_m = Mechanical power

P_e = Electrical air gap power

This second order differential equation can be written as two simultaneous first order equations.

$$\frac{d^2\delta}{dt^2} = \frac{d\,w}{dt} = \frac{\pi f}{H} (P_m - P_e) \qquad \text{and}$$

$$\frac{d\delta}{dt} = \frac{d\,\Theta_e}{dt} - w_0 \qquad (6.1.8)$$

Since the roted synchronous speed in radians per second is $2\pi f$, equation (6.1.8) becomes

$$\frac{d\delta}{dt} = (W - 2\pi f)$$

The present study was done by considering the mechanical power input unchanged i.e no governor action during and after clearance of fault. However governor and exciter characteristics are given in the following sections for ready reference for future study with their effects.

6.1A Swing Equation with Speed Governor Characteristics[32]

The effects of the speed governor control during transient periods can be taken into consideration by using the simplified representation of the governor control system shown in the Fig.(6.1a). This representation includes a transfer function describing the steam system with a time constant T_s and a transfer function describing the control system with a time constant T_c. The differential equations relating the input and output variables of these transfer functions, respectively are

$$\frac{dP_m}{dt} = \frac{1}{T_s}\left(P_m^{i} - P_m\right) \qquad (6.1a.1)$$

$$\frac{dP_m^{i}}{dt} = \frac{1}{T_c}\left(P_m^{ii} - P_m^{i}\right)$$

where P_m is the mechanical power and the intermediate variables are designated by P_m^{i}, P_m^{ii}, P_m^{iii} and P_m^{iv}. The variables P_m^{ii} and P_m^{iii} are related by

$$P_m^{ii} = 0 \qquad P_m^{iii} \lneq 0$$

$$P_m^{ii} = P_m^{iii} \qquad 0 \angle P_m^{iii} \angle P_{max}$$

$$P_m^{ii} = P_{max} \qquad P_m^{iii} \geqslant P_{max}$$

where P_{max} is the maximum turbine capability. The intermediate variable P_m^{iii} is

$$P_m^{iii} = P_{m(o)} - P_m^{iv}$$

where $P_{m(o)}$ is the initial mechanical power. The intermediate variable P_m^{iv} is

$$P_m^{iv} = \frac{1}{R} \left(\frac{w_0 - w}{2\pi f} \pm DB_T \right)$$

where R is the speed regulation in per unit and DB_T is the dead band travel, that is, the change in speed required to overcome the dead band of the governor system.

Equations (6.1a.1) are solved simultaneously with equations (6.1.8) if the effects of the governor control system are included.

6.1B Swing Equation with Exciter Control[33]

The exciter control system provides the proper field voltage to maintain a desired system voltage, usually at the high voltage bus of the power plant. An important characteristic of an exciter control system is its ability to respond rapidly to voltage deviations during both normal and emergency system operation . Many different types of exciter control systems are employed on power systems. The basic components of an exciter control system are the regulator, amplifier and exciter. The regulator measures the actual regulated voltage and determines the voltage deviation. The deviation signal produced by the regulator is then amplified to provide the signal required to change the exciter field current. This in turn produces a change in the exciter output voltage which results in a new excitation level for the generator.

A block diagram for a simplified representation of continuously acting excieter control system is shown in the Fig. (6.1b). This is one of the important types of exciter control systems. This representation includes transfer functions to describe the regulator, amplifier, exciter and stabilizing loop. The stabilizing loop modifies the response to eliminate undesired oscillations and over shoot of the regulated voltage. The differential equations relating the input and output variables of the regulator, amplifier, exciter and stabilizing loop, respectively, are

$$\frac{dE^{v}}{dt} = \frac{1}{T_R}(E_s - E_t - E^{v})$$

$$\frac{dE^{iii}}{dt} = \frac{1}{T_A}\left(K_A \left(E^{v} + \frac{E_o^{iii}}{K_A} - E^{iv}\right) - E^{iii}\right)$$

$$\frac{dE_{fd}}{dt} = \frac{1}{T_E}(E^{ii} - K_E E_{fd}) \qquad \ldots \quad (6.1b.1)$$

$$\frac{dE^{iv}}{dt} = \frac{1}{T_F}\left(K_F \frac{dE_{fd}}{dt} - E^{iv}\right)$$

where,

E_s = Scheduled voltage in per unit

E_0^{iii} = Output voltage of the amplifer in per unit prior to the disturbance

T_R = Regulator time constant

K_A = Amplifier gain

T_A = Amplifier time constant

K_E = Exciter gain

T_E = Exciter time constant

K_F = Stabilizing loop gain

T_F = Stabilizing loop time constant

and the intermediate variables are designated by E^{kk} E^{ii}, E^{iii}, E^{iv}, E^{v} and E^{vi}. The intermediate variable $E^{ii}$is

$$E^{ii} = E^{iii} - E^{vi}$$

where E^{vi} is equivalent to the damagnetizing effect due to saturation in the exciter. This determined from

$$E^{vi} = A\, \epsilon^{BE_{fd}}$$

where A and B are constants depending upon the exciter saturation characteristic.

To include the effects of the exciter control system equations (6.1b.1) are solved simultaneously with the equations (6.1.8) describing the machine.

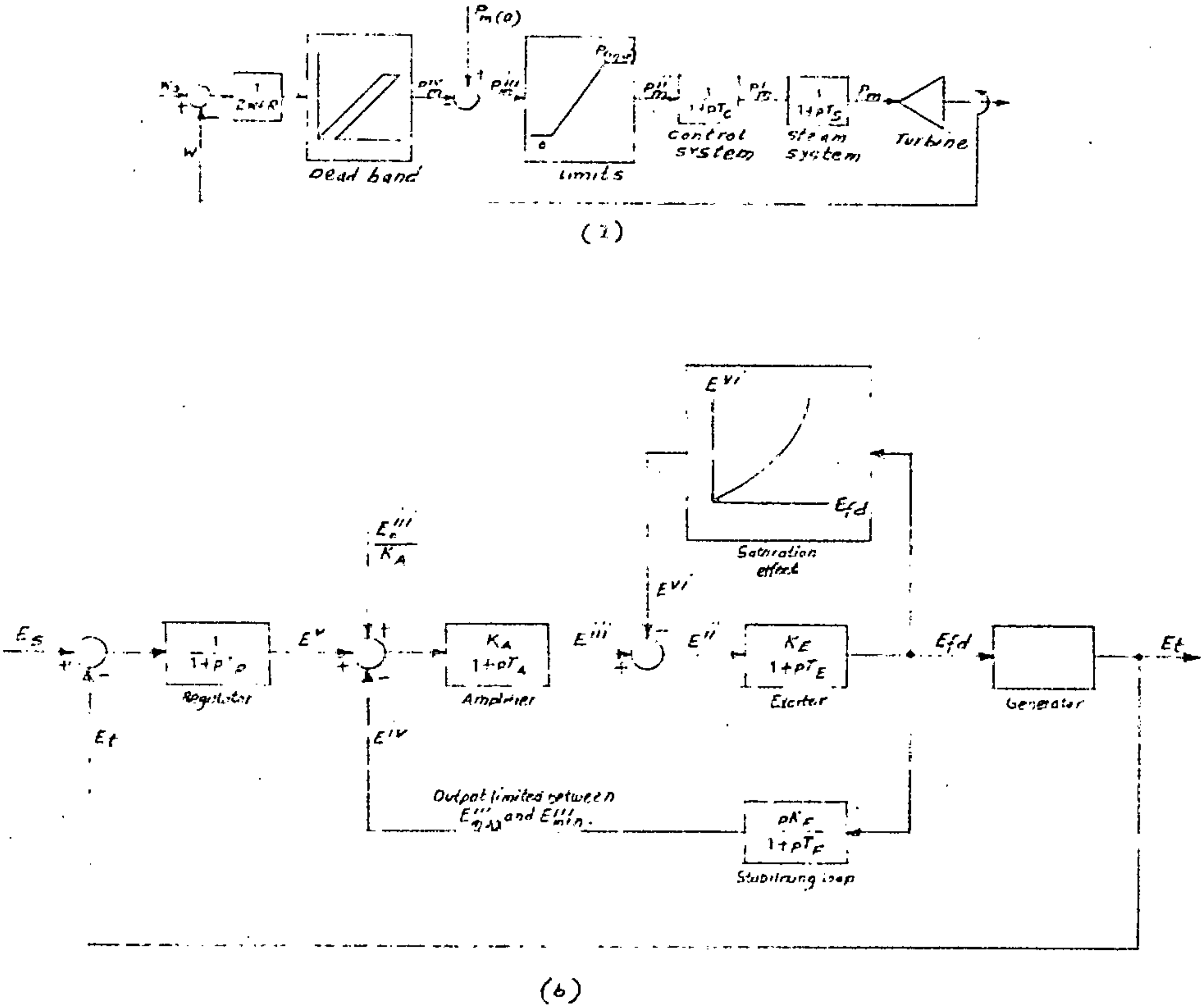


FIG: 6·1

(a) BLOCK DIAGRAM FOR A SIMPLIFIED REPRESENTATION OF A SPEED GOVERNOR CONTROL SYSTEM.

(b) BLOCK DIAGRAM FOR A REPRESENTATION OF AN EXCITER CONTROL SYSTEM.

6.2 Power Angle Equation:

The general equation for real power out of a machine is given by

$$P_i = \sum_{k=1}^{n} E_i E_k Y_{ik} \cos(\Theta_{ik} - \delta_i + \delta_k) \qquad (6.2.1)$$

where,

E = voltage

Y_{ii} = Self admittance

Y_{ik} = Mutual admittance

Θ = Angle associated with admittances

δ = Internal voltage angles

6.3 Solution of Swing Equation:

The author has solved swing equation first by 1) step by step method and then by 2) Runge-Kutta fourth-order approximation method. Two separate computer programmes have also been developed for solving swing equation by the above methods.

Step by step method:

In this method the acceleration as calculated at the beginning of a particular time interval, is assumed to remain constant from the middle of the preceeding interval to the middle of the interval being considered. Let us, consider calculations for the nth interval, which begins at $t = (n-1)\,\Delta t$, where Δt is the time interval. The angular position at this instant is δ_{n-1}. The acceleration α_{n-1}, as claculated at this instant, is assumed to be constant from

$$t = (n - 3/2)\,\Delta t \quad \text{to } t = (n-\tfrac{1}{2})\,\Delta t$$

over this period a change in speed occurs, which is calculated as

$$\Delta w_{n-\frac{1}{2}} = \Delta t\ \alpha_{n-1} = \frac{\Delta t}{M}\ P_{a(n-1)} \qquad (6.3.1)$$

where, M = inertia constant in megajoule seconds/Electrical degree. The speed at the end of this time is

$$w_{n-\frac{1}{2}} = w_{n-3/2} + \Delta w_{n-\frac{1}{2}} \qquad (6.3.2)$$

As a logical outcome of the assumption regarding acceleration, the change in speed would occur linearly with time. To simplify the ensuing calculations the change in speed is assumed to occur as a step at the middle of the period, i.e., at $t = (n-1)\,\Delta t$, which is the same instant for which the acceleration was calculated. Between steps the speed is assumed to be constant. From $t = (n-1)\,\Delta t$ to $t = n\,\Delta t$, or throughout the nth interval, the speed will be constant at the value $w_{n-\frac{1}{2}}$. The change in angular positionx during the nth interval is, therefore,

$$\Delta\delta_n = \Delta t .\ w_{n-\frac{1}{2}} \qquad (6.3.3)$$

and the position at the end of the interval is

$$\delta_n = \delta_{n-1} + \Delta\delta_n \qquad (6.3.4)$$

substituting equations (6.3.1) into (6.3.2), and the result in equation (6.3.3), gives

$$\Delta\delta_n = \Delta t \cdot w_{n-3/2} + \frac{(\Delta t)^2}{M} P_{a(n-1)} \qquad (6.3.5)$$

By analogy with equation (6.3.3)

$$\Delta\delta_{n-1} = \Delta t \cdot w_{n-3/2} \qquad (6.3.6)$$

Substituting equation (6.3.6) into (6.3.5)

$$\Delta\delta_n = \Delta\delta_{n-1} + \frac{(\Delta t)^2}{M} P_{a(n-1)} \qquad (6.3.7)$$

Before proceeding with equation (6.3.7) for calculation of internal angles some consideration is given for the effects of discontinuities in the acceleration power P_a which occur, for example, when a fault is applied or removed or when any switching operation takes place. If such a discontinuity occurs at the beginning of an interval, then the average of the values of P_a before and after the discontinuity must be used. Thus in computing the increment of angle occuring during the first interval after fault is applied at t = o, equation (6.3.7) becomes

$$\Delta\delta_1 = \frac{(\Delta t)^2}{M} \frac{P_{ao+}}{2} \qquad (6.3.8)$$

where P_{ao+} is the accelerating power immediately after occurence of the fault. Immediately before the fault the system is in the steady state; hence the accelerating power, P_{ao-}, and the previous increment of angle, $\Delta\delta_o$, are both equal to zero. If the fault is cleared at the beginning of the mth interval, in calculations for this interval one should use for $P_{a(n-1)}$ the value

$\frac{1}{2}(P_{a(m-1)-} + P_{a(m-1)+})$, where $P_{a(m-1)-}$ is the accelerating power immediately before clearing and $P_{a(m-1)+}$ is that immediately after clearing the fault. If the discontinuity occurs at the middle of an interval, no special procedure is needed. The increment in angle during such an interval is calculated, as usual, from the value of P_a at the beginning of the interval.

If the discontinuity occurs at some time other than the beginning or the middle of an interval, a weighted average of the values of P_a before and after the discontinuity should be used, but the need for such a refinement seldom appears because the time intervals used in calculation are so short that it is sufficiently accurate to assume the discontinuity to occur at the beginning or at the middle of an interval.

Runge-Kutta Fourth order Approximation Method:[34]

In the application of the Runge-Kutta fourth order approximation, the changes in the internal voltage angles and machine speeds for the simplified machine representation, are obtained from

$$\Delta \delta_{i(t+\Delta t)} = \frac{1}{6} (k_{1i} + 2k_{2i} + 2k_{3i} + k_{4i})$$

$$\Delta w_{i(t+\Delta t)} = \frac{1}{6} (L_{1i} + 2L_{2i} + 2L_{3i} + L_{4i}), \; i = 1,2,\ldots m$$

The k's and L's are the changes in δ_i and w_i respectively, obtained using derivatives evaluated at predetermined points. Then

$$\delta_{i(t+\Delta t)} = \delta_{i(t)} + \frac{1}{6} (k_{1i} + 2k_{2i} + 2k_{3i} + k_{4i})$$

$$w_{i(t+\Delta t)} = w_{i(t)} + \frac{1}{6} (L_{1i} + 2L_{2i} + 2L_{3i} + L_{4i}) \qquad (6.3.9)$$

The initial estimates of changes are obtained from

$$k_{1i} = (w_{i(t)} - 2\pi f) \Delta t$$

$$L_{1i} = \frac{\pi f}{H_i} (P_{mi} - P_{ei(t)}) \Delta t \qquad i = 1,2,\ldots m$$

where $w_{i(t)}$ and $P_{ei(t)}$ are the machine speeds and air-gap powers at time t. The second set of estimates of changes in δ_i and w_i are obtained from

$$k_{2i} = ((w_{i(t)} + \frac{L_{1i}}{2}) - 2\pi f) \Delta t$$

$$L_{2i} = \frac{\pi f}{H_i} (P_{mi} - P_{ei}^{(1)}) \Delta t \qquad i = 1,2,\ldots m$$

where $P_{ei}^{(1)}$ are the machine powers when the internal voltage angles are $\delta_{i(t)} + (k_{1i}/2)$.

The third set of estimates are obtained from

$$k_{3i} = (\ (w_{i(t)} + \frac{L_{2i}}{2}) - 2\pi f) \Delta t$$

$$L_{3i} = \frac{\pi f}{H_i} (P_{mi} - P_{ei(t)}^{(2)}) \Delta t \qquad i = 1,2,\ldots m$$

where $P_{ei}^{(2)}$ are obtained from a second solution of the net work equations with the internal voltage angles equal to

$$\delta_{i(t)} + (k_{2i}/2).$$

The fourth estimates are obtained from

$$K_{4i} = (\ (w_{i(t)} + L_{3i}) - 2\pi f) \Delta t$$

$$L_{4i} = \frac{\pi f}{H_i} (P_{mi} - P_{ei}^{(3)}) \Delta t \qquad i = 1,2,\ldots m$$

where $P_{ei}^{(3)}$ are obtained from a third solution of the network equations with internal voltage angles equal to $\delta_{i(t)} + K_{3i}$.

The final estimates of the internal voltage angles and machine speeds at time $t + \Delta t$ are obtained by substituting the k's and L's into equations (6.3.9). Then the time is advanced by Δt and the process is repeated until t equals the maximum time T_{max}.

6.4 Computer Programme:

The author developed two seprate computer programmes, one employing step by step method and the other by Runge-Kutta fourth-order approximation method for solving the swing equations.

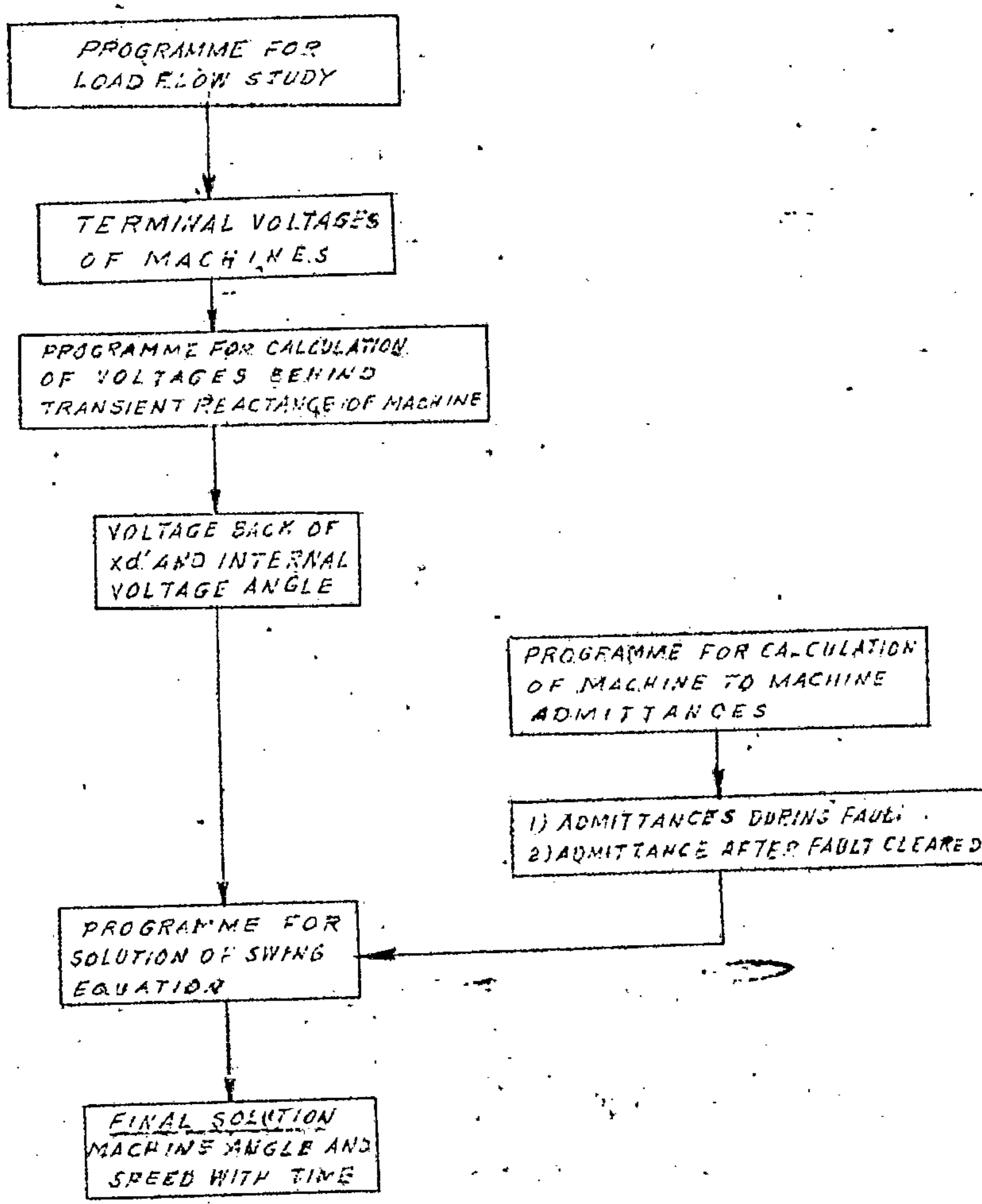
For both the programmes data inputs are same. Data required are number of machines, machine to machine self and mutual admittances during and after faults along with their angles, initial internal voltage angles, inertia constants and real power output of the machines. Throughout the solution the mechanical power of the machines were considered constant.

In both the programmes the accelerating power of machines are calculated through the same sub-routine in the main programme. The sub-routine, when called for solves the network equation and x calculates the accelerating power.

The detailed computer programmes are given in the Appendix-D. Sequence chart of computer operations and output for complete solutions of transient stability is given on Fig. 6.

6.5 Results:

Machine constants are given in Table 5.1 of Chapter-5. Initial machine voltage and angles are obtained from the results given in page 32 of Chapter-4. Machine to machine admittances during and after fault are obtained from Chapter-5. Real power output of machines are obtained from load flow solution.



SEQUENCE CHART OF COMPUTER OPERATIONS AND OUT-PUT FOR COMPLETE SOLUTION

[FIG-6]

Stability of test system consisting of six machines were studied by simulating 3-phase fault at three different places. Stability study was also done by opening Shahjibazar generator from the grid.

Swing Curve for 3-phase Fault in Ullon-Tongi Line:

A three phase fault was considered at Ullon-Tongi line and was cleared in 0.15 and 0.2 seconds. Swing equation was solved with fault clearing time 0.15 second by step by step method and with clearing time 0.2 sec. by Runge-Kutta method. Individual machine angles with time and name of machines were printed by computer. Angular speed of machine were also calculated by Runge-Kutta method.

Computer print outs of step by step method is given on page 72 and that of Runge-Kutta method on page 73. Computer print outs was taken for 1 sec. Time interval for step by step method was taken 0.05 sec. and that for Runge-Kutta method was taken as 0.1 sec. Fig. 6.2 to 6.5 indicates the relative angular displacement of machines obtained by step by step methods. These curve shows that machines remain in synchronism even if 3-phase fault in Ullon-Tongi line is cleared in 0.15 sec.

