TSRK: A DIGITAL COMPUTER PROGRAM FOR STUDYING POWER SYSTEM TRANSIENT STABILITY CHARACTERISTICS

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PREFACE

The objective of the project described in this report was to develop digital computer programs which will enable the students and faculty in the Department of Electrical Engineering at KSU to make meaningful studies of the transient stability of electrical power systems.

I gratefully acknowledge the patient help and suggestions received from professor Floyd W. Harris, my academic advisor. I would also like to thank the Department of Electrical Engineering in giving me this chance to continue my advanced studies.

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INTRODUCTION

1.1 Project Background

The objective of the project described in this report was to develop programs that will enable the students and faculty of the Department of Electrical Engineering at KSU to make meaningful studies of the dynamic behavior of electrical power systems in the first 2 or 3 seconds after the occurrence of a major disturbance, such as a three-phase fault, at a bus and subsequent clearing of that fault. The resulting set of programs are dimensioned to handle electrical power systems containing up to 50 significant buses, 150 transmission lines and transformers, and 20 synchronous machines. All component and system modeling is designed to be consistent with the observation interval of 2 or 3 seconds and to give the user as much flexibility as is judged to be practical. The models used account for the action of the excitation and speed governor control loops. Although it is recognized that these control loops are relatively slow and may not affect the response significantly in this time interval, these control loops were included in anticipation of future extension of the program to larger observation intervals.

Stability is defined in "American Standard Definition of Electrical Terms" published by the American Institute of Electrical Engineering [1], as follows:

> Stability, when used with reference to a power system, is that attribute of the system, which enables it to develop restoring forces between the elements thereof, equal to or greater than the disturbing forces so as to restore a state of equilibrium between the elements.

In the steady state condition, the mechanical input of a machine is equal to its electrical output, the machine speed and the relative rotor angular position are constant. In the transient period resulting from a disturbance such as a momentary fault in the network or a sudden change in load, there arises a difference between the mechanical input of a machine and its electrical output, which causes an accelerating torque to be applied to the rotor. This makes the machine swing relative to the other machines, its speed and relative angular position along with bus terminal voltage, machine internal voltage and generated power thus change with time.

The transient stability problem must be solved on the basis of a given initial static power flow condition which is the solution of a load flow program. In this report, the load flow program is formulated using the Newton Raphson method.

Roughly speaking, in a load flow program, a set of nonlinear algebraic equations must be solved simultaneously based on some specified