Fig. 6.6 to 6.9 indicates the relative angular displacement of machines for a 3-phase fault in Ullon-Tongi line and cleared in 0.2 sec. The swing equation was solved by Runge-Kutta method. These curves also indicates that the machines are stable. It is apparent from Fig. 6.2 to 6.9 that machines at Kaptai and Sikalbaha oscillates together and the rest of the machines also oscillates together. Fig. 6.10 indicates the angular speed of individual machines with time.

Comments on Results Obtained by the two Methods:

Step by step method is a simple method for solving swing equation. Runge -Kutta 4th order approximation method is a rigorous method for the solution of swing equation, but it gives better accuracy over step by step method. Time required by computer for solution of swing equation by step by step method is less than that required for Runge-Kutta method. So Step by Step method gives economic advantage over Runge-Kutta method, but at the cost of accuracy of calculation. The aim of this study was not to differentiate between two methods and as a result distinct advantages of one method over the other was not studied in detail. However, computer times required for solving swing equation for a 3-phase fault in Ullon-Tongi line by Runge-Kutta method over an interval of 1 sec and by step by step method over an interval of 1.5 sec. were noted as 2.33 and 2.21 minutes respectively.

Swing Curve for 3-phase Fault in Kaptai-Madanhat Line:

A three phase fault at Kaptai-Madanhat line was considered and cleared in 0.3 sec. The swing equation was solved by Runge-Kutta method. Computer print outs upto 10 seconds showing individual machine angles with time are given on pages (74 to 77). Fig. 6.11 to 6.14

in indicates the relative angular displacement of machines for 3-phase fault in Kaptai Madanhat line and cleared in 0.3 sec. These figure indicates that machines are stable. It is also cleared from the figures that machines at Kaptai and Sikalbaha oscillates very closely.

Swing Curve while Shahjibazar Machine Trips from Grid (An Open Circuit Case)

A three phase fault was considered in between Shahjibazar 11 KV and 132 KV buses and cleared in 0.3 seconds. The swing equation was solved by Runge-Kutta method and computer point outs upto 10 seconds showing individual machine angles with time are given on pages 78 to 8[illegible].

Figure 6.15 to 6.18 indicates the relative angular displacement of machines. Shahjibazar machine will be unstable and will ultimately be tripped by the machines protective devices. Fig. 6.16 to 6.18 indicates that the remaining machines will be stable even if the Shahjibazar machine with 13 MW load is tripped.

COMPUTATION OF INTERNAL MACHINE ANGLE

SHAHJIBAZAR	AHSHU GANJ	GHORA SAL	SHIDDIRGANJ	SIKAL BAHA	KAPTAIHYDRO	TIME
0.65511	7.10500	8.18821	3.48882	5.65693	13.55498	0.05
-0.01621	7.90482	10.96981	6.48695	7.89749	18.72385	0.10
-0.62415	9.25242	14.48695	10.88272	12.22039	26.82671	0.15
-0.40242	11.45807	17.52412	15.71338	19.17317	36.81592	0.20
1.00582	14.67775	20.18651	20.64041	28.90041	47.69524	0.25
3.86944	18.91626	22.86049	25.48296	41.04684	58.60658	0.30
8.34574	24.06528	26.09583	30.27226	54.74083	68.98000	0.35
14.47438	29.98901	30.45680	35.25073	68.74832	78.57642	0.40
22.18835	36.61986	36.38805	40.81697	81.75032	87.42548	0.45
31.33972	44.02576	44.13029	47.43556	92.65166	95.69766	0.50
41.73656	52.42209	53.69945	55.53389	100.82928	103.57274	0.55
53.18466	62.11842	64.91946	65.40135	106.27625	111.15852	0.60
65.52550	73.41164	77.48839	77.10371	109.63712	118.48621	0.65
78.66109	86.45854	91.05603	90.43556	112.12032	125.58167	0.70
92.55887	101.17538	105.29666	104.94305	115.26175	132.58533	0.75
107.23430	117.20868	119.96310	120.03494	120.56978	139.86203	0.80
122.71532	133.99945	134.91093	135.15776	129.16879	148.03458	0.85
138.99898	150.92731	150.09038	149.97183	141.57449	157.91116	0.90
156.01495	167.48869	165.51837	164.46240	157.66197	170.32829	0.95
173.61026	183.45021	181.25157	178.94936	176.81013	185.95557	1.00
191.56390	198.92712	197.37617	193.99374	198.16026	205.11185	1.05
209.63222	214.36008	214.01611	210.22871	220.89822	227.64424	1.10
227.61583	230.39178	231.34697	228.16664	244.46341	252.91888	1.15
245.42999	247.67862	249.59680	248.04666	268.61743	279.94604	1.20
263.15649	266.70093	269.02075	269.77686	293.36621	307.60913	1.25
281.06030	287.64014	289.85327	292.99048	318.78882	334.91162	1.30
299.56421	310.36108	312.24902	317.18604	344.86328	361.15894	1.35
319.18457	334.49634	336.23291	341.89160	371.35889	386.03540	1.40
340.44189	359.59204	361.67017	366.79199	397.82520	409.59302	1.45
363.76880	385.25903	388.26904	391.78223	423.67920	432.17676	1.50

COMPUTATION OF INTERNAL MACHINE ANGLE AND SPEED

	SHAHJIBAZAR	AHSHU GANJ	GHORA SAL	SHIDDIRGANJ	SIKAL BAHA	KAPTAIHYDRO	TIME
ANGLE	-0.00128	7.90187	10.95661	6.48253	7.95282	18.68317	0.10
SPEED	313.86743	314.52783	315.43530	315.54834	315.27930	316.50781	
ANGLE	-1.99227	11.02474	21.49464	18.27600	19.15762	37.66426	0.20
SPEED	313.80859	314.87793	316.51514	316.86816	317.07178	318.33032	
ANGLE	-0.20714	18.61591	32.15529	32.38382	41.93953	62.11545	0.30
SPEED	315.23438	316.10425	315.54272	316.30225	319.07373	318.35889	
ANGLE	11.03660	32.77245	38.60385	42.80807	72.81993	84.49800	0.40
SPEED	317.01221	317.04028	315.21777	315.75073	319.68604	317.74219	
ANGLE	31.99677	50.15303	46.91985	52.36365	101.19456	103.39212	0.50
SPEED	318.53101	317.27832	316.19312	316.08130	318.27441	317.20386	
ANGLE	59.70744	68.37502	63.72040	66.96431	118.04501	119.85672	0.60
SPEED	319.32739	317.49780	318.03711	317.46045	315.95117	316.86597	
ANGLE	89.73573	90.09592	91.12520	91.10495	123.56873	134.41635	0.70
SPEED	319.38916	318.55078	319.73804	319.25269	314.61060	316.53979	
ANGLE	119.12523	120.02956	125.76891	124.05911	127.96895	147.66553	0.80
SPEED	319.20825	320.19727	320.50513	320.38696	315.62939	316.53223	
ANGLE	148.30513	158.04582	161.92334	160.01865	144.38412	163.84827	0.90
SPEED	319.38159	321.16870	320.33667	320.33105	318.56567	317.67480	
ANGLE	180.04068	197.42314	195.96788	193.64749	178.68932	190.70378	1.00
SPEED	320.06689	320.69922	319.88110	319.75122	321.59106	320.17383	

COMPUTATION OF INTERNAL MACHINE ANGLE AND SPEED

	SHAHJIBAZAR	AHSHU GANJ	GHORA SAL	SHIDDIRGANJ	SIKAL BAHA	KAPTAIHYDRO	TIME
ANGLE	-0.12368	7.82493	11.03261	6.02162	5.45825	18.89111	0.10
SPEED	313.82397	314.50024	315.46533	315.38574	314.34741	316.61450	
ANGLE	-2.50447	10.69975	21.91336	16.38620	7.49610	39.44191	0.20
SPEED	313.71436	314.61812	316.61328	316.53003	314.72607	318.81812	
ANGLE	0.59112	22.07381	37.49902	34.41190	19.28641	47.43389	0.30
SPEED	315.79980	317.33887	316.91992	317.68457	317.61450	312.79199	
ANGLE	16.89975	43.68842	50.79156	51.44792	43.45261	35.68071	0.40
SPEED	318.16113	318.08887	315.88550	316.24243	318.59668	312.77856	
ANGLE	44.87317	62.60072	57.42268	57.23065	64.05165	44.53572	0.50
SPEED	319.71265	316.77075	315.06348	314.51611	316.70947	318.55273	
ANGLE	77.54150	75.06982	66.06694	62.47366	72.81410	79.35777	0.60
SPEED	319.76221	316.29785	316.69482	316.25098	315.06738	320.76953	
ANGLE	106.60437	92.14502	89.79424	86.05687	80.66708	108.70996	0.70
SPEED	318.59717	318.22363	319.81812	320.15869	316.48633	317.65771	
ANGLE	128.27446	122.77386	127.74872	126.61760	104.15215	123.01012	0.80
SPEED	317.40601	320.56079	321.29004	321.67285	320.10059	316.64453	
ANGLE	146.27077	161.65950	166.45833	165.41912	147.38136	148.57314	0.90
SPEED	317.46558	321.00977	320.37769	320.05054	322.95850	320.89941	
ANGLE	169.44832	198.40355	199.08073	195.40984	199.62088	198.68176	1.00
SPEED	319.15381	320.14478	319.60840	319.22021	323.17139	323.97095	
ANGLE	205.09032	231.63141	232.76344	229.25272	246.19961	249.41963	1.10
SPEED	321.61768	319.59072	320.66016	321.10669	321.21753	321.48633	
ANGLE	254.07104	267.94092	274.46167	274.80518	279.95508	280.53101	1.20
SPEED	323.63550	321.12891	322.01733	322.68066	319.04248	318.33374	
ANGLE	311.03296	312.33374	319.85498	321.29688	305.96094	307.46631	1.30
SPEED	324.32666	322.62134	321.95239	321.59473	318.81372	320.15747	
ANGLE	367.89990	363.63281	362.81836	359.53369	339.15210	354.95483	1.40
SPEED	323.70215	323.48535	321.55469	320.50610	321.47852	324.40942	
ANGLE	419.94346	417.80054	407.87085	400.56641	392.56885	418.19800	1.50
SPEED	322.67065	323.68042	322.79761	322.64111	325.41431	325.29370	
ANGLE	466.57227	472.39355	464.49585	460.41187	464.82593	476.51416	1.60
SPEED	322.21509	323.71948	325.24512	326.36035	327.61816	323.49097	
ANGLE	514.07983	528.17310	532.83618	535.22998	540.05566	529.23584	1.70
SPEED	322.87329	324.17188	326.58569	327.42920	326.52905	323.81909	
ANGLE	568.47168	588.50830	602.86719	605.76147	603.55518	592.71460	1.80
SPEED	324.56079	325.29395	325.99121	325.34033	324.05542	326.57202	
ANGLE	634.25220	656.22314	667.45288	664.08960	656.86987	667.70386	1.90
SPEED	326.73096	326.59473	324.98682	323.75635	323.31763	327.29395	
ANGLE	711.88599	729.43726	729.11133	721.54590	713.87524	736.95410	2.00
SPEED	328.54248	327.08789	325.04224	324.95337	325.15088	325.13110	
ANGLE	796.63647	802.33838	794.31152	790.21021	784.17212	795.95264	2.10
SPEED	329.10767	326.61914	326.11377	327.20215	327.56616	324.42993	
ANGLE	880.24854	872.77075	866.75708	868.42285	864.73535	862.46143	2.20
SPEED	328.22388	326.49683	327.52100	328.20776	328.64087	327.43481	
ANGLE	956.76489	946.82593	947.58081	949.41626	947.80762	948.85913	2.30
SPEED	326.86206	327.90186	329.02734	328.45850	328.65918	330.57813	
ANGLE	1027.69897	1031.92578	1036.79468	1033.73022	1031.54224	1043.85059	2.40
SPEED	326.47681	330.03101	330.32715	329.41895	329.01440	330.43994	
ANGLE	1101.38574	1126.25024	1131.00781	1125.02051	1119.51221	1132.16479	2.50
SPEED	327.81763	330.89258	330.66602	330.62695	330.03198	328.89893	
ANGLE	1186.50952	1220.17627	1223.77905	1220.15796	1213.07495	1216.63574	2.60
SPEED	330.28564	330.06934	329.94604	330.66895	330.81445	329.26221	

ANGLE	1285.96484	1308.38354	1311.95020	1312.18848	1308.56030	1308.24292	2.70
SPEED	332.61133	329.25024	329.30493	329.79419	330.71191	330.91577	
ANGLE	1395.37964	1396.70215	1399.90820	1400.73730	1401.77222	1406.05957	2.80
SPEED	333.63159	330.20679	329.94482	329.68408	330.17285	331.25903	
ANGLE	1505.84741	1495.15845	1495.10571	1493.19995	1493.22046	1502.03760	2.90
SPEED	333.05078	332.47168	331.65161	331.07178	330.24805	330.70972	
ANGLE	1610.43457	1604.92505	1600.07593	1595.66211	1588.73438	1598.85498	3.00
SPEED	331.78687	333.86914	333.19702	332.96558	331.62378	331.78174	
ANGLE	1709.05908	1717.39087	1711.73877	1707.57324	1695.48486	1707.38037	3.10
SPEED	331.14600	333.53296	334.01392	334.30249	334.02905	334.37793	
ANGLE	1807.82666	1826.13525	1826.79370	1824.96851	1816.03735	1828.07007	3.20
SPEED	331.86450	332.89014	334.44604	334.89746	336.16699	335.63281	
ANGLE	1914.15112	1934.67188	1944.00610	1944.04517	1944.06348	1948.59106	3.30
SPEED	333.67505	333.53931	334.73975	334.88892	336.46240	334.58057	
ANGLE	2032.02710	2050.35205	2062.03198	2061.63135	2067.43677	2061.96094	3.40
SPEED	335.76367	335.16724	334.70972	334.43140	334.71875	333.58276	
ANGLE	2160.75610	2174.51001	2179.10181	2176.59424	2179.08594	2175.08667	3.50
SPEED	337.35229	336.30835	334.51953	334.13843	332.79492	334.47046	
ANGLE	2295.70142	2301.82593	2296.56836	2292.69800	2285.47021	2296.54492	3.60
SPEED	337.87866	336.33643	334.97681	334.92212	333.14893	336.14185	
ANGLE	2430.38477	2428.05615	2419.73169	2416.67773	2402.22876	2425.12378	3.70
SPEED	337.31885	336.12817	336.44409	336.73608	336.18994	336.90552	
ANGLE	2560.18481	2555.19067	2552.48438	2551.14502	2538.99927	2556.08813	3.80
SPEED	336.32397	336.72046	338.13525	338.37207	339.66431	337.22021	
ANGLE	2685.46045	2688.22363	2692.94824	2691.98486	2690.16821	2690.97363	3.90
SPEED	335.90112	338.07397	339.05811	338.95825	340.95117	338.31885	
ANGLE	2811.95410	2829.03076	2836.12158	2834.05518	2840.57300	2833.70923	4.00
SPEED	336.79932	335.28955	339.17285	338.95557	339.61353	339.68188	
ANGLE	2947.26074	2974.60718	2979.29028	2976.59155	2980.67139	2981.03271	4.10
SPEED	338.86865	339.71509	339.14355	339.16089	337.76196	339.81128	
ANGLE	3095.65259	3120.61206	3122.83203	3120.86987	3114.34790	3125.46045	4.20
SPEED	341.18311	339.53467	339.28906	339.47192	337.55225	338.93530	
ANGLE	3255.22241	3265.66821	3267.40601	3266.05493	3252.63574	3266.41333	4.30
SPEED	342.60669	339.52515	339.50439	339.49634	339.21362	338.85229	
ANGLE	3418.48389	3413.05518	3413.72925	3411.54614	3402.39307	3411.68921	4.40
SPEED	342.46265	340.38208	339.98535	339.75342	341.29907	340.32544	
ANGLE	3577.36279	3567.46533	3564.76563	3561.54224	3561.80835	3566.99390	4.50
SPEED	341.25913	341.84082	341.19189	341.12256	342.49731	342.09546	
ANGLE	3729.40332	3729.59180	3724.75513	3722.21167	3725.23340	3730.03564	4.60
SPEED	340.29028	342.93433	342.98389	343.25635	342.80225	343.00439	
ANGLE	3879.45166	3895.39429	3894.29321	3893.43677	3889.85840	3896.29688	4.70
SPEED	340.65234	343.14966	344.33008	344.55786	343.03394	343.34717	
ANGLE	4035.78564	4061.10107	4067.87891	4067.09448	4056.99512	4064.67432	4.80
SPEED	342.39526	343.05151	344.37183	344.16724	343.66602	343.74683	
ANGLE	4204.11328	4227.50000	4238.62109	4235.88281	4228.11719	4235.12891	4.90
SPEED	344.67456	343.46094	343.51465	343.13647	344.31445	343.98486	
ANGLE	4384.55469	4398.08203	4404.89844	4401.00391	4401.34375	4405.56641	5.00
SPEED	346.47510	344.43799	343.01392	343.04419	344.35669	343.80762	
ANGLE	4571.98438	4574.46484	4571.86719	4569.58984	4573.14844	4575.45313	5.10
SPEED	347.04883	345.38574	343.79834	344.24878	343.95264	343.98193	
ANGLE	4758.95703	4754.98828	4746.69922	4746.62500	4743.91797	4749.60938	5.20
SPEED	346.39746	345.88916	345.61865	345.83154	344.19238	345.29272	
ANGLE	4940.58203	4937.67188	4932.33984	4931.67578	4920.30469	4933.36719	5.30
SPEED	345.35522	346.22754	347.39917	347.01294	345.92749	347.11157	
ANGLE	5117.76172	5123.08984	5125.78516	5122.26563	5109.84375	5125.67969	5.40
SPEED	344.99414	346.87646	348.27417	347.79565	348.52612	348.14111	
ANGLE	5296.50000	5313.16797	5321.31641	5316.63672	5312.25391	5320.55469	5.50
SPEED	345.92139	347.78540	348.19775	348.31689	350.11646	348.11572	
ANGLE	5483.79688	5508.03516	5515.27344	5512.99219	5517.34375	5514.48828	5.60
SPEED	347.87427	348.48120	347.85474	348.46558	349.45874	347.96387	
ANGLE	5683.25781	5705.58984	5708.33594	5709.05469	5713.96094	5708.93750	5.70
SPEED	350.01270	348.75244	347.95605	348.27295	347.49219	348.28174	
ANGLE	5893.19141	5904.27734	5903.82813	5904.18750	5901.16016	5905.96875	5.80
SPEED	351.39673	348.97144	348.67236	348.25537	346.52344	348.80640	
ANGLE	6107.31641	6105.42578	6104.39844	6101.29688	6089.83984	6106.01172	5.90
SPEED	351.45728	349.64380	349.66089	349.01099	348.02734	349.37988	

ANGLE	6318.56250	6311.70703	6310.49219	6305.08594	6292.57813	6310.30078	6.00
SPEED	350.52417	350.68604	350.58618	350.50806	351.11182	350.34424	
ANGLE	6524.05859	6523.66406	6521.73828	6518.02344	6512.16406	6521.56641	6.10
SPEED	349.63501	351.55054	351.48999	352.07959	353.58105	351.73462	
ANGLE	6727.15625	6739.28906	6738.48828	6738.39844	6740.07813	6740.42578	6.20
SPEED	349.79443	351.98926	352.48828	353.02783	353.95654	352.85083	
ANGLE	6935.01953	6956.90625	6960.61719	6961.71484	6964.82422	6963.14063	6.30
SPEED	351.25269	352.31592	353.27612	353.12549	352.70679	353.07007	
ANGLE	7153.60938	7177.00781	7185.36719	7183.91016	7181.95703	7185.12500	6.40
SPEED	353.39648	352.66841	353.36108	352.73022	351.56909	352.72949	
ANGLE	7384.19531	7400.79688	7408.57031	7404.01563	7396.33594	7405.66797	6.50
SPEED	355.29102	353.56030	352.84766	352.50757	351.82495	352.67969	
ANGLE	7622.84766	7628.32422	7629.31641	7624.83984	7616.24609	7628.03516	6.60
SPEED	356.12134	354.15649	352.69214	353.03662	353.36987	353.36011	
ANGLE	7862.48047	7858.92578	7852.65234	7851.14844	7846.12500	7855.85938	6.70
SPEED	355.68018	354.66162	353.79761	354.36670	355.12842	354.51416	
ANGLE	8097.39063	8092.64453	8085.56641	8086.10938	8084.38672	8090.55469	6.80
SPEED	354.63672	355.27368	355.86182	355.94214	356.24194	355.71802	
ANGLE	8327.25000	8330.47656	8329.91406	8329.10156	8327.03516	8331.76563	6.90
SPEED	354.08447	356.08521	357.56836	357.08838	356.72510	356.76001	
ANGLE	8557.44141	8573.16016	8580.26563	8576.57813	8571.89063	8578.00781	7.00
SPEED	354.80762	356.91968	357.91870	357.51099	357.07690	357.42676	
ANGLE	8795.39063	8819.99609	8829.24609	8824.85156	8819.07813	8826.48438	7.10
SPEED	356.69531	357.50293	357.25220	357.42700	357.51685	357.53662	
ANGLE	9045.57031	9069.17188	9074.30859	9072.20313	9068.42969	9074.34766	7.20
SPEED	358.91382	357.75562	356.72607	357.25073	357.77686	357.30029	
ANGLE	9306.92188	9319.40625	9318.95703	9319.19141	9318.12891	9321.39844	7.30
SPEED	360.44385	357.94922	357.15186	357.35840	357.66919	357.36963	
ANGLE	9573.20313	9571.79297	9568.76172	9568.41016	9567.14063	9571.16016	7.40
SPEED	360.60132	358.55981	358.44141	358.06860	357.67432	358.25903	
ANGLE	9836.86328	9829.22266	9826.76953	9823.67188	9818.58203	9827.89453	7.50
SPEED	359.66406	359.65479	359.90894	359.43457	358.61108	359.69385	
ANGLE	10094.57813	10093.10938	10092.26172	10087.72266	10078.72266	10092.62109	7.60
SPEED	358.71973	360.71069	361.00830	361.02246	360.61768	360.95166	
ANGLE	10349.57813	10361.57031	10362.62109	10359.67188	10351.17969	10362.91016	7.70
SPEED	358.82886	361.22510	361.61377	362.07813	362.66846	361.62622	
ANGLE	10609.10547	10631.58984	10635.33594	10634.91016	10631.91797	10635.61328	7.80
SPEED	360.25195	361.33813	361.85596	362.18042	363.34863	361.84058	
ANGLE	10879.14453	10902.53125	10908.84766	10908.81641	10911.38672	10909.01172	7.90
SPEED	362.35474	361.62573	361.91821	361.73901	362.33618	361.90161	
ANGLE	11160.91797	11176.46094	11182.61328	11180.66797	11182.99609	11182.78125	8.00
SPEED	364.20386	362.37109	361.98413	361.58008	360.89868	362.00220	
ANGLE	11450.62109	11455.46875	11457.40625	11453.79688	11449.60156	11457.81250	8.10
SPEED	365.04395	363.32520	362.32837	362.19995	360.80591	362.39844	
ANGLE	11741.66016	11739.40234	11735.65234	11732.44531	11721.57813	11736.65625	8.20
SPEED	364.71655	364.04346	363.20996	363.43848	362.70068	363.34546	
ANGLE	12028.81250	12026.39844	12020.45703	12018.74609	12007.68750	12022.25000	8.30
SPEED	363.82983	364.43091	364.56689	364.79932	365.45703	364.67749	
ANGLE	12311.58594	12315.47266	12313.33594	12312.21484	12307.64063	12315.25000	8.40
SPEED	363.33276	364.83740	365.92651	365.89844	367.29248	365.83887	
ANGLE	12594.46094	12607.82031	12612.51953	12610.72266	12612.76172	12613.27734	8.50
SPEED	363.92139	365.57983	366.69775	366.53418	367.26294	366.41211	
ANGLE	12883.96875	12905.11719	12913.82813	12911.36719	12913.73828	12913.00781	8.60
SPEED	365.58057	366.49658	366.69800	366.65137	366.07471	366.48486	
ANGLE	13184.57813	13207.03125	13213.82813	13211.57031	13208.42188	13212.65234	8.70
SPEED	367.66187	367.13281	366.34668	366.43994	365.28931	366.44385	
ANGLE	13496.19141	13511.23438	13512.48828	13510.72266	13502.42969	13512.60547	8.80
SPEED	369.27905	367.33350	366.32935	366.38208	365.87305	366.63867	
ANGLE	13813.84766	13816.32031	13813.21484	13811.35547	13803.19922	13814.95703	8.90
SPEED	369.70752	367.54248	367.08862	367.01172	367.50488	367.30493	
ANGLE	14130.36328	14124.02344	14120.30859	14117.89844	14113.75781	14122.57031	9.00
SPEED	368.97437	368.27686	368.48071	368.39429	369.14111	368.44995	
ANGLE	14441.39063	14437.36328	14435.85547	14433.31641	14431.89844	14437.46094	9.10
SPEED	367.97803	369.42965	369.94238	369.98755	370.12720	369.77100	
ANGLE	14748.76172	14757.05078	14758.60156	14756.62109	14754.00781	14759.22266	9.20
SPEED	367.84326	370.39868	370.92969	371.05249	370.58765	370.76733	

ANGLE	15059.31250	15080.66797	15085.00781	15083.50781	15078.27734	15084.82813	9.30
SPEED	369.07544	370.80249	371.22144	371.24731	370.91626	371.10498	
ANGLE	15379.83984	15405.4[illegible]875	15411.48828	15409.70313	15404.35547	15410.81641	9.40
SPEED	371.18506	370.[illegible]8940	371.01733	370.90869	371.19409	370.97412	
ANGLE	15712.61328	15731.09766	15736.49219	15734.07031	15731.42969	15735.97656	9.50
SPEED	373.18930	371.16064	370.79590	370.71265	371.25195	370.90576	
ANGLE	16054.22266	16059.62891	16061.53125	16059.07422	16058.33203	16062.14844	9.60
SPEED	374.16650	371.90649	371.10620	371.17456	371.21045	371.37061	
ANGLE	16397.62891	16393.47656	16390.66797	16388.83203	16386.09766	16392.78906	9.70
SPEED	373.85596	372.94775	372.21777	372.33179	371.66162	372.43115	
ANGLE	16736.96094	16732.94531	16727.81641	16726.26953	16719.16406	16730.37500	9.80
SPEED	372.90405	373.80493	373.80005	373.77173	373.06714	373.72192	
ANGLE	17071.58594	17076.13281	17073.63281	17071.48438	17062.39453	17074.90625	9.90
SPEED	372.36816	374.26001	375.12671	374.97412	375.06128	374.79688	
ANGLE	17406.25391	17421.32422	17424.84766	17422.00000	17416.07422	17424.27344	****
SPEED	372.96704	374.57007	375.65186	375.59399	376.51782	375.39331	

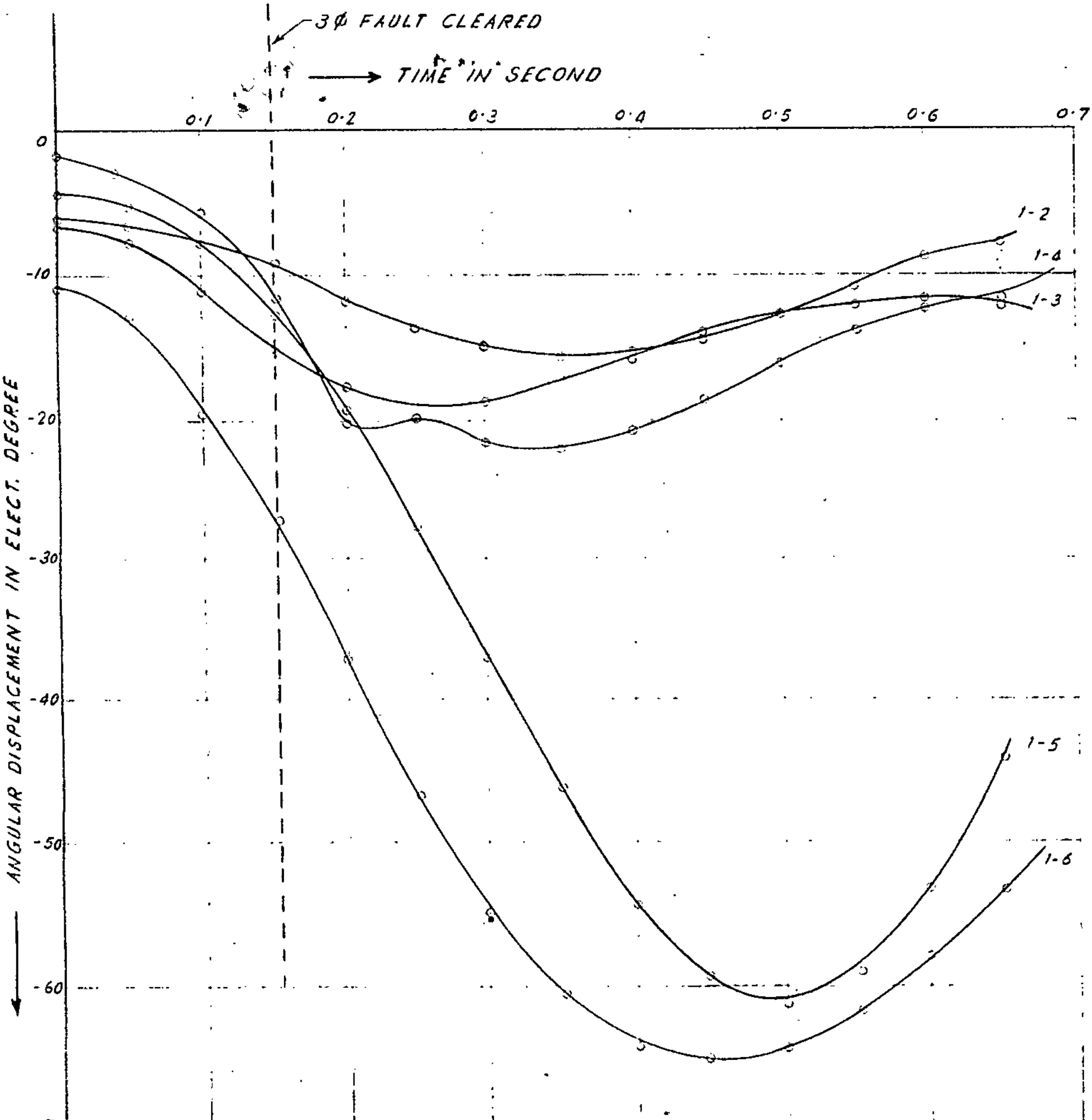
COMPUTATION OF INTERNAL MACHINE ANGLE AND SPEED

	SHAHJIBAZAR	ASHU GANJ	GHORA SAL	SHIDDIRGANJ	SIKAL BAHA	KAPTAIHYDRO	TIME
ANGLE	1.31525	8.42829	8.00206	4.30270	7.82320	18.31573	0.10
SPEED	314.30566	314.71753	314.45361	314.80591	315.22339	316.34399	
ANGLE	2.57838	13.32814	11.25176	10.14629	18.17540	35.16151	0.20
SPEED	314.45264	315.32373	315.06641	315.57764	316.77612	317.68945	
ANGLE	4.68361	20.56494	19.38008	20.98250	38.04498	55.95268	0.30
SPEED	314.59961	315.61792	316.14258	316.50610	318.36743	317.75781	
ANGLE	7.63093	31.47972	34.25888	36.69873	64.37502	75.57466	0.40
SPEED	314.74658	316.63379	317.34937	317.27563	318.90747	317.42505	
ANGLE	11.42034	50.15982	55.48973	56.55408	89.74429	94.10323	0.50
SPEED	314.89355	318.24390	318.33984	317.99194	318.11548	317.43750	
ANGLE	16.05183	78.17708	81.74423	80.98662	108.91490	114.11407	0.60
SPEED	315.04053	319.76831	319.13062	318.89087	316.98999	317.90991	
ANGLE	21.52542	112.97348	112.42506	111.09744	124.49965	127.47231	0.70
SPEED	315.18750	320.55615	319.90063	319.92700	317.05688	318.57446	
ANGLE	27.84109	149.92455	147.53038	146.65970	145.77644	164.92513	0.80
SPEED	315.33447	320.58838	320.64600	320.73193	318.91333	319.37183	
ANGLE	34.99867	186.33543	186.30994	185.46443	180.67264	197.92871	0.90
SPEED	315.48145	320.48315	321.14893	321.06543	321.55908	320.55127	
ANGLE	42.99873	223.34758	226.95972	225.31479	229.08099	239.09911	1.00
SPEED	315.62842	320.84790	321.32446	321.17798	323.43799	322.17969	
ANGLE	51.84068	264.07837	268.36523	266.48682	284.07251	289.83276	1.10
SPEED	315.77539	321.73779	321.49609	321.59692	323.88770	323.76245	
ANGLE	61.52472	310.49243	311.98022	311.64624	338.98096	347.60449	1.20
SPEED	315.92236	322.77002	322.15356	322.55469	323.57715	324.54517	
ANGLE	72.05086	362.45215	361.23682	363.24341	392.46240	406.78921	1.30
SPEED	316.06934	323.66797	323.43335	323.77441	323.48560	324.29932	
ANGLE	83.41908	419.35425	418.77222	421.54541	446.87036	462.82715	1.40
SPEED	316.21631	324.53174	324.94873	324.84863	323.86475	323.59033	
ANGLE	95.62939	481.63623	484.19116	485.09204	503.92090	515.78418	1.50
SPEED	316.36328	325.54956	326.10425	325.60498	324.34644	323.37085	
ANGLE	108.68179	549.95850	554.27661	552.22192	563.35059	570.74854	1.60
SPEED	316.51025	326.57861	326.57886	326.12671	324.73022	324.32446	
ANGLE	122.57629	623.18237	625.60303	622.14453	625.64136	634.23169	1.70
SPEED	316.65723	327.20215	326.61914	326.60498	325.45532	326.22070	
ANGLE	137.31288	698.27612	697.29443	694.99072	694.53052	708.98413	1.80
SPEED	316.80420	327.26221	326.78223	327.14795	327.05322	328.10547	
ANGLE	152.89156	772.98389	771.14014	771.06470	774.61304	792.54858	1.90
SPEED	316.95117	327.17432	327.37427	327.72388	329.21045	329.25000	
ANGLE	169.31232	848.40430	849.33325	850.44702	865.95313	880.44971	2.00
SPEED	317.09814	327.59375	328.25537	328.31372	330.78711	329.67773	
ANGLE	186.57518	928.48291	932.70239	933.48022	962.25317	969.88745	2.10
SPEED	317.24512	328.77734	329.15698	329.02222	330.90601	329.85181	
ANGLE	204.68013	1016.71997	1021.11133	1021.22607	1055.54883	1060.37744	2.20
SPEED	317.39209	330.34082	330.03174	329.96411	329.90625	330.05005	
ANGLE	223.62718	1113.41870	1114.79443	1114.96606	1142.92969	1151.94458	2.30
SPEED	317.53906	331.64453	331.01318	331.08130	329.06079	330.21533	
ANGLE	243.41632	1215.64546	1214.47119	1214.96948	1228.85840	1244.33008	2.40
SPEED	317.68604	332.33301	332.08960	332.09546	329.48999	330.38062	
ANGLE	264.04736	1320.73901	1319.88452	1319.72681	1321.30908	1338.58252	2.50
SPEED	317.83301	332.56738	332.95239	332.71802	331.22974	330.99215	
ANGLE	285.52051	1426.74683	1428.80469	1426.88403	1425.19507	1438.35596	2.60
SPEED	317.97998	332.78198	333.29907	332.97485	333.30151	332.22446	

ANGLE	307.83569	1534.65088	1538.41528	1535.30054	1539.40576	1547.95898	2.70
SPEED	318.12695	333.23682	333.26563	333.22388	334.75562	334.27417	
ANGLE	330.99316	1645.74561	1648.07007	1646.01855	1659.67456	1668.37866	2.80
SPEED	318.27393	333.67280	333.41309	333.80371	335.46729	335.94580	
ANGLE	354.99268	1760.64624	1760.34229	1761.09595	1782.99585	1795.57861	2.90
SPEED	318.42090	334.56274	334.20679	334.71509	335.88428	336.58789	
ANGLE	379.83423	1879.73657	1878.94189	1881.73999	1908.60278	1923.44702	3.00
SPEED	318.56787	335.36206	335.55591	335.70947	336.25586	336.26636	
ANGLE	405.51782	2004.13525	2005.64917	2007.87573	2035.83691	2048.41016	3.10
SPEED	318.71484	336.42822	336.94873	336.62598	336.41528	335.71045	
ANGLE	432.04370	2135.38916	2139.27783	2139.05249	2162.98584	2171.47729	3.20
SPEED	318.86182	337.70947	337.93213	337.47388	336.25952	335.69849	
ANGLE	459.41162	2273.68213	2277.08447	2274.91992	2289.26904	2297.05054	3.30
SPEED	319.00879	338.80347	338.43433	338.25244	336.23975	336.58276	
ANGLE	487.62158	2416.59082	2417.03516	2414.85352	2417.78955	2429.72266	3.40
SPEED	319.15576	339.28931	338.73438	338.87842	337.13672	338.09351	
ANGLE	516.67358	2560.52417	2558.90210	2557.80737	2554.84668	2571.42456	3.50
SPEED	319.30273	339.22778	339.12646	339.31470	339.14844	339.65503	
ANGLE	546.56763	2703.86108	2703.44043	2702.96509	2704.80566	2721.22339	3.60
SPEED	319.44971	339.18823	339.65479	339.68164	341.44067	340.89331	
ANGLE	577.30396	2848.50366	2851.15747	2850.57251	2865.66016	2877.03003	3.70
SPEED	319.59668	339.73364	340.23242	340.20410	342.79810	341.75708	
ANGLE	608.88232	2998.22144	3002.37036	3002.00415	3030.10840	3036.87012	3.80
SPEED	319.74365	340.91309	340.90063	341.01953	342.73267	342.29858	
ANGLE	641.30273	3155.49951	3158.08325	3158.82349	3191.54175	3198.82910	3.90
SPEED	319.89063	342.28931	341.82544	342.05811	341.92139	342.48853	
ANGLE	674.56519	3320.06226	3320.01270	3321.77417	3348.93579	3360.84595	4.00
SPEED	320.03760	343.41162	343.04712	343.12622	341.46973	342.35010	
ANGLE	708.66968	3489.93677	3489.20215	3490.44751	3506.48315	3521.86108	4.10
SPEED	320.18457	344.15527	344.28809	344.03052	341.99585	342.23218	
ANGLE	743.61646	3663.33276	3664.43530	3663.52954	3669.54712	3683.77856	4.20
SPEED	320.33154	344.67090	345.09766	344.66040	343.31128	342.75854	
ANGLE	779.40527	3839.46509	3842.49780	3839.50903	3840.91162	3851.56030	4.30
SPEED	320.47852	345.12085	345.29785	345.06470	344.81152	344.26270	
ANGLE	816.03613	4018.06934	4020.70703	4017.61035	4020.40479	4029.85645	4.40
SPEED	320.62549	345.52930	345.24146	345.43530	346.13721	346.29028	
ANGLE	853.50903	4198.85156	4199.30859	4198.21484	4207.03906	4218.97266	4.50
SPEED	320.77246	345.89648	345.51196	345.95898	347.31372	347.90015	
ANGLE	891.82397	4381.93750	4381.19531	4382.42578	4400.02344	4414.47656	4.60
SPEED	320.91943	346.37280	346.38135	346.69092	348.31323	348.50024	
ANGLE	930.98120	4568.65625	4569.29297	4571.28516	4597.53125	4610.89844	4.70
SPEED	321.06641	347.19531	347.61255	347.57056	348.83667	348.31372	
ANGLE	970.98047	4761.33984	4764.42969	4765.44531	4796.03125	4805.60938	4.80
SPEED	321.21338	348.43457	348.78638	348.53149	348.66895	348.00635	
ANGLE	1011.82178	4961.75781	4965.54688	4965.20313	4992.16016	4999.56641	4.90
SPEED	321.36035	349.82227	349.69482	349.50757	348.11914	348.09985	
ANGLE	1053.50513	5169.36719	5171.20313	5170.29688	5186.01563	5195.67188	5.00
SPEED	321.50732	350.87158	350.38892	350.36792	348.02637	348.75342	
ANGLE	1096.03052	5381.16406	5380.51172	5379.62891	5382.62109	5396.88672	5.10
SPEED	321.65430	351.28027	350.97681	350.97729	349.12573	349.85889	
ANGLE	1139.39819	5593.83984	5592.91406	5591.73828	5588.80859	5605.26953	5.20
SPEED	321.80127	351.25488	351.45898	351.36011	351.24878	351.22705	
ANGLE	1183.60791	5806.45313	5807.65234	5805.85938	5807.73047	5821.78125	5.30
SPEED	321.94824	351.34253	351.79834	351.71802	353.38550	352.66089	
ANGLE	1228.65967	6020.94922	6024.17188	6022.51563	6036.37891	6046.10938	5.40
SPEED	322.09521	351.93579	352.12378	352.27002	354.55200	353.90283	
ANGLE	1274.55247	6240.26172	6243.21875	6243.09375	6268.31641	6276.26172	5.50
SPEED	322.24219	352.97949	352.72705	353.08008	354.59790	354.64893	
ANGLE	1321.28931	6466.02734	6467.03125	6468.82422	6498.82813	6508.82813	5.60
SPEED	322.38916	354.13721	353.78564	354.04541	354.18359	354.75244	
ANGLE	1368.86743	6698.11328	6697.92188	6700.20703	6727.49219	6740.54297	5.70
SPEED	322.53613	355.17090	355.13965	355.03809	354.02783	354.42188	
ANGLE	1417.28760	6935.69531	6936.40625	6937.13672	6956.76172	6970.39453	5.80
SPEED	322.68311	356.06274	356.36328	355.96484	354.39600	354.21118	
ANGLE	1466.54980	7178.07422	7180.52734	7178.92969	7189.42578	7200.98828	5.90
SPEED	322.83008	356.83740	357.07422	356.71826	355.19043	354.75830	

ANGLE	1516.65405	7424.38281	7427.12891	7424.34375	7427.52734	7437.56641	6.00
SPEED	322.97705	357.41357	357.27222	357.22876	356.29468	356.26050	
ANGLE	1567.60034	7673.19141	7674.31641	7672.15234	7672.87109	7684.32813	6.10
SPEED	323.12402	357.71509	357.35547	357.58472	357.71851	358.18237	
ANGLE	1619.38852	7923.20313	7922.73438	7922.07813	7927.10156	7941.25000	6.20
SPEED	323.27100	357.88184	357.74341	358.00342	359.33960	359.69897	
ANGLE	1672.01953	8174.62109	8174.58203	8175.03125	8190.08594	8204.51563	6.30
SPEED	323.41797	358.26685	358.53564	358.65479	360.67065	360.39014	
ANGLE	1725.49219	8429.62500	8431.67969	8432.42578	8458.43750	8469.78125	6.40
SPEED	323.56494	359.15161	359.53906	359.53979	361.15771	360.46558	
ANGLE	1779.80688	8691.08594	8694.60547	8695.27344	8726.85547	8734.86719	6.50
SPEED	323.71191	360.47363	360.55396	360.53613	360.75488	360.39111	
ANGLE	1834.96387	8960.47656	8963.23828	8963.82813	8991.80859	8999.88281	6.60
SPEED	323.85889	361.84399	361.53174	361.51294	360.09424	360.46948	
ANGLE	1890.96265	9236.74609	9237.37109	9237.66016	9254.50000	9266.10156	6.70
SPEED	324.00586	362.82349	362.46216	362.36230	360.09302	360.83154	
ANGLE	1947.80396	9517.00781	9516.44141	9515.79297	9520.51953	9535.51172	6.80
SPEED	324.15283	363.25000	363.22534	363.00757	361.25757	361.60962	
ANGLE	2005.48706	9798.64063	9799.00000	9797.04297	9795.85938	9810.84766	6.90
SPEED	324.29980	363.36548	363.66772	363.46387	363.22192	362.89771	
ANGLE	2064.01221	10081.06250	10083.20313	10080.65234	10082.58984	10094.72266	7.00
SPEED	324.44678	363.98081	363.83667	363.85791	365.09790	364.52979	
ANGLE	2123.37939	10365.65234	10368.33594	10366.75000	10378.07422	10387.82031	7.10
SPEED	324.59375	364.13135	364.05957	364.35669	366.22998	366.02173	
ANGLE	2183.58887	10654.28906	10655.84766	10656.28906	10677.73047	10687.73438	7.20
SPEED	324.74072	364.97144	364.70435	365.06592	366.59863	366.85205	
ANGLE	2244.64038	10948.17578	10948.52734	10950.48438	10978.25391	10990.06250	7.30
SPEED	324.88770	365.94604	365.83643	365.97119	366.59570	366.89355	
ANGLE	2306.53394	11247.82422	11248.44141	11250.22266	11278.56641	11291.17188	7.40
SPEED	325.03467	366.98047	367.16528	366.98364	366.55762	366.51685	
ANGLE	2369.26953	11553.53125	11555.54688	11555.78516	11578.92578	11590.39453	7.50
SPEED	325.18164	368.04688	368.29321	367.97900	366.63330	366.33618	
ANGLE	2432.84717	11865.14063	11867.90625	11866.60156	11880.40234	11890.51172	7.60
SPEED	325.32861	369.00366	368.98950	368.79126	366.99023	366.88159	
ANGLE	2497.26709	12181.33594	12183.12109	12181.24609	12185.40234	12196.20313	7.70
SPEED	325.47559	369.61670	369.32617	369.31616	367.90747	368.24194	
ANGLE	2562.52905	12499.80859	12499.90234	12498.28125	12497.66406	12511.00391	7.80
SPEED	325.62256	369.81958	369.58057	369.66016	369.50317	369.96216	
ANGLE	2628.63306	12818.65938	12818.50781	12817.36328	12820.25781	12835.16016	7.90
SPEED	325.76953	369.88867	369.98340	370.06909	371.40356	371.42896	
ANGLE	2695.57910	13139.01563	13140.03125	13139.43359	13152.78125	13166.10938	8.00
SPEED	325.91650	370.26660	370.59937	370.71191	372.84473	372.31836	
ANGLE	2763.36719	13462.89453	13465.62891	13465.83203	13490.71484	13500.59375	8.10
SPEED	326.06348	371.18970	371.40259	371.56372	373.26270	372.69287	
ANGLE	2831.99756	13793.30859	13796.31250	13797.40625	13828.30078	13836.30078	8.20
SPEED	326.21045	372.49146	372.37280	372.50098	372.81519	372.77710	
ANGLE	2901.46997	14131.30859	14132.97656	14134.37891	14162.59375	14172.11328	8.30
SPEED	326.35742	373.77368	373.47583	373.44092	372.25220	372.75903	
ANGLE	2971.78442	14475.75781	14476.02734	14476.63672	14495.30078	14508.01563	8.40
SPEED	326.50439	374.71362	374.56372	374.33423	372.34961	372.85962	
ANGLE	3042.94092	14824.38672	14824.64063	14823.67188	14831.32422	14845.66016	8.50
SPEED	326.65137	375.24609	375.37817	375.08862	373.39478	373.42456	
ANGLE	3114.93970	15175.28906	15176.68750	15174.39063	15175.32813	15188.54688	8.60
SPEED	326.79834	375.54419	375.76294	375.61719	375.04590	374.69263	
ANGLE	3187.78052	15527.81250	15530.00000	15527.58594	15529.04297	15540.33203	8.70
SPEED	326.94531	375.84204	375.87427	375.97876	376.70068	376.44775	
ANGLE	3261.46338	15882.41406	15884.11328	15882.86719	15891.19922	15902.06641	8.80
SPEED	327.09229	376.28271	376.10840	376.38501	377.95825	378.05127	
ANGLE	3335.98828	16240.07813	16240.76172	16241.12891	16259.14453	16271.02344	8.90
SPEED	327.23926	376.91846	376.78125	377.03760	378.71973	378.91553	
ANGLE	3411.35522	16602.00781	16602.55859	16603.92969	16630.12891	16642.51563	9.00
SPEED	327.38623	377.77759	377.87207	377.95483	379.02588	378.97974	
ANGLE	3487.56445	16969.53516	16971.13281	16972.42188	17001.75000	17013.07813	9.10
SPEED	327.53320	378.86426	379.09497	378.99512	378.96484	378.68140	
ANGLE	3564.61572	17343.72656	17346.36328	17346.80078	17372.42969	17382.25781	9.20
SPEED	327.68018	380.06982	380.16235	379.98511	378.75439	378.57593	

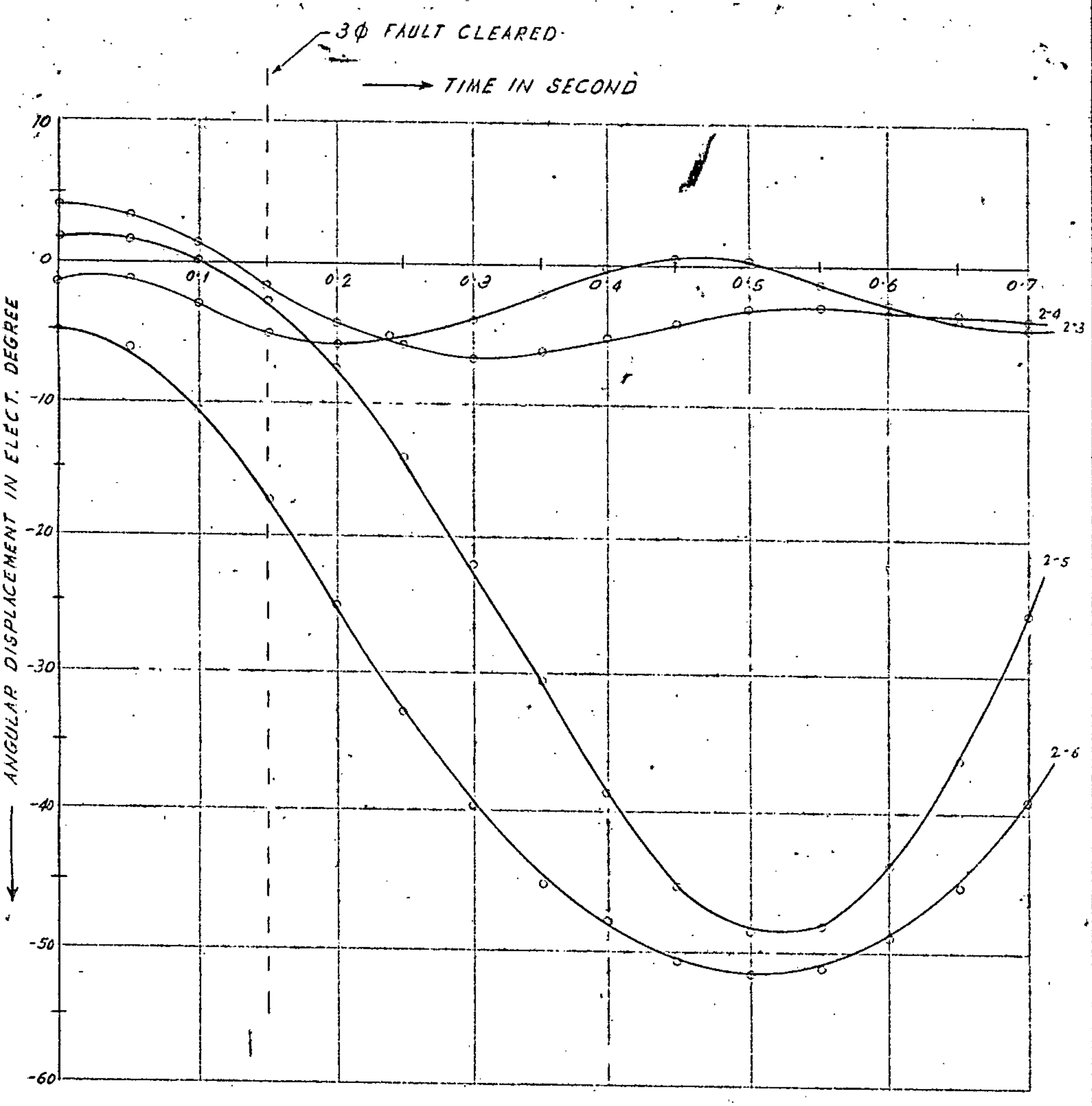
ANGLE	3642.50903	17724.53516	17726.89453	17726.35547	17742.49609	17752.39844	9.30
SPEED	327.82715	381.11963	380.93945	380.78516	378.83887	379.05249	
ANGLE	3721.24438	18110.16797	18111.08203	18109.80078	18115.13672	18127.18750	9.40
SPEED	327.97412	381.72705	381.45288	381.34790	379.70557	380.17700	
ANGLE	3800.82178	18497.89844	18497.73438	18495.99219	18495.30469	18509.67969	9.50
SPEED	328.12109	381.88770	381.81787	381.76807	381.41431	381.68311	
ANGLE	3881.24146	18886.06641	18886.35547	18884.58984	18886.42188	18900.91016	9.60
SPEED	328.26807	381.95410	382.16064	382.21216	383.39697	383.16602	
ANGLE	3962.50317	19275.43359	19277.17969	19276.10156	19287.64844	19299.75000	9.70
SPEED	328.41504	382.35742	382.61084	382.79541	384.82813	384.30029	
ANGLE	4044.60693	19668.56250	19671.21094	19671.42578	19694.22266	19703.69141	9.80
SPEED	328.56201	383.25806	383.29810	383.54175	385.25659	384.93555	
ANGLE	4127.55078	20067.85938	20070.03516	20071.41797	20100.86328	20109.86719	9.90
SPEED	328.70898	384.45947	384.28052	384.41846	384.94409	385.09717	
ANGLE	4211.33594	20474.10547	20475.16016	20476.71484	20505.20313	20516.00000	****
SPEED	328.85596	385.64038	385.46704	385.38550	384.56201	384.96606	



RELATIVE ANGULAR DISPLACEMENT OF MACHINES

1-2 : SHAHJIBAZAR – ASHUGANJ
1-3 : SHAHJIBAZAR – GHORASAL
1-4 : SHAHJIBAZAR – SIDDHIRGANJ
1-5 : SHAHJIBAZAR – SIKALBAHA
1-6 : SHAHJIBAZAR – KAPTAI

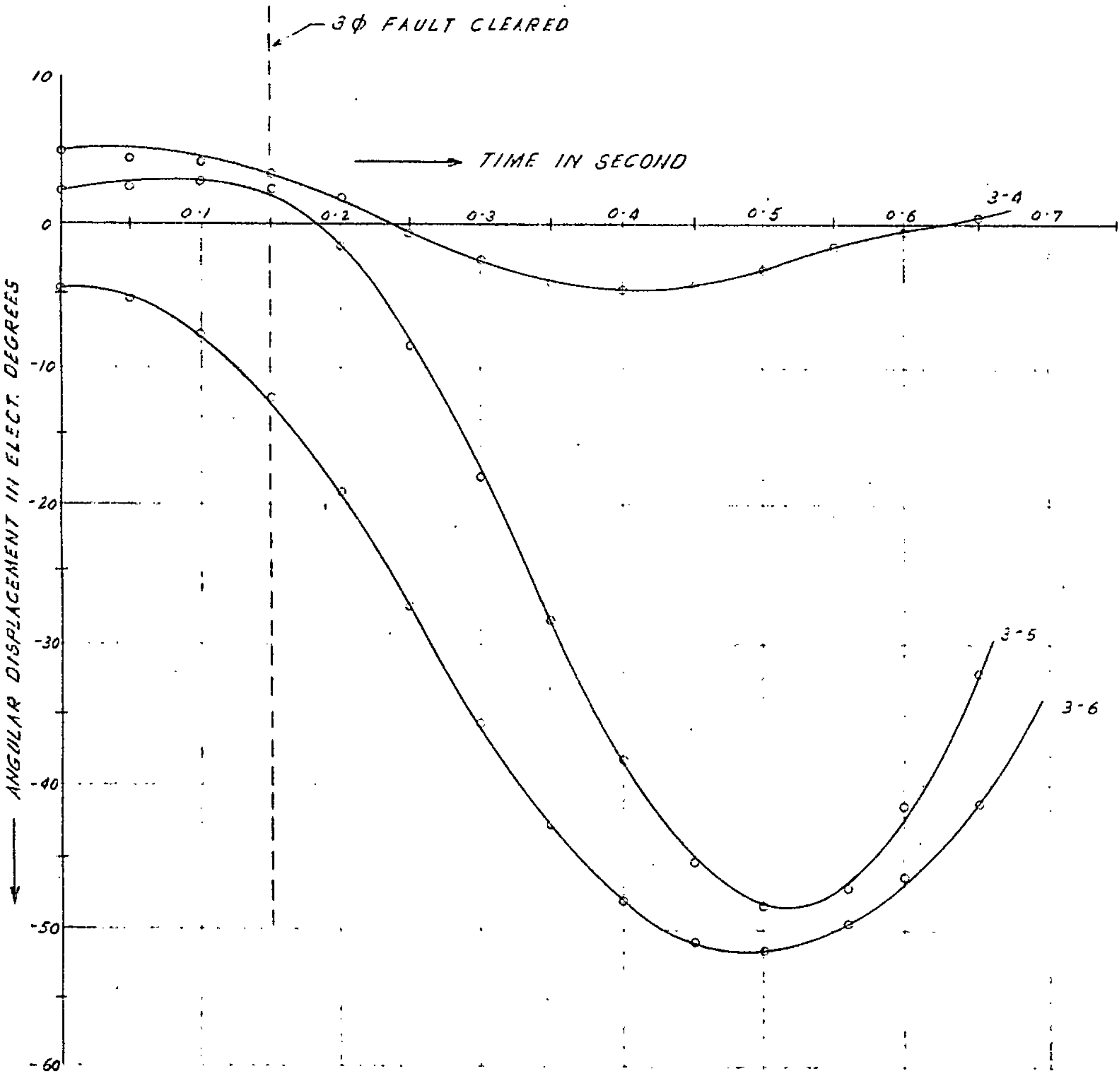
FIG: 6·2



RELATIVE ANGULAR DISPLACEMENT OF MACHINES

2-3 : ASHUGANJ - GHORASAL
2-4 : ASHUGANJ - SIDDHIRGANJ
2-5 : ASHUGANJ - SIKALBAHA
2-6 : ASHUGANJ - KAPTAI

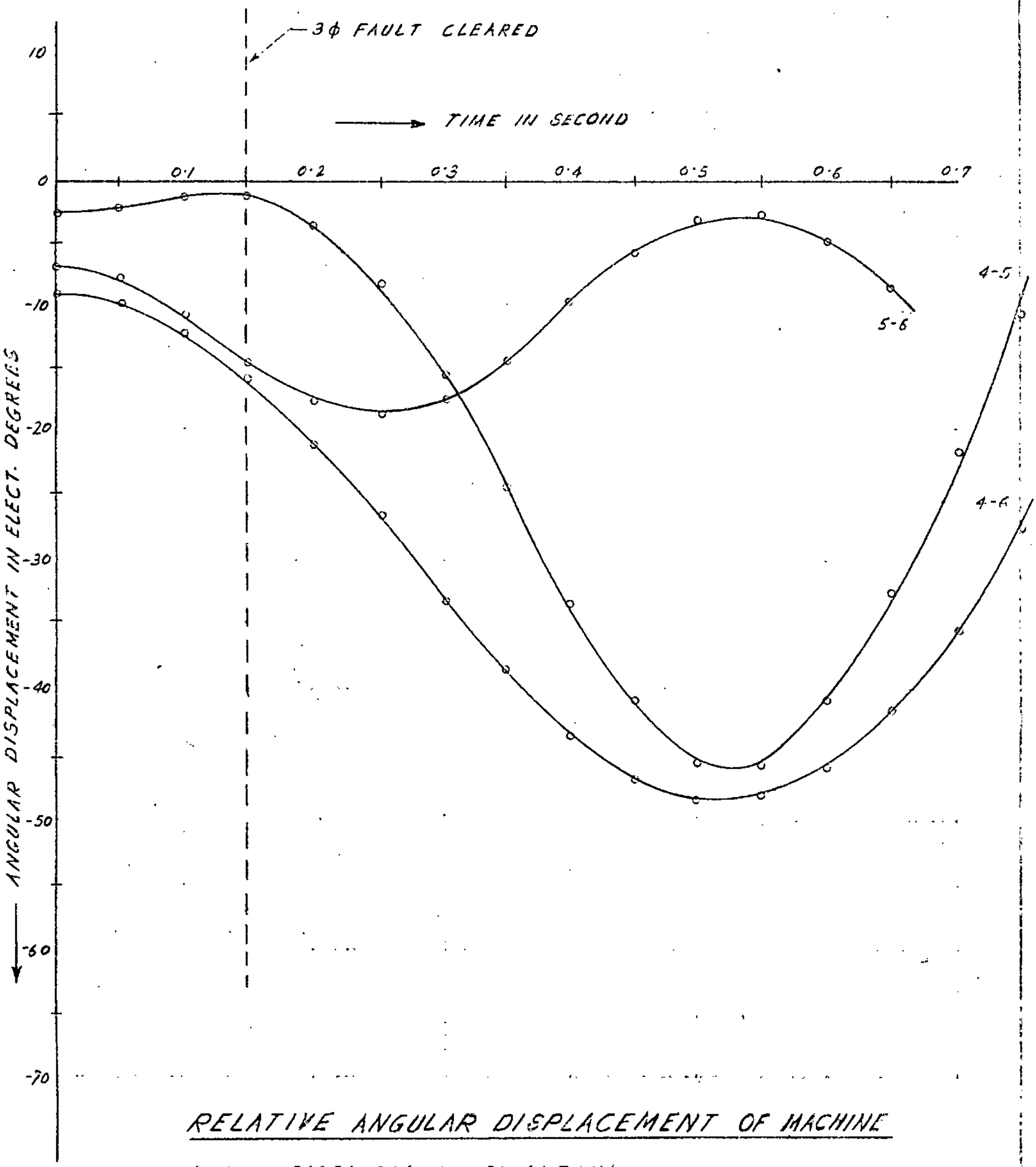
FIG: 6·3



RELATIVE ANGULAR DISPLACEMENT OF MACHINES

3-4 : GHORASAL - SIDDHIRGANJ
3-5 : GHORASAL - SIKALBAHA
3-6 : GHORASAL - KAPTAI

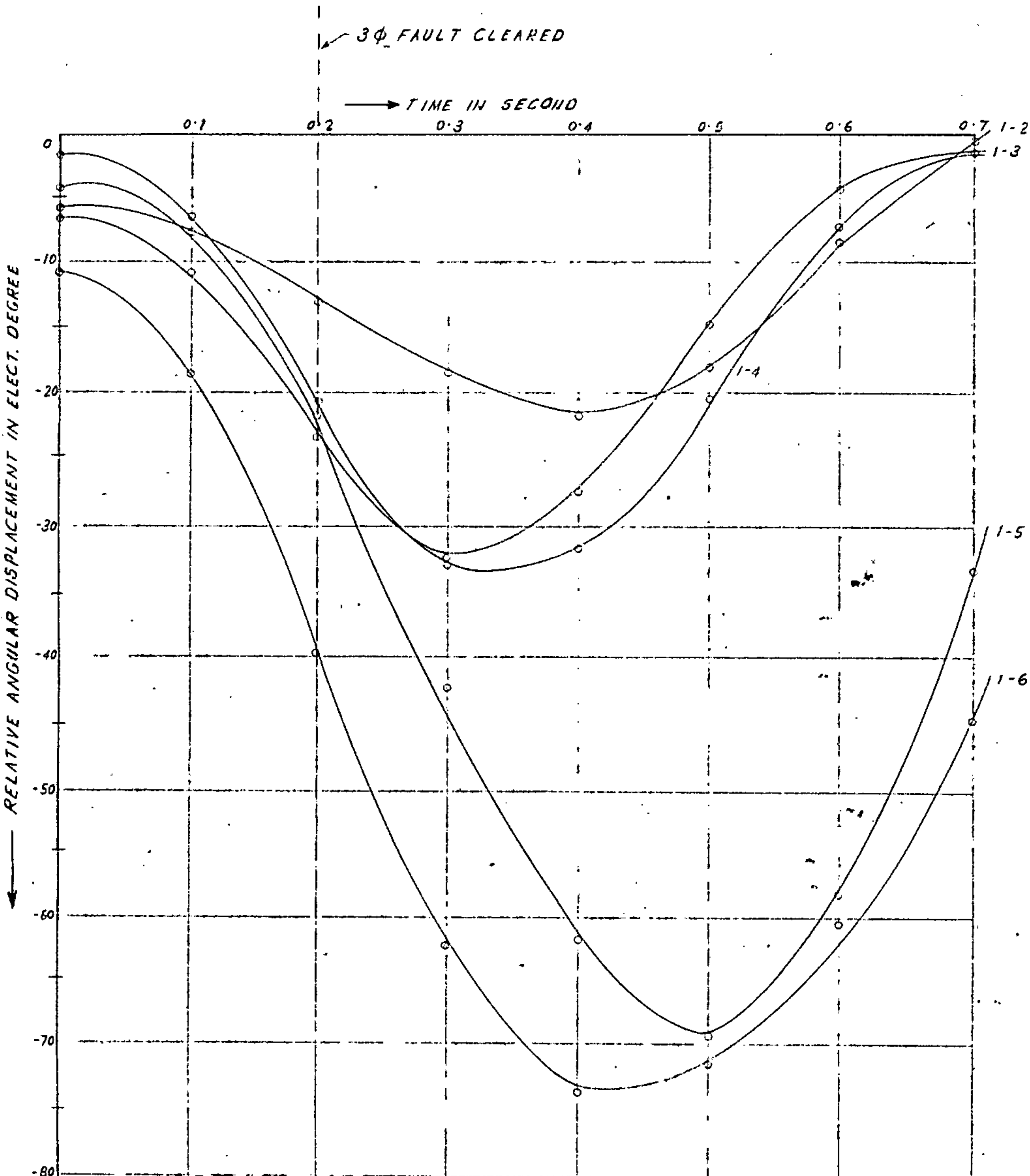
FIG: 6·4



RELATIVE ANGULAR DISPLACEMENT OF MACHINE

4-5 : SIDDHIRGANJ - SIKALBAHA
4-6 : SIDDHIRGANJ - KAPTAI
5-6 : SIKALBAHA - KAPTAI

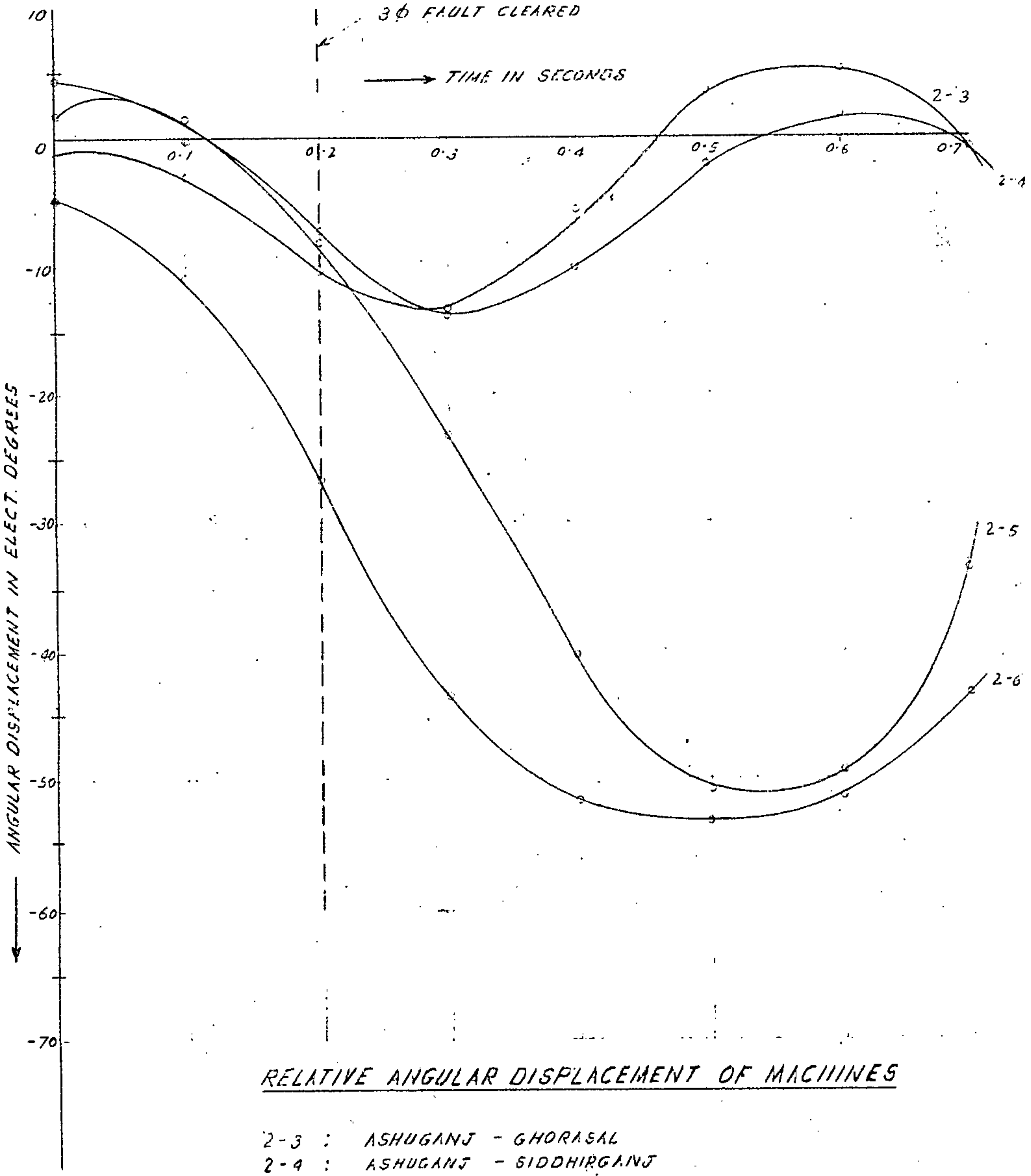
FIG: 6·5



RELATIVE ANGULAR DISPLACEMENT OF MACHINES

1-2 : SHAHJIBAZAR - ASHUGANJ
1-3 : SHAHJIBAZAR - GHORASAL
1-4 : SHAHJIBAZAR - SIDDHIRGANJ
1-5 : SHAHJIBAZAR - SIKALBAHA
1-6 : SHAHJIBAZAR - KAPTAI

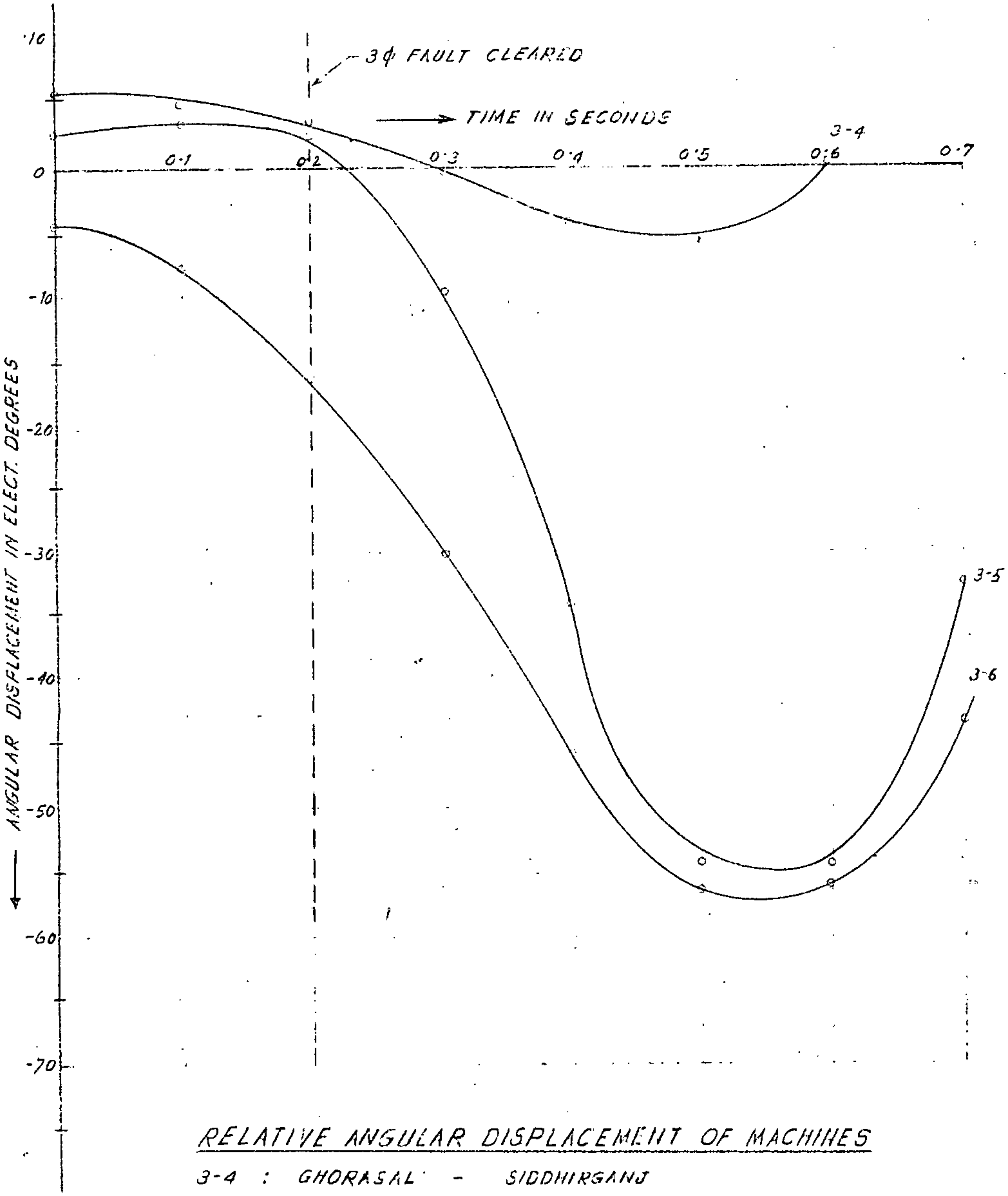
FIG: 6·6



RELATIVE ANGULAR DISPLACEMENT OF MACHINES

2-3 : ASHUGANJ - GHORASAL
2-4 : ASHUGANJ - SIDDHIRGANJ
2-5 : ASHUGANJ - SIKALBAHA
2-6 : ASHUGANJ - KAPTAI

FIG: 6·7



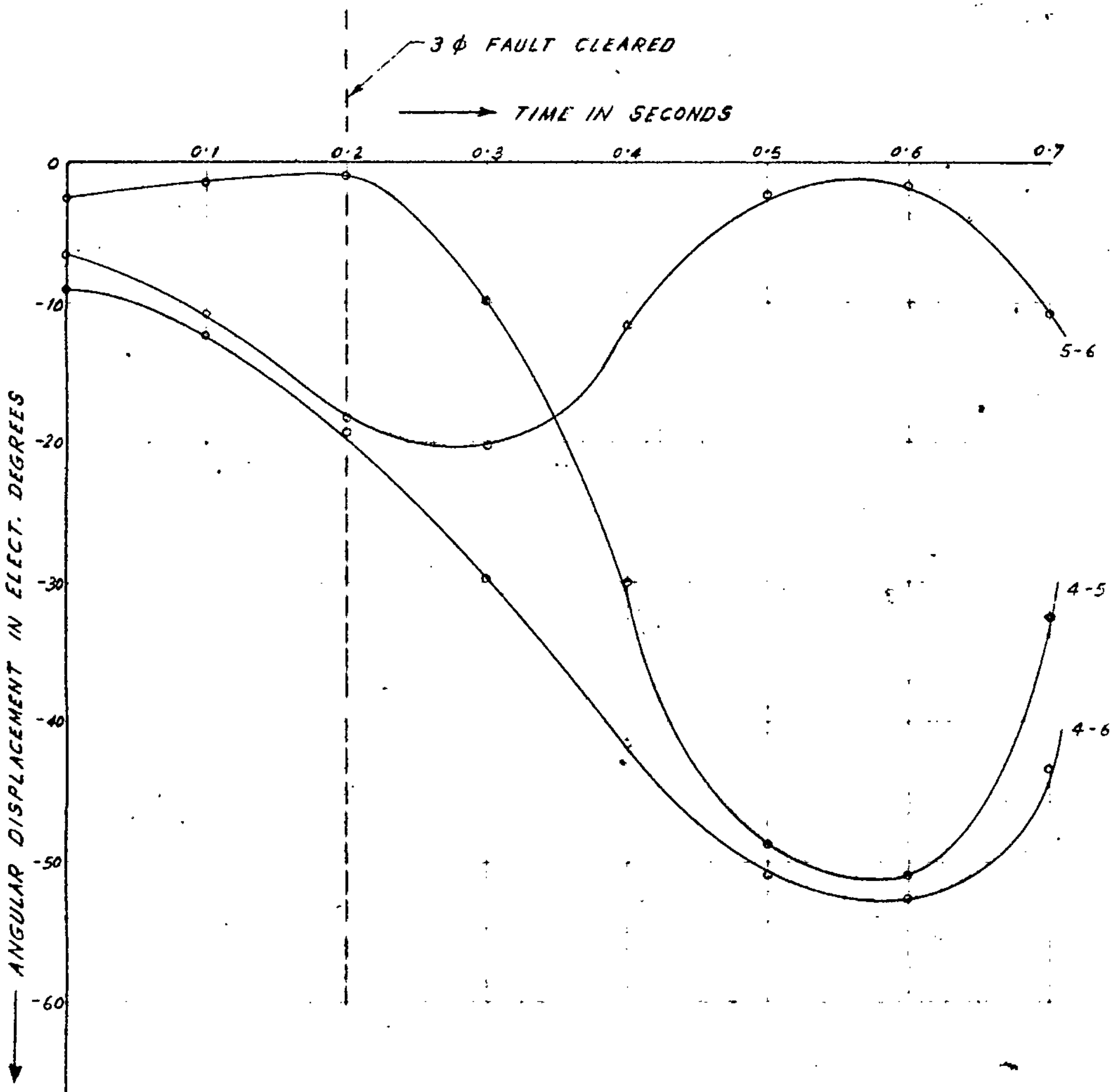
RELATIVE ANGULAR DISPLACEMENT OF MACHINES

3-4 : GHORASAL - SIDDHIRGANJ

3-5 : GHORASAL - SIKALBAHA

3-6 : GHORASAL - KAPTAI

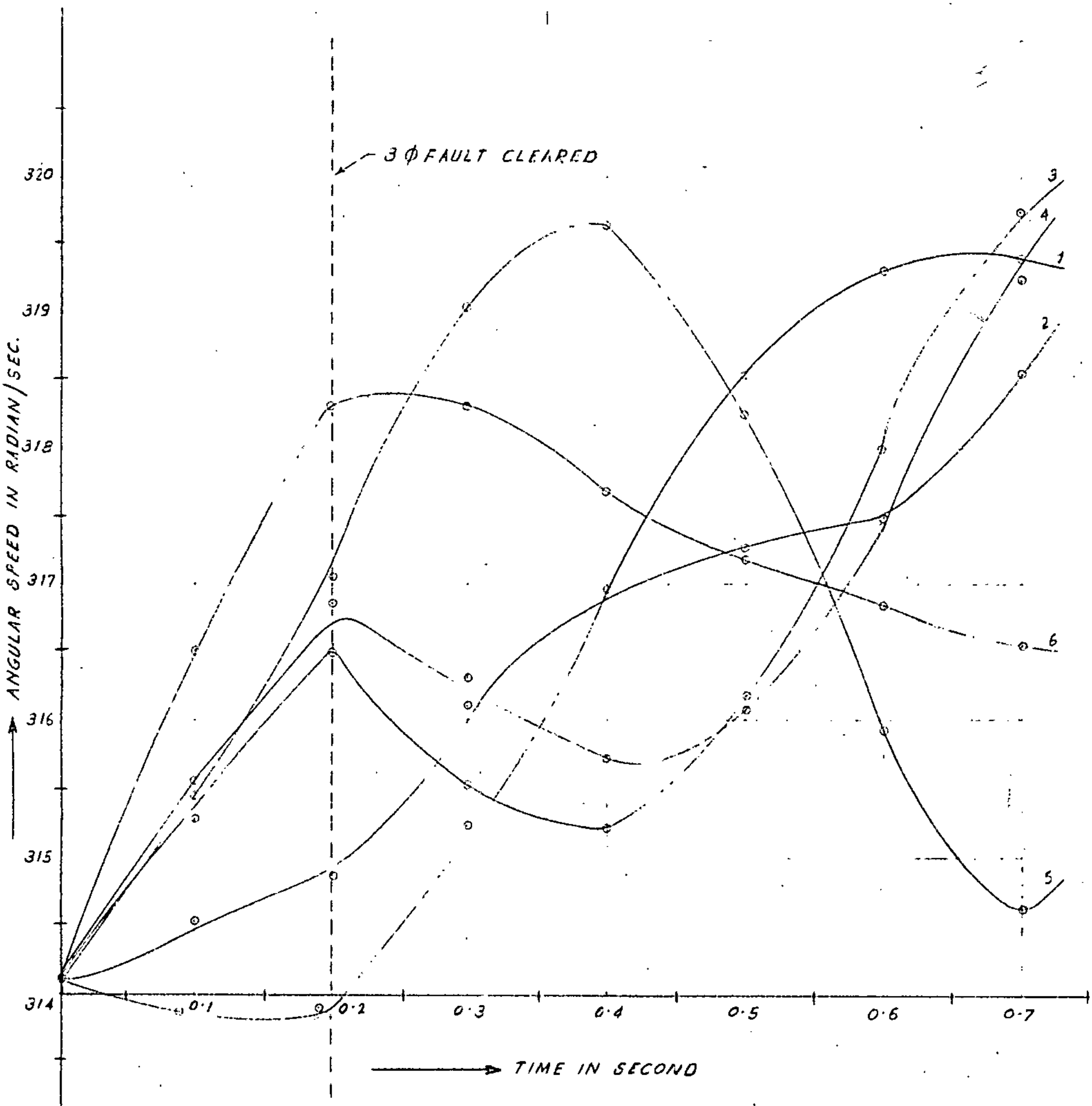
FIG: 6·8



RELATIVE ANGULAR DISPLACEMENT OF MACHINES

4-5 : SIDDHIRGANJ - SIKALBAHA
4-6 : SIDDHIRGANJ - KAPTAI
5-6 : SIKALBAHA - KAPTAI

FIG: 6'9



ANGULAR SPEED OF MACHINES

1 - SHAHJIBAZAR
2 - ASHUGANJ
3 - GHORASAL
4 - SIDDHIRGANJ
5 - SIKALBAHA
6 - KAPTAI

FIG: 6·10

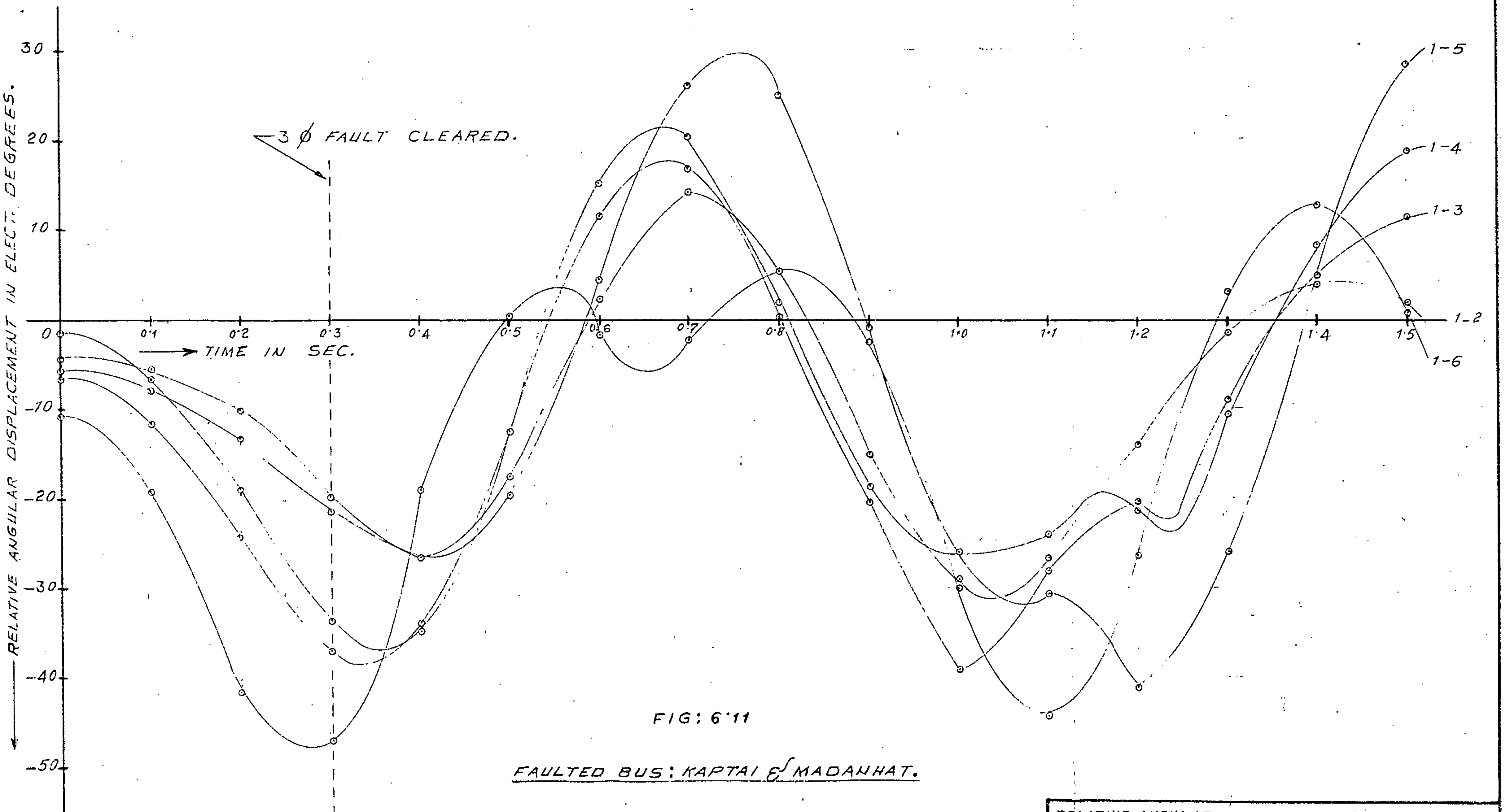


FIG: 6·11

FAULTED BUS: KAPTAI & MADANHAT.

RELATIVE ANGULAR DISPLACEMENT OF MACHINES.		
1 - 2 :	SHAJIBAZAR	- ASHUGANJ
1 - 3 :	"	- GHORASAL
1 - 4 :	"	- SHIDDIRGANJ
1 - 5 :	"	- SIKALBAHA
1 - 6 :	"	- KAPTAI

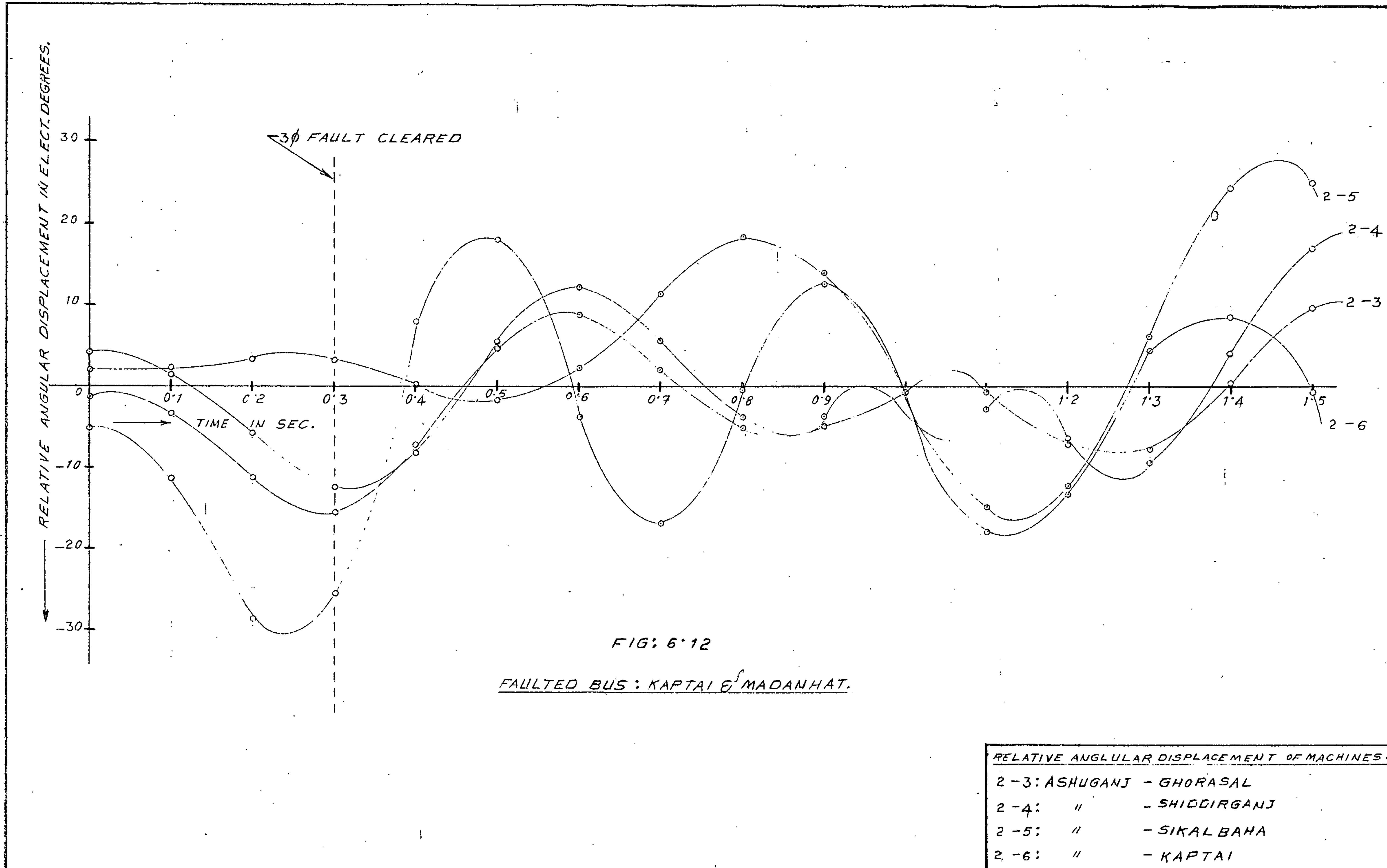


FIG: 6·12

FAULTED BUS: KAPTAI & MADANHAT.

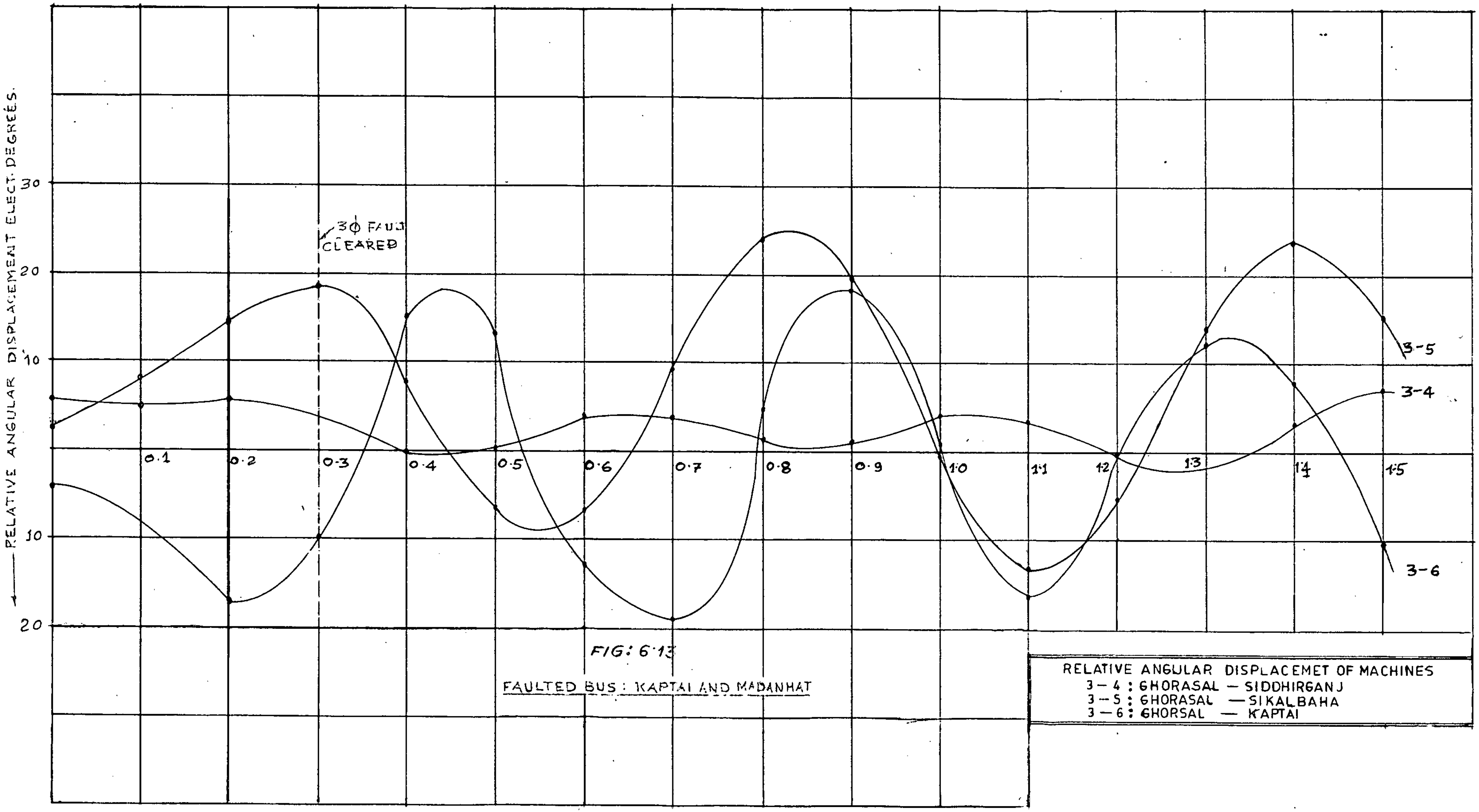


FIG: 6·13

FAULTED BUS : KAPTAI AND MADANHAT

RELATIVE ANGULAR DISPLACEMET OF MACHINES
3 — 4 : GHORASAL — SIDDHIRGANJ
3 — 5 : GHORASAL — SIKALBAHA
3 — 6 : GHORSAL — KAPTAI

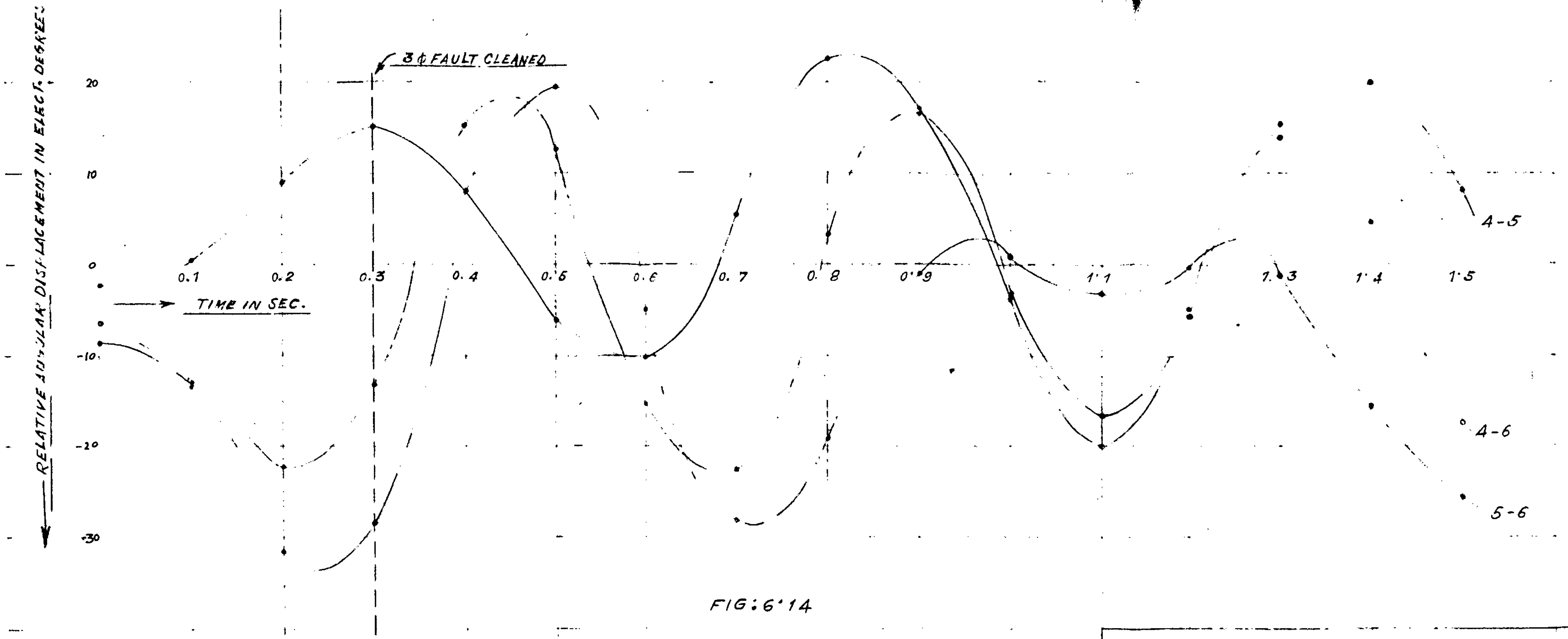


FIG: 6·14

FAULTED BUS KAPTAI & MALANHAT

RELATIVE ANGULAR DISPLACEMENT OF MACHINES

4-5 : … - SIKALBAHA

4-6 : … - KAPTAI

5-6 : SIKALBAHA - KAPTAI

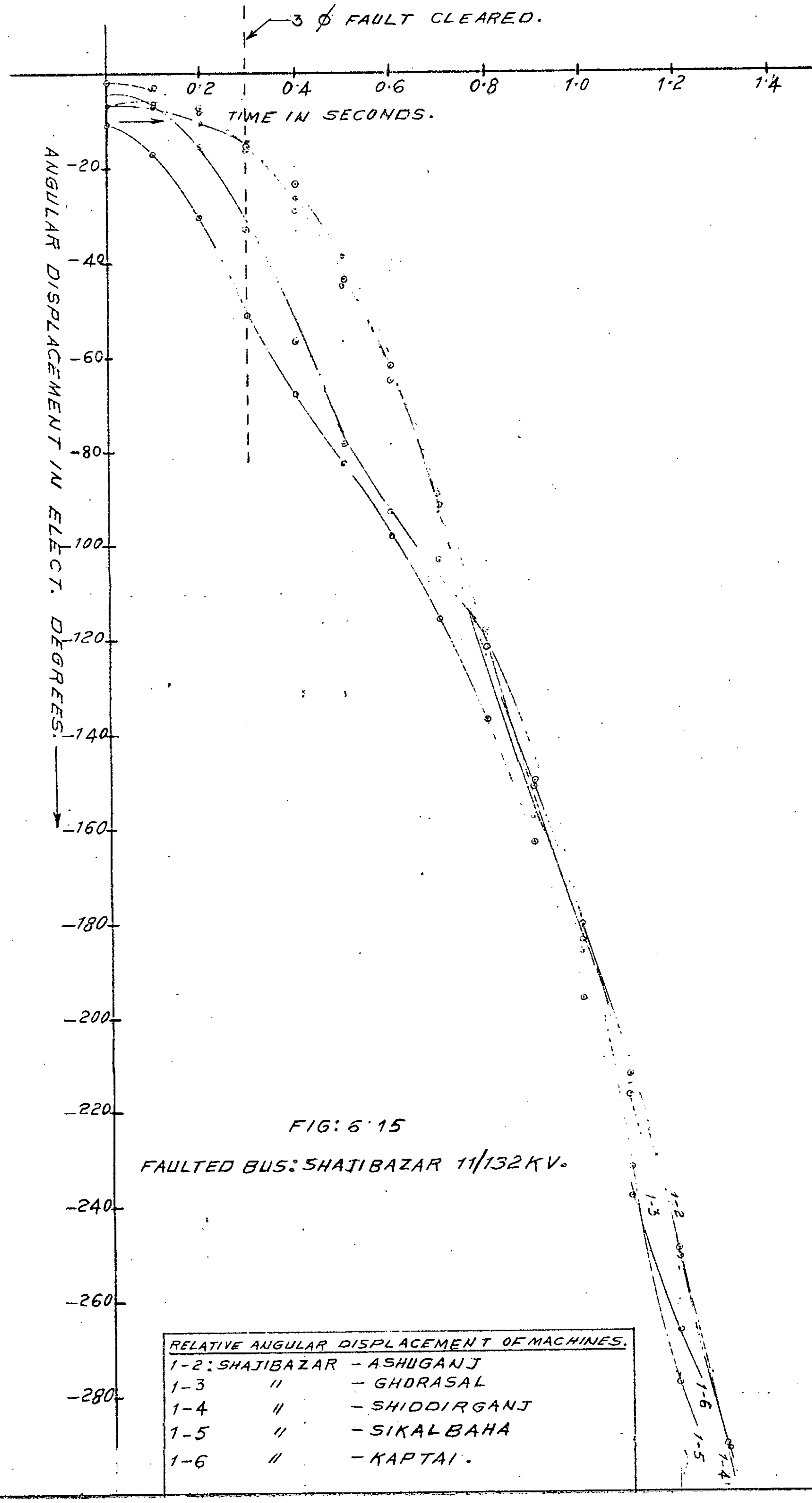


FIG: 6·15

FAULTED BUS: SHAJIBAZAR 11/132 KV.

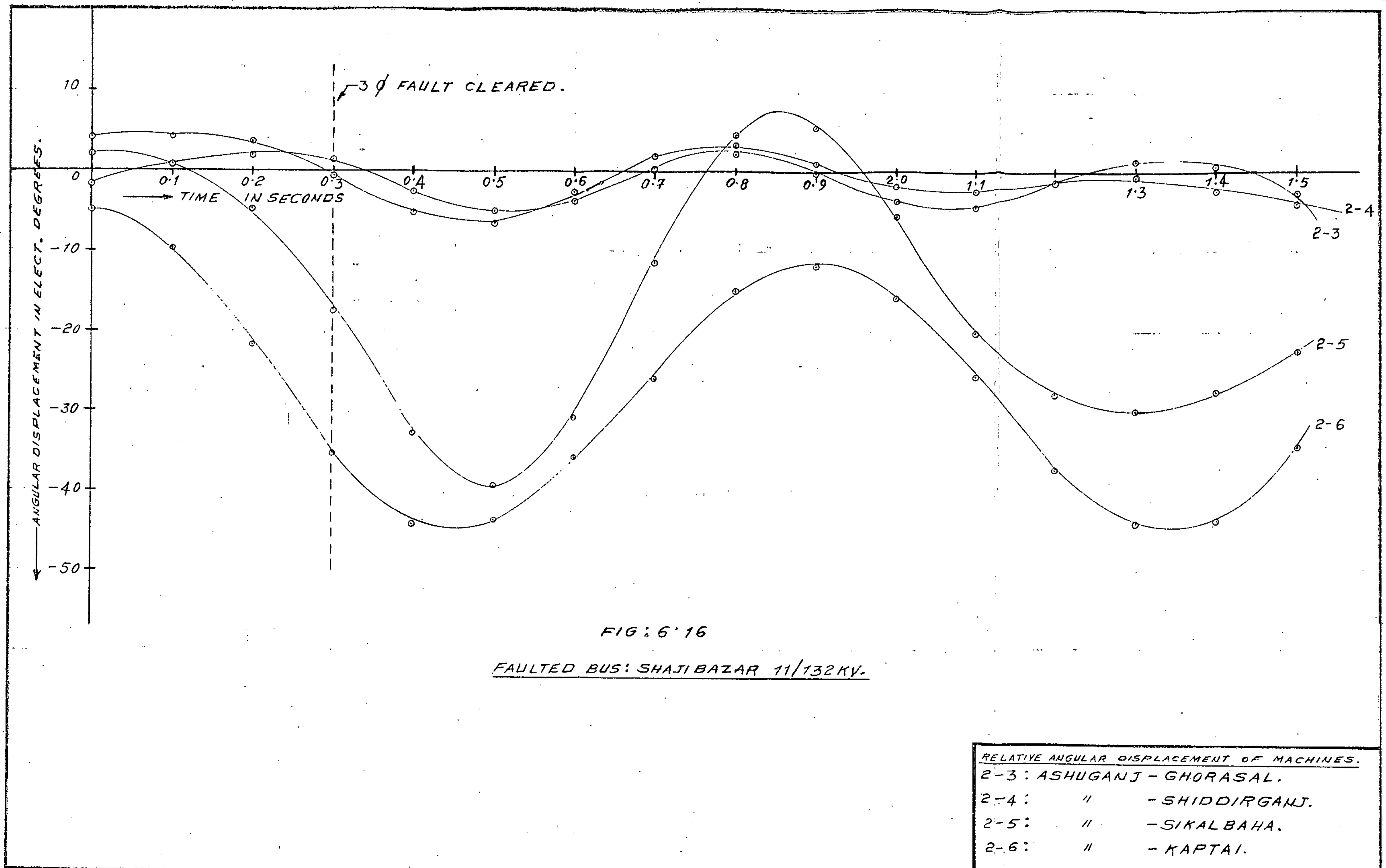


FIG: 6'16

FAULTED BUS: SHAJIBAZAR 11/132 KV.

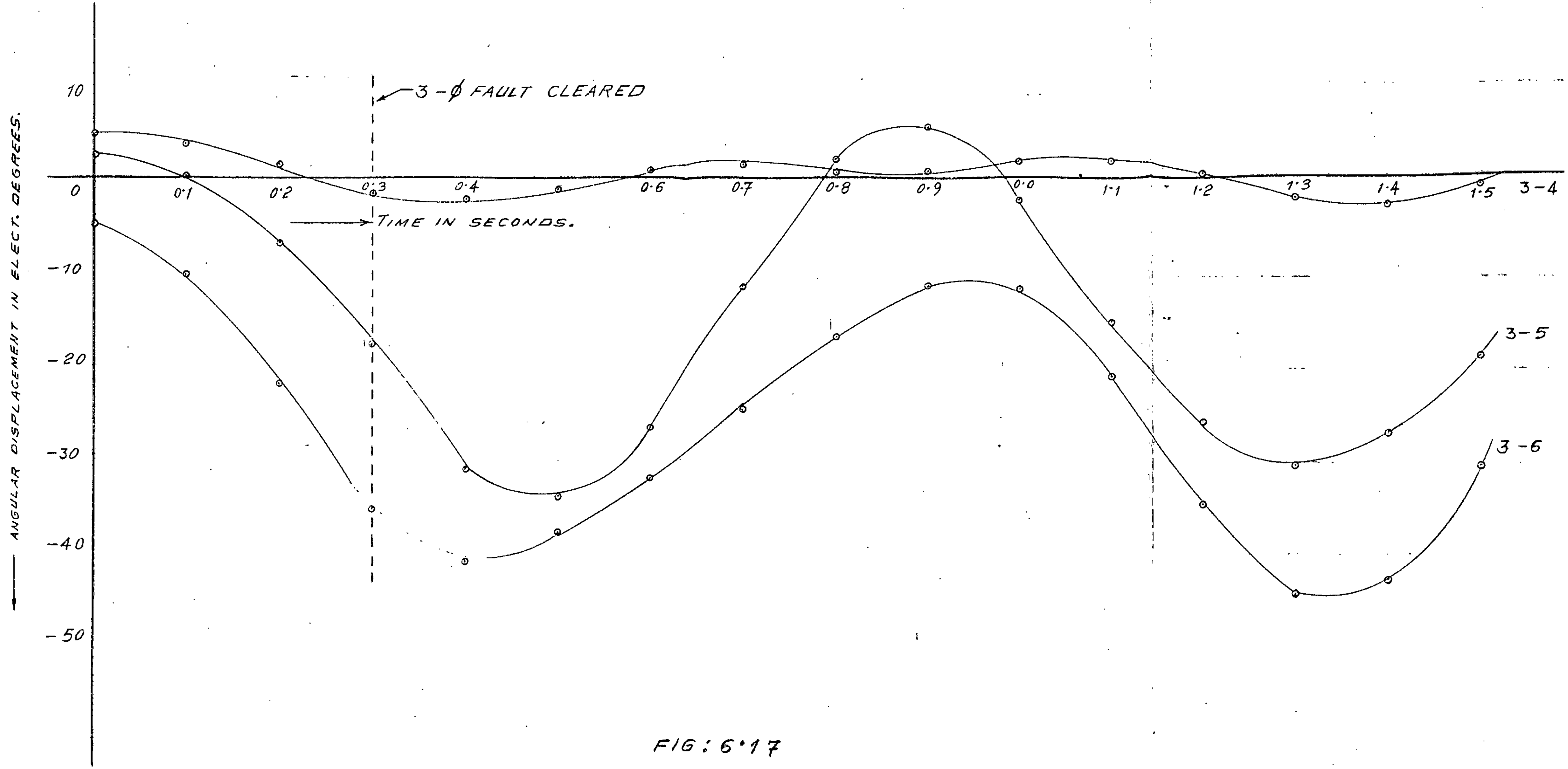


FIG: 6·17

FAULTED BUS: SHAJIBAZAR 11/132KV.

RELATIVE ANGULAR DISPLACEMENT OF MACHINES.		
3 - 4:	GHORASAL	- SHIDDIRGANJ
3 - 5:	"	- SIKALBAHA
3 - 6:	"	- KAPTAI

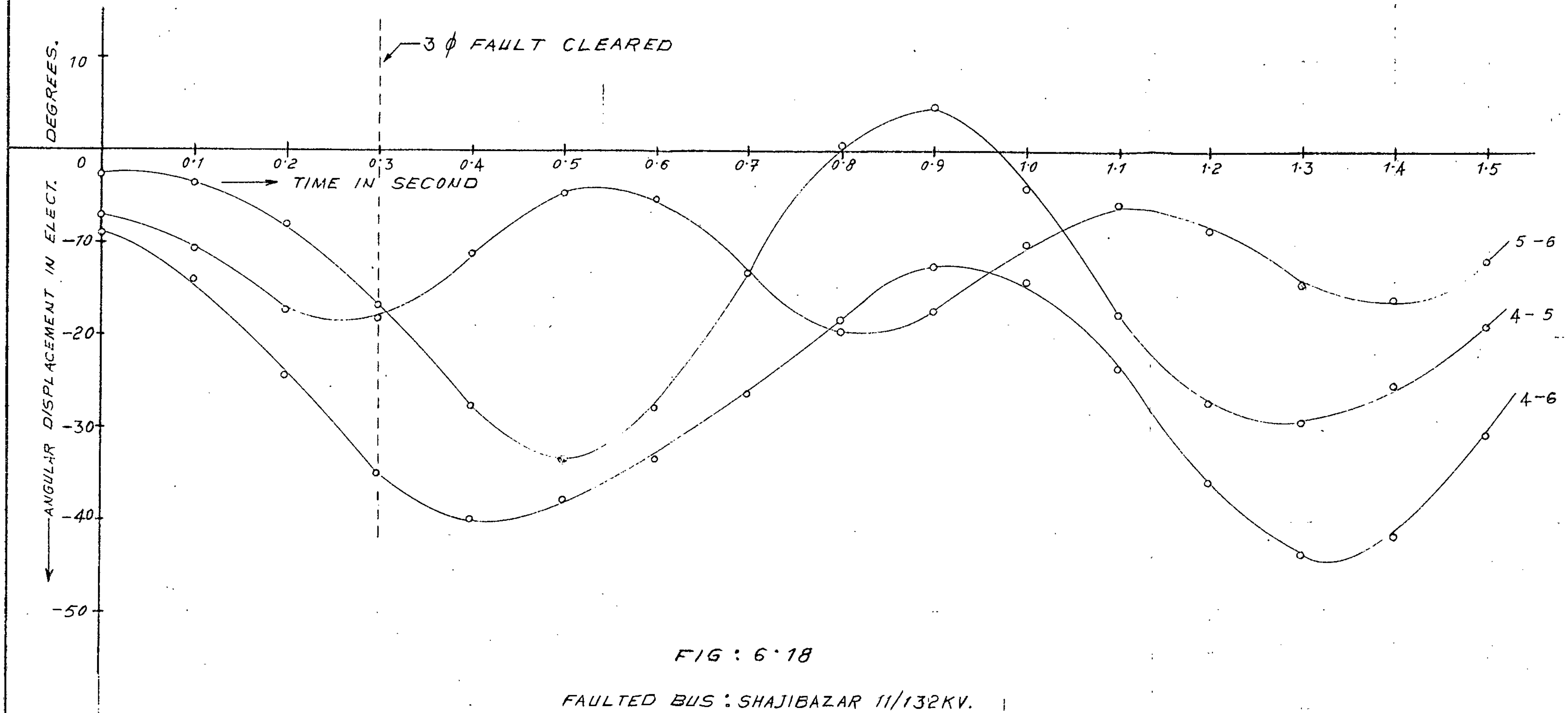


FIG : 6·18

FAULTED BUS : SHAJIBAZAR 11/132KV.

RELATIVE ANGULAR DISPLACEMENT OF MACHINES.

4 – 5 : SHIDDIRGANJ – SIKALBAHA
4 – 6 : " – KAPTAI
5 – 6 : SIKALBAHA – KAPTAI

CHAPTER - 7

CONCLUSION AND FUTURE SCOPE OF WORK

Conclusion and Future Scope of Work:

For complete analysis of a power network it requires many load-flow studies for various load conditions and also various stability studies for various conditions and for faults at different sections of the network. The main aim of this work was to develop computer programmes for such studies, so that these can be used by the country's only power authority to analyze their system from time to time. However the stability studies of Eastern grid of Bangladesh Power Development Board done in this work will be valid upto 1985 if the Eastern grid and Western grid interconnector is not constructed within this period.

Computer programmes developed are suitable for use on IBM360 computer which is available here. In this study various programmes developed were used separately for ease of understanding and computation, but all the programmes may be used together for complete solution of load-flow and stability problems automatically. Load-flow programme can be used to calculate flow conditions for any networks for any loading conditions. Calculation of machine to machine admittances can be done easily and automatically for any fault location by making suitable changes in the line data and bus numbers designating the faulted buses. The programmes for step-by-step and Runge-Kutta fourth order approximation methods can be used for the solution of swing equations for different number of machines for different fault clearing times by only changing the numbers of machines and giving proper instructions to reflect different fault clearing times.

This study was done considering fixed mechanical power input and fixed voltages behind transient reactance of the machines. The original aim of this work was also to consider variation of mechanical power due to governor action. But precise data required for such a study could not be obtained from the authorities running the power system under investigation and as a result stability study including the governor response could not be done. If variation of mechanical power input is considered the stability would definitely improve. So in future, stability study including the governor response can be done. In order to include the governor response, some modifications should be done in computer programmes used in this study for the solution of swing equation. Change of mechanical power as dictated by the characteristics of the governor should be calculated first and then the calculated mechanical power should be used for determining the accelerating power. This can be accomplished easily through another sub-routine for calculation of the new mechanical powers with time interval and feeding this value to the sub-routine already given in the computer programmes for swing-equation solution.

Future aim of study in this field should be to minimize the storage capacity and memory requirements in the computer, so that larger systems can be accomodated in the computer studies. Another important factor to be considered is the computational time. As the complete analysis requires many runs of load-flow and stability study programmes the computational cost will be less if the time of computation can be lowered.

The more complex systems can be reduced to reasonable size by the use of equivalents to represent portions of the network beyond the area of immediate interest and using such reduced system the computational time and cost can also be lowered.

Future studies can also done to include the excitation characteristics. The effect of excitation can also be taken into account through another sub-routine in the computer programmes for swing equation. Through the sub-routine the magnitude of voltages will be calculated and these changed values with time interval should be used for solving swing equation. Extensive search should be undertaken to gather exciter characteristics from the authorities running the power-system in this country.

In this study it was observed that machines at Kaptai and Sikalbaha used to oscillate almost together in the same manner with other machines of the system. So infuture studies these two machines can be grouped together and may be represented by a single equivalent machine with suitable inertia constant.

Machines of Ashuganj, Ghorasal and Shiddirganj also oscillates with smaller relative angular displacement between themselves. These machines may also be grouped together. These informations may be useful for further studies of the network in future.

REFERENCES

1. Beg Daud, Primary grid system power flow and stability studies of East Pakistan Water and Power Development Authority, Aprl. 1963.

2. Fichtner, East Pakistan Electric Net work study, April,1967.

3. Ewbank and Partners Ltd., Report on loan application for the Development of the transmission and distribution systems in Greater Dacca, Jun. 1974.

4. Evans R.D. and Bergvall C.R., Experimental Analysis of Stability and Power Limitations, A.I.E.E. transactions on power apparatus and systems, pp. 39-58, 1924.

5. Wilkins, Roy, Practical Aspects of System Stability, A.I.E.E. transactions on power apparatus and systems, pp. 41-50, 1926.

6. Evans R.D. and Wagner C.F, Further Studies of Transmission System Stability, A.I.E.E. transactions on power apparatus and systems, pp. 51-80, 1926.

7. Wood R.J.C. , Hunt L.F, and Griscom, Transient due to short circuits - A study of tests made on the southern California Edison 220 KV system, A.I.E.E. transactions on power appratus and systems, pp. 68-86, Jan., 1928.

8. Edward W. Kimbark, Improving stability by rapid reclosing of Bus-tie switches, A.I.E. E. transactions on power apparatus and systems, Vol. 64, pp. 61-64, Feb. 1945.

9. Boast W.B and Rector J.D., An Electric Analogue Method for the Direct Determination of Power System Stability Swing Curves, A.I.E.E. transactions on power apparatus and systems, vol. 70, pp. 1833-36, 1951.

10. Bekey G.A., Scholt F.W., Analyzer Interconnection for Direct Determination of Power system swing curves, A.I.E.E. transactions on power apparatus and systems, Vol. 53, pp. 238-42, Apri. 1954.

11. Norinder E.O., A Rational Method for the Step by Step calculations in power system transient stability studies, A.I.E.E. transactions on power apparatus and systems, vol. 74, pp. 1087-92, Dec. 1965.

12. Morgan W.A., Power system stability criteria for Design, A.I.E.E. transactions on power apparatus and systems, vol. 71, pp. 499-504, Jan. 1952.

13. Batler R.M., Hopkins D.L., Transient stability limits and their effects on the choice of conductor size, A.I.E.E. transactions on power apparatus and systems, vol. 73, pp. 991-1004, Aug. 1954.

14. Anderson H.C., Simmon H.O., Woodrow C.A., System stability limitations and Generator loading, A.I.E.E. transactions on power apparatus and systems, vol. 72, pp. 406-23, Jun 1953.

15. Gaggbard J.L., Rowe J.E., Digital Computation of Induction Motor transient stability, A.I.E.E. transactions on power apparatus and systems, vol. 76, pp. 970-77, Dec. 1957.

16. Jhonson D.L., Ward J.B., The solution of power system stability problems by means of digital computer, A.I.E.E. transactions on power appratus and systems, vol. 75, pp. 1321-28, Feb. 1957.

17. Brown W.T., Cloues W.J., Combination load-Flow and stability equivalent for power system representation on A.C. network Analyzers, A.I.E.E. transactions on power apparatus and systems, vol. 74, pp. 782-86, Aug. 1955.

18. Brown H.E., Shipley R.B., Coleman D. and Nied R.E., A study of stability equivalents, A.I.E.E. transactions on power apparatus and systems, pp. 200-6, Mar. 1969.

19. Stagg G.W., Gabrielle A.F., Moore D.R., Hohenstien J.F. calculation of transient stability problems using high speed digital computer, A.I.E.E. transactions on power apparatus and systems, vol. 78, pp. 566-74, Aug. 1959.

20. Dyrkacz M.S., Lewis D.G., A new Digital transient stability program, A.I.E.E. transactions on power apparatus and systems, vol. 78, pp. 913-18, Oct. 1959.

21. Dyrkacz M.S., Young C.C., Maginniss F.J., A digital transient stability program Including the effects of Regulator, Exciter and Governor Response, A.I.E.E. transactions on power appratus and systems, vol. 79, pp. 1245-56, Feb. 1961.

22. Happ H.H., Person C.E., Young C.C., Transient stability solution by an impedance matrix method, I.E.E.E. transactions on power apparatus and systems, vol. 84, pp. 1204-14, Dec. 1965,

23. Lokay H.E., and Bolger R.L., Effect of turbine-generator representation in system stability studies, I.E.E.E. transactions on power apparatus and systems, vol. PAS-84, pp. 933, Oct. 1965.

24. Gevary B.J., Schippel W.H., Transient stability of an isolated radial power network with varied load division, I.E.E.E. transactions on power apparatus and systems, pp. 964-70, Sept. 1964.

25. Jones G.A., Transient stability of a synchronous generator under conditions of Bang-Bang Excitation scheduling, I.E.E.E. transactions on power apparatus and systems, pp. 114-20, Feb. 1965.

26. Undrill J.M., Dynamic stability calculations for an arbitrary number of interconnected synchronous machines, I.E.E.E. transactions on power apparatus and systems, pp. 835-44, Mar. 1968.

27. Stagg Glenn W. and El-Abiad Ahmed H., Computer Methods in Power System Analysis (a book), pp. 260-62, McGraw-Hill Book Company, 1968.

28. Stagg Glenn W. and El-Abiad Ahmed H., Computer Methods in Power system Analysis (a book), pp. 378, McGraw-Hill Company, 1968.

29. Rindt L.J., Long R.W., Byerly R.T., Transient stability studies Part III. Improved computational techniques, A.I.E.E. transactions on power apparatus and systems, Vol. 78, Part IIIB, pp. 1973-76, Feb. 1960.

30. Lane C.M., Long R.W., Powers J.N., Transient stability studies II - Automatic Digital computation, A.I.E.E. transactions on power apparatus and systems, vol. 77, pp. 1291-96, F b. 1959.

31. Stagg Glenn W. and El-Abiad Ahmed H., Computer Methods in Power System Analysis (a book), pp. 366-69, McGraw-Hill Book Company, 1968.

32. Stagg Glenn W. and El-Abiad Ahmed H., Computer Methods in Power System Analysis (a book), pp. 401-03, McGraw-Hill Book Company, 1968.

33. Stagg Glenn W. and El-Abiad Ahmed H., Computer Methods in Power System Analysis (a book), pp. 397-402, McGraw-Hill Book Company, 1968.

34. Stagg Glenn W. and El-Abiad Ahmed H., Computer Methods in Power System Analysis (a book), pp. 384-86, McGraw-Hill Book Company, 1968.

APPENDIX - A

COMPUTER PROGRAMME FOR LOAD FLOW PROBLEM

```
C     ------------------------COMPUTER PROGRAMME NO. 1.000-------------------
C     --------/-----------------------------------------------/-----------

C     LOAD FLOW STUDY OF TEST SYSTEM
C     BUS-1 SHAHJIBAZAR WHICH IS SWING BUS
C     BUS-2 ASHUGANJ  BUS-3 GHORASAL  BUS-4 SHIDDIRGANJ  BUS-5 ULLON
C     BUS-6 TONGI  BUS-7 MIRPUR  BUS-8 POSTAGOLA  BUS-9 COMILLA
C     BUS-10 FENI  BUS-11 MADANHAT  BUS-12 SIKALBAHA
C     BUS-13 CHANDRAGHONA  BUS-14 KAPTAI
C     AR=RESISTANCE MATRIX
C     AI=REACTANCE MATRIX
C     BI=LINE CHARGING MATRIX
C     WG=MW GENARATION IN P.U.
C     VG=MVAR GENARATION IN P.U.
C     WL=P.U. REAL LOAD IN MW
C     VL=P.U. IM LOAD IN MVAR
C     ER=P.U. REAL BUS VOLTAGE
C     EI=P.U. IM BUS VOLTAGE
C     C=ACCELERATION FACTOR
      DIMENSION AR(23,23),AI(23,23),BI(23,23),LINE(23,23),WG(23),VG(23),
     1WL(23),VL(23),ER(23),EI(23)
      DIMENSION ADR(23,23),ADI(23,23),AZR(23,23),AZI(23,23),AMI(23,23),
     1BZR(23,23),BZI(23,23),P(23,23),Q(23,23)
      DIMENSION ABR(23),ABI(23),PN(23),QN(23),RAM(23),ARL(23),AIL(23),
     1STER(23),STEI(23),CORR(23),CORI(23),E(23),ANGLE(23),C(5)
      READ(1,112)N,TOLER,ITMAX
  112 FORMAT(I4,F10.5,I6)
      M=1
      READ(1,122)(C(I),I=1,5)
  122 FORMAT(5F6.2)
      READ(1,114)((AR(I,J),J=1,14),I=1,N)
      READ(1,114)((AI(I,J),J=1,14),I=1,N)
      READ(1,114)((BI(I,J),J=1,14),I=1,N)
  114 FORMAT(7F10.5)
      READ(1,115)((LINE(I,J),J=1,N),I=1,N)
  115 FORMAT(14I4)
      READ(1,116)((WG(I),VG(I),WL(I),VL(I)),I=1,N)
  116 FORMAT(2(4F10.4))
      DO  120  I=1,N
      DO  120  J=1,N
      IF(LINE(I,J)) 430,431,430
  430 ADR(I,J)=AR(I,J)/(AR(I,J)**2+AI(I,J)**2)
       ADI(I,J)=-AI(I,J)/(AR(I,J)**2+AI(I,J)**2)
      GO  TO  120
  431 ADR(I,J)=AR(I,J)
      ADI(I,J)=AI(I,J)
  120 CONTINUE
      DO  450  I=1,N
      ABR(I)=0.0
```

```
      DO   455   J=1,N
      ABR(I)=ABR(I)+ADR(I,J)
  455 CONTINUE
  450 CONTINUE
      DO   460   I=1,N
      DO   460   J=1,N
      AMI(I,J)=BI(I,J)+ADI(I,J)
  460 CONTINUE
      DO   465   I=1,N
      ABI(I)=0.0
      DO   470   J=1,N
      ABI(I)=ABI(I)+AMI(I,J)
  470 CONTINUE
  465 CONTINUE
      DO   475   I=1,N
      DO   475   J=1,N
      IF(I-J) 480,481,480
  480 AZR(I,J)=-ADR(I,J)
      AZI(I,J)=-ADI(I,J)
      GO   TO   475
  481 AZR(I,J)=ABR(I)
      AZI(I,J)=ABI(I)
  475 CONTINUE
      DO   490   I=1,N
      PN(I)=(WG(I)-WL(I))
  490 QN(I)=(VG(I)-VL(I))
      DO   495   I=1,N
  495 RAM(I)=(AZR(I,I)**2+AZI(I,I)**2)
      DO   500   I=1,N
      ARL(I)=(PN(I)*AZR(I,I)-QN(I)*AZI(I,I))/RAM(I)
  500 AIL(I)=(-PN(I)*AZI(I,I)-QN(I)*AZR(I,I))/RAM(I)
      DO   502   I=1,N
      DO   502   J=1,N
      IF(LINE(I,J))   505,503,505
  503 BZR(I,J)=0.0
      BZI(I,J)=0.0
      GO   TO   502
  505 BZR(I,J)=(AZR(I,J)*AZR(I,I)+AZI(I,J)*AZI(I,I))/RAM(I)
      BZI(I,J)=(AZI(I,J)*AZR(I,I)-AZR(I,J)*AZI(I,I))/RAM(I)
  502 CONTINUE
      DO   510   I=1,N
      ER(I)=1.0
  510 EI(I)=0.0
      ER(1)=1.03
      DO   606   K=1,5
  515 ITER=0
  516 ITER=ITER+1
      DO   520   I=2,N
      STER(I)=0.0
      STEI(I)=0.0
      DO   525   J=1,N
      STER(I)=STER(I)+BZR(I,J)*ER(J)-BZI(I,J)*EI(J)
      STEI(I)=STEI(I)+BZI(I,J)*ER(J)+BZR(I,J)*EI(J)
  525 CONTINUE
```

```
      DIVIDE=ER(I)**2+EI(I)**2
      EER=(ARL(I)*ER(I)-AIL(I)*EI(I))/DIVIDE-STER(I)
      EEI=(AIL(I)*ER(I)+ARL(I)*EI(I))/DIVIDE-STEI(I)
  530 CORR(I)=(EER-ER(I))
      CORI(I)=(EEI-EI(I))
  532 ER(I)=ER(I)+CORR(I)*C(K)
      EI(I)=EI(I)+CORI(I)*C(K)
  520 CONTINUE
      IF(ITER-ITMAX) 540,542,542
  540 DO  550  I=1,N
      IF(I-M) 535,550,535
  535 IF(ABS(CORR(I))-TOLER) 536,538,538
  536 IF(ABS(CORI(I))-TOLER) 537,538,538
  537 IF(I-N)  550,555,555
  550 CONTINUE
  538 GO  TO  516
  555 WRITE(3,250)
  250 FORMAT(1H1)
      WRITE(3,558)ITER
  558 FORMAT(///20X,5HITER=,I4)
      WRITE(3,620)
  620 FORMAT(/60H                         REAL VOLTAGE    IMG VOLTAGE    BUS
     1 CODE/)
      DO  565  I=1,N
  564 WRITE(3,560)(ER(I),EI(I),I)
  560 FORMAT(24X,F10.7,5X,F10.7,5X,I4)
  565 CONTINUE
      WRITE(3,621)
  621 FORMAT(/45H                         CALCULATION OF LINE FLOWS)
      WRITE(3,622)
  622 FORMAT(/56H                         REAL POWER    IMG  POWER    BUS COD
     1E/)
      DO  570  I=1,N
      DO  573  J=1,N
      IF(LINE(I,J)) 572,575,572
  572 SUR=ER(I)-ER(J)
      SUI=EI(I)-EI(J)
      SRU=ER(I)*SUR+EI(I)*SUI
      SIU=ER(I)*SUI-EI(I)*SUR
      P(I,J)=SRU*ADR(I,J)-SIU*ADI(I,J)
      Q(I,J)=-((SIU*ADR(I,J)+SRU*ADI(I,J))+(ER(I)**2+EI(I)**2)*BI(I,J))
      WRITE(3,590)(P(I,J),Q(I,J),I,J)
  590 FORMAT(20X,F10.6,4X,F10.4,4X,2I3)
  575 GO TO 573
  573 CONTINUE
  570 CONTINUE
      DO  580  I=1,N
      E(I)=SQRT(ER(I)**2+EI(I)**2)
      ANGLE(I)=ATAN(EI(I)/ER(I))*180.0/3.14159
  580 CONTINUE
      WRITE(3,623)
  623 FORMAT(1H1,///////////////58H                         CALCULATION OF
     1BUS VOLTAGE AND ANGLE/)
      WRITE(3,600)(E(I),ANGLE(I),I=1,N)
```

```
  600 FORMAT(7(F10.6,F6.2))
      GO  TO  610
  542 WRITE(3,605)
  605 FORMAT(30X,30HGAUSS SEIDEL DOES NOT CONVERGE)
  606 CONTINUE
  610 STOP
      END
```

APPENDIX - B

COMPUTER PROGRAMME FOR CALCULATION OF VOLTAGES BEHIND TRANSIENT REACTANCE OF MACHINES

```
C      THIS PROGRAMME WILL CALCULATE VOLTAGE BACK CF TRANSIENT
C      REACTANCE OF MACHINE
C      ER  REAL PART OF TERMINAL VOLTAGE
C      EI  IM  PART OF TERMINAL VOLTAGE
C      X  REACTANCE OF MACHINE
C      WG  WATT GENERATION
C      VG  VAR  GENERATION
C      ETR AND ETI ARE REAL AND IM PART OF VOLTAGE BACK CF TRANSIENT
C      REACTANCE OF MACHINE
C      E   VOLTAGE BACK OF TRANSIENT REACTANCE OF MACHINE
C      DELTA  INTERNAL VOLTAGE ANGLE
       DIMENSION ER(6),EI(6),ETR(6),X(6),WG(6),VG(6),E(6),DELTA(6),ETI(6)
       N=6
       READ(1,100)(ER(I),EI(I),I=1,N)
       READ(1,1C1)(X(I),I=1,N)
       READ(1,102)(WG(I),VG(I),I=1,N)
   1C0 FORMAT(3(2F10.6))
   101 FORMAT(6F10.6)
   102 FORMAT(3(2F10.5))
       DO  104  I=1,N
       ETR(I)=ER(I)+((VG(I)*ER(I)-WG(I)*EI(I))*X(I))/(ER(I)**2+EI(I)**2)
   104 ETI(I)=EI(I)+((WG(I)*ER(I)+VG(I)*EI(I))*X(I))/(ER(I)**2+EI(I)**2)
       DO  1C6  I=1,N
   106 E(I)=SQRT(ETR(I)**2+ETI(I)**2)
       WRITE(3,125)
   125 FORMAT(1H1)
       WRITE(3,110)
   110 FORMAT(///////////////80H                      COMPUTATION OF VOLTAGE
      1BACK OF TRANSIENT REACTANCE OF MACHINE)
       WRITE(3,111)
   111 FORMAT(////91H              SHAHJIBAZAR   AHSHU   GANJ   GHORA   SAL
      1SHIDDIRGANJ   SIKAL   BAHA    KAPTAIHYDRO)
       WRITE(3,112)(E(I),I=1,N)
   112 FORMAT(//8H VOLTAGE,6F14.5)
       DO  108  I=1,N
   108 DELTA(I)=ATAN(ETI(I)/ETR(I))*180./3.141592
       WRITE(3,115)(DELTA(I),I=1,N)
   115 FORMAT(7H  ANGLE,6F14.5)
       STOP
       END
```

APPENDIX - C

COMPUTER PROGRAMME FOR CALCULATION OF MACHINE TO MACHINE ADMITTANCES

```
C     PROGRAMME FOR CALCULATION OF MACHINE TO MACHINE ADMITTANCE
C       FOR DIFFERENT CIRCUIT CONDITION
C       BUS-1 BUS BACK OF TRANSIENT REACTANCE OF SHAHJIBAZAR GENERATOR
C       BUS-2 BUS BACK OF TRANSIENT REACTANCE OF ASHUGANJ GENERATOR
C       BUS-3 BUS BACK OF TRANSIENT REACTANCE OF GHORASAL GENERATOR
C       BUS-4 BUS BACK OF TRANSIENT REACTANCE OF SHIDDIRGANJ GENERATOR
C       BUS-5 BUS BACK OF TRANSIENT REACTANCE OF SIKALBAHA GENERATOR
C       BUS-6 BUS BACK OF TRANSIENT REACTANCE OF KAPTAI GENERATOR
C       BUS-7 ULLON 132KV BUS   BUS-8 TONGI 132KV BUS
C       BUS-9 SHAHJIBAZAR 11KV BUS   BUS-10 SHAHJIBAZAR 132KV BUS
C       BUS-11 ASHUGANJ 11KV BUS   BUS-12 ASHUGANJ 132KV BUS
C       BUS-13 GHORASAL 132KV BUS   BUS BUS-14 GHORASAL 11KV BUS
C       BUS-15 SHIDDIRGANJ 132KV BUS   BUS-16 SHIDDIRGANJ 11KV BUS
C       BUS-17 MIRPUR 132KV BUS   BUS-18 POSTAGOLA 132KV BUS
C       BUS-19 COMILLA 132KV BUS   BUS-20 FENI 132KV BUS
C       BUS-21 MADANHAT 132KV BUS   BUS-22 SIKALBAHA 132KV BUS
C       BUS-23 SIKALBAHA 11KV BUS   BUS-24 CHANDRAGHONA 132KV BUS
C       BUS-25 KAPTAI 132KV BUS   BUS-26 KAPTAI 11KV BUS
C       ZR  RESISTANCE MATRIX
C       ZI  REACTANCE MATRIX
C       AMI  ADMITTANCE TO GROUND MATRIX
C       CX AND CZ ARE REAL AND IM PART OF LOAD EQUIVALENT ADMITTANCE
        DIMENSION AR(26,26),AI(26,26),AMI(26),ABR(26),ABI(26),
       1BR(2,6),BI(2,6),CR(6,2),CI(6,2),DR(6,6),DI(6,6),XR(6,6),XI(6,6),
       1BZR(6,6),DEL(6,6),CZR(6,6),DELTA(6,6),AZR(26,26),AZI(26,26),
       1SZR(8,8),SZI(8,8),LINE(26,26),ZR(26,26),ZI(26,26),CX(26),CZ(26)
        DIMENSION UR(2,2),UI(2,2)
        READ(1,100)N
    100 FORMAT(I4)
        READ(1,50)((ZR(I,J),J=1,24),I=1,N)
        READ(1,50)((ZI(I,J),J=1,24),I=1,N)
        READ(1,51)((ZR(I,J),J=25,N),I=1,N)
        READ(1,51)((ZI(I,J),J=25,N),I=1,N)
     50 FORMAT(8F8.4)
     51 FORMAT(2F8.4)
        READ(1,53)((LINE(I,J),J=1,N),I=1,N)
     53 FORMAT(26I3)
        READ(1,40)(AMI(I),I=1,N)
     40 FORMAT(8F10.5)
        READ(1,52)(CX(I),I=7,N)
        READ(1,52)(CZ(I),I=7,N)
     52 FORMAT(10F8.4)
        DO  60  I=1,N
        DO  60  J=1,N
        IF(LINE(I,J))55,56,55
     55 AR(I,J)=ZR(I,J)/(ZR(I,J)**2+ZI(I,J)**2)
        AI(I,J)=-ZI(I,J)/(ZR(I,J)**2+ZI(I,J)**2)
        GO  TO  60
     56 AR(I,J)=0.0
        AI(I,J)=0.0
     60 CONTINUE
     64 FORMAT(13F10.5)
        DO  106  I=1,N
        ABR(I)=0.0
```

```
          ABI(I)=0.0
          DO   106  J=1,N
          ABR(I)=ABR(I)+AR(I,J)
          ABI(I)=ABI(I)+AI(I,J)
      106 CONTINUE
          DO   110  I=1,N
          DO   110  J=1,N
          IF(I-J)107,108,107
      107 AZR(I,J)=-AR(I,J)
          AZI(I,J)=-AI(I,J)
          GO   TO   110
      108 AZR(I,J)=ABR(I)
          AZI(I,J)=ABI(I)+AMI(I)
      110 CONTINUE
          DO   112  I=7,N
          AZR(I,I)=AZR(I,I)+CX(I)
      112 AZI(I,I)=AZI(I,I)+CZ(I)
          DO   113  M=9,N
          K=35-M
      113 CALL  DETRED(K,AZR,AZI)
          DO   85   I=1,8
          DO   85   J=1,8
          SZR(I,J)=AZR(I,J)
       85 SZI(I,J)=AZI(I,J)
          DO   115  J=1,6
          SZR(8,J)=0.0
      115 SZI(8,J)=0.0
          DO   215  I=1,2
          DO   215  J=1,2
          UR(1,J)=0.0
      215 UI(1,J)=0.0
          UR(1,1)=-SZR(7,7)/(SZR(7,7)**2+SZI(7,7)**2)
          UI(1,1)=SZI(7,7)/(SZR(7,7)**2+SZI(7,7)**2)
          DO   116  I=7,8
          DO   116  J=1,6
          L=I-6
          BR(L,J)=SZR(I,J)
      116 BI(L,J)=SZI(I,J)
          DO   117  I=1,6
          DO   117  J=7,8
          M=J-6
          CR(I,M)=SZR(I,J)
      117 CI(I,M)=SZI(I,J)
          DO   118  I=1,2
          DO   118  J=1,6
          DR(I,J)=0.0
          DI(I,J)=0.0
          DO   118  K=1,2
          DR(I,J)=DR(I,J)+UR(I,K)*BR(K,J)-UI(I,K)*BI(K,J)
      118 DI(I,J)=DI(I,J)+UR(I,K)*BI(K,J)+UI(I,K)*BR(K,J)
          DO   119  I=1,6
          DO   119 J=1,6
          XR(I,J)=0.0
          XI(I,J)=0.0
```

```
      DO   119  K=1,2
      XR(I,J)=XR(I,J)+CR(I,K)*DR(K,J)-CI(I,K)*DI(K,J)
  119 XI(I,J)=XI(I,J)+CI(I,K)*DR(K,J)+CR(I,K)*DI(K,J)
      DO   120  I=1,6
      DO   120  J=1,6
      SZR(I,J)=SZR(I,J)+XR(I,J)
  120 SZI(I,J)=SZI(I,J)+XI(I,J)
  250 FORMAT(1H1)
      WRITE(3,250)
      WRITE(3,131)
  131 FORMAT(///48H        MACHINE TO MACHINE ADMITTANCE DURING FAULT)
      WRITE(3,133)
  133 FORMAT(///100H    REAL      IMG      REAL      IMG      REAL      IMG
     1REAL      IMG      REAL      IMG      REAL      IMG     //)
      WRITE(3,121)((SZR(I,J),SZI(I,J),J=1,6),I=1,6)
  121 FORMAT(6(2F8.3))
      DO   122  I=1,6
      DO   122  J=1,6
  122 BZR(I,J)=SQRT(SZR(I,J)**2+SZI(I,J)**2)
      WRITE(3,134)
  134 FORMAT(//62H                         MAGNITUDE OF MACHINE TO MACHINE AD
     1MITTANCE/)
      WRITE(3,135)((BZR(I,J),J=1,6),I=1,6)
  135 FORMAT(20X,6F10.6)
      DO   123  I=7,8
      DO   123  J=7,8
      IF(I-J)130,132,130
  130 AZR(I,J)=AZR(I,J)+AR(7,8)
      AZI(I,J)=AZI(I,J)+AI(7,8)
      GO   TO   123
  132 AZR(I,J)=AZR(I,J)-AR(7,8)
      AZI(I,J)=AZI(I,J)-AI(7,8)
  123 CONTINUE
      AZI(7,7)=AZI(7,7)-0.0046
      AZI(8,8)=AZI(8,8)-0.0046
      DO   124  M=7,8
      K=15-M
  124 CALL DETRED(K,AZR,AZI)
      WRITE(3,136)
  136 FORMAT(///49H        MACHINE TO MACHINE ADMITTANCE FAULT CLERED/)
      WRITE(3,133)
      WRITE(3,121)((AZR(I,J),AZI(I,J),J=1,6),I=1,6)
      DO   126  I=1,6
      DO   126  J=1,6
  126 CZR(I,J)=SQRT(AZR(I,J)**2+AZI(I,J)**2)
      WRITE(3,134)
      WRITE(3,135)((CZR(I,J),J=1,6),I=1,6)
      STOP
      END
```

```
      SUBROUTINE DETRED(K,YZR,YZI)
      DIMENSION RP(26),RQ(26),YZR(26,26),YZI(26,26)
      L=K-1
      RA=(YZR(K,K)**2+YZI(K,K)**2)
      I=1
  110 DO  120  J=I,L
      RM=(YZR(J,K)*YZR(K,K)+YZI(J,K)*YZI(K,K))/RA
      RN=(YZI(J,K)*YZR(K,K)-YZR(J,K)*YZI(K,K))/RA
      RP(J)=(YZR(K,I)*RM-YZI(K,I)*RN)
      RQ(J)=(YZR(K,I)*RN+YZI(K,I)*RM)
      YZR(I,J)=YZR(I,J)-RP(J)
      YZI(I,J)=YZI(I,J)-RQ(J)
      IF(I-J) 115,120,115
  115 YZR(J,I)=YZR(I,J)
      YZI(J,I)=YZI(I,J)
  120 CONTINUE
      IF(I-L)122,123,123
  122 I=I+1
      GO  TO  110
  123 RETURN
      END
```

APPENDIX - D

COMPUTER PROGRAMMES FOR SOLUTION OF SWING

REQUATION BY

1. Step by Step Method
2. Runge-Kutta 4th order approximation method.

```
C      THIS PROGRAMME WILL SOLVE SWING EQUATION BY STEP BY STEP METHOD
C      BZR  MACHINE TO MACHINE ADMITTANCE DURING FAULT
C      CZR  MACHINE TO MACHINE ADMITTANCE AFTER FAULT CLEARED
C      DEL  ANGLE OF MACHINE TO MACHINE ADMITTANCE DURING FAULT
C      DELTA  ANGLE OF MACHINE TO MACHINE ADMITTANCE AFTER FAULT CLEARED
C      H    INERTIA CONSTANT
C      THETA MACHINE ANGLE IN ELECTRICAL DEGREE
C      Y  INERTIA CONSTANT IN MEGAJOULE-SECONDS PER ELECTRICAL DEGREE
C      DT  INCREMENT OF TIME IN SECOND
C      E  VOLTAGE BEHIND TRANSIENT REACTANCE OF MACHINE
C      PR  INITIAL OUTPUT OF MACHINE
C      TA  ACCELERATING POWER OF MACHINE
C      DTH  CHANGE OF MACHINE ANGLE
C      T    TIME IN SECOND
       DIMENSION BZR(6,6),CZR(6,6),DEL(6,6),DELTA(6,6),H(6),THETA(6),Y(6)
      1,DTH(6),QR(6),ST(6)
       COMMON E(6),PR(6)
       READ(1,102)N
   102 FORMAT(I2)
       READ(1,101)((BZR(I,J),J=1,N),I=1,N)
       READ(1,101)((CZR(I,J),J=1,N),I=1,N)
   101 FORMAT(6F10.4)
       READ(1,103)(E(I),I=1,N)
       READ(1,104)(PR(I),I=1,N)
       READ(1,105)(THETA(I),I=1,N)
       READ(1,106)((DEL(I,J),J=1,N),I=1,N)
       READ(1,106)((DELTA(I,J),J=1,N),I=1,N)
   103 FORMAT(6F8.4)
   104 FORMAT(6F8.4)
   105 FORMAT(6F10.4)
   106 FORMAT(6F10.4)
       READ(1,107)(H(I),I=1,N)
   107 FORMAT(6F10.5)
       DT=0.05
       T=0.0
       DO  100  I=1,N
   100 Y(I)=(180.0*50.0/H(I))*(DT**2)
       WRITE(3,222)
   222 FORMAT(1H1)
       WRITE(3,112)
   112 FORMAT(///67H                                         COMPUTATION OF  INTERNAL
      1 MACHINE ANGLE)
       WRITE(3,116)
   116 FORMAT(///100H            SHAHJIBAZAR   AHSHU  GANJ    GHORA    SAL
      1SHIDDIRGANJ    SIKAL   BAHA    KAPTAIHYDRO       TIME/)
       DO  114  I=1,N
   114 DTH(I)=0.0
       DO  115  I=1,N
       CALL POWER(I,THETA,DEL,BZR,TA)
   115 QR(I)=Y(I)*TA/2.0
   118 T=T+DT
       DO  120  I=1,N
   120 DTH(I)=DTH(I)+QR(I)
       DO  125  I=1,N
```

```
125 THETA(I)=THETA(I)+DTH(I)
    WRITE(3,127)(THETA(I),I=1,N),T
127 FORMAT(7X,6F14.5,5X,F4.2)
    IF(T-0.10)130,135,135
130 DO   132   I=1,N
    CALL  POWER(I,THETA,DEL,BZR,TA)
132 QR(I)=Y(I)*TA
    GO   TO   118
135 DO   140   I=1,N
    CALL  POWER(I,THETA,DEL,BZR,TA)
140 ST(I)=TA
    DO   142   I=1,N
    CALL  POWER(I,THETA,DELTA,CZR,TA)
142 QR(I)=Y(I)*(ST(I)+TA)/2.0
144 T=T+DT
    DO   145   I=1,N
145 DTH(I)=DTH(I)+QR(I)
    DO   150   I=1,N
150 THETA(I)=THETA(I)+DTH(I)
    WRITE(3,127)(THETA(I),I=1,N),T
    IF(T-1.45)155,160,160
155 DO   156   I=1,N
    CALL  POWER(I,THETA,DELTA,CZR,TA)
156 QR(I)=Y(I)*TA
    GO   TO   144
160 STOP
    END
```

```
      SUBROUTINE POWER(I,RAMA,CETA,XZR,XA)
      DIMENSION RAMA(6),CETA(6,6),GAMA(6,6),BETA(6,6),TR(6),
     1XZR(6,6),Z(6,6)
      COMMON E(6),PR(6)
      N=6
      DO  110  J=1,N
      IF(I-J)111,112,111
  111 GAMA(I,J)=RAMA(I)-RAMA(J)
      BETA(I,J)=CETA(I,J)-GAMA(I,J)
      GO  TO  110
  112 BETA(I,J)=CETA(I,J)
  110 CONTINUE
      C=3.14159/180.
      DO  116  J=1,N
  116 Z(I,J)=BETA(I,J)*C
      TR(I)=0.0
      DO  114  J=1,N
  114 TR(I)=TR(I)+E(I)*E(J)*XZR(I,J)*COS(Z(I,J))
      XA=PR(I)-TR(I)
      RETURN
      END
```

```
C     THIS PROGRAMME WILL SOLVE SWING EQUATION BY RUNGE-KUTTA FOURTH
C     ORDER APPROXIMATION FORMULA
C     BZR  MACHINE TO MACHINE ADMITTANCE DURING FAULT
C     CZR  MACHINE TO MACHINE ADMITTANCE AFTER FAULT CLEARED
C     DEL  ANGLE OF MACHINE TO MACHINE ADMITTANCE DURING FAULT
C     DELTA  ANGLE OF MACHINE TO MACHINE ADMITTANCE AFTER FAULT CLEARED
C     H   INERTIA CONSTANT
C     THETA MACHINE ANGLE IN ELECTRICAL DEGREE
C     Y  INERTIA CONSTANT IN MEGAJOULE-SECONDS PER ELECTRICAL DEGREE
C     DT  INCREMENT OF TIME IN SECOND
C     E  VOLTAGE BEHIND TRANSIENT REACTANCE OF MACHINE
C     PR  INITIAL OUTPUT OF MACHINE
C     TA  ACCELERATING POWER OF MACHINE
C     T   TIME IN SECOND
C     W  ANGULAR SPEED OF MACHINE
C     BT  CHANGES IN THE INTERNAL VOLTAGE ANGLES
C     CT  CHANGES IN THE MACHINE SPEED
C     R,S AND C,S ARE THE CHANGES IN INTERNAL VOLTAGE ANGLE AND SPEED
C     OF MACHINE RESPECTIVELY
      DIMENSIONBZR(6,6),CZR(6,6),DEL(6,6),DELTA(6,6),H(6),THETA(6),W(6)
     1,CT(6),BT(6),R1(6),R2(6),R3(6),R4(6),C1(6),C2(6),C3(6),C4(6),
     1PHI(6),Y(6)
      COMMON E(6),PR(6)
      READ(1,102)N
  102 FORMAT(I2)
      READ(1,101)((BZR(I,J),J=1,N),I=1,N)
      READ(1,101)((CZR(I,J),J=1,N),I=1,N)
  101 FORMAT(6F10.4)
      READ(1,103)(E(I),I=1,N)
      READ(1,104)(PR(I),I=1,N)
      READ(1,105)(THETA(I),I=1,N)
      READ(1,106)((DEL(I,J),J=1,N),I=1,N)
      READ(1,106)((DELTA(I,J),J=1,N),I=1,N)
  103 FORMAT(6F8.4)
  104 FORMAT(6F8.4)
  105 FORMAT(6F10.4)
  106 FORMAT(6F10.4)
      READ(1,107)(H(I),I=1,N)
  107 FORMAT(6F10.5)
      DT=0.1
      X=180./3.14159
      P=2.0*3.14159*50.0
      DO   110   I=1,N
  110 Y(I)=P/(2.0*H(I))
      DO   120   I=1,N
  120 W(I)=P
      WRITE(3,222)
  222 FORMAT(1H1)
      WRITE(3,201)
  201 FORMAT(////67H                          COMPUTATION OF INTERNAL MACHINE
     1ANGLE AND SPEED)
      WRITE(3,202)
  202 FORMAT(///100H              SHAHJIBAZAR   AHSHU   GANJ   GHORA   SAL
     1SHIDDIRGANJ   SIKAL  BAHA   KAPTAIHYDRO     TIME/)
```

```
          T=0.0
      124 T=T+DT
          DO  125  I=1,N
          C1(I)=(W(I)-P)*DT
          IF(T-0.2)122,123,123
      122 CALL POWER(I,THETA,DEL,BZR,TA)
          GO  TO  125
      123 CALL POWER(I,THETA,DELTA,CZR,TA)
      125 R1(I)=Y(I)*TA*DT
          DO  126  I=1,N
          ST=X*C1(I)/2.0
      126 PHI(I)=THETA(I)+ST
          DO  130  I=1,N
          C2(I)=((W(I)+R1(I)/2.0)-P)*DT
          IF(T-0.2)132,133,133
      132 CALL POWER(I,PHI,DEL,BZR,TA)
          GO  TO  130
      133 CALL POWER(I,PHI,DELTA,CZR,TA)
      130 R2(I)=Y(I)*TA*DT
          DO  135  I=1,N
          ST=X*C2(I)/2.0
      135 PHI(I)=THETA(I)+ST
          DO  140  I=1,N
          C3(I)=((W(I)+R2(I)/2.0)-P)*DT
          IF(T-0.2)136,137,137
      136 CALL POWER(I,PHI,DEL,BZR,TA)
          GO  TO  140
      137 CALL POWER(I,PHI,DELTA,CZR,TA)
      140 R3(I)=Y(I)*TA*DT
          DO  142  I=1,N
          ST=X*C3(I)
      142 PHI(I)=THETA(I)+ST
          DO  145  I=1,N
          C4(I)=((W(I)+R3(I))-P)*DT
          IF(T-0.2)143,144,144
      143 CALL POWER(I,PHI,DEL,BZR,TA)
          GO  TO  145
      144 CALL POWER(I,PHI,DELTA,CZR,TA)
      145 R4(I)=Y(I)*TA*DT
          DO  150  I=1,N
          BT(I)=(C1(I)+2.0*C2(I)+2.0*C3(I)+C4(I))/6.0*X
      150 CT(I)=(R1(I)+2.0*R2(I)+2.0*R3(I)+R4(I))/6.0
          DO  152  I=1,N
          THETA(I)=THETA(I)+BT(I)
      152 W(I)=W(I)+CT(I)
          WRITE(3,154) (THETA(I),I=1,N),T
      154 FORMAT(7H  ANGLE,6F14.5,5X,F4.2)
          WRITE(3,155)(W(I),I=1,N)
      155 FORMAT(7H  SPEED,6F14.5)
          IF(T-0.9)124,160,160
      160 STOP
          END
```

```
      SUBROUTINE POWER(I,RAMA,CETA,XZR,XA)
      DIMENSION RAMA(6),CETA(6,6),GAMA(6,6),BETA(6,6),TR(6),
     1XZR(6,6),Z(6,6)
      COMMON E(6),PR(6)
      N=6
      DO 110 J=1,N
      IF(I-J)111,112,111
  111 GAMA(I,J)=RAMA(I)-RAMA(J)
      BETA(I,J)=CETA(I,J)-GAMA(I,J)
      GO TO 110
  112 BETA(I,J)=CETA(I,J)
  110 CONTINUE
      C=3.14159/180.0
      DO 116 J=1,N
  116 Z(I,J)=BETA(I,J)*C
      TR(I)=0.0
      DO 114 J=1,N
  114 TR(I)=TR(I)+E(I)*E(J)*XZR(I,J)*COS(Z(I,J))
      XA=PR(I)-TR(I)
      RETURN
      END
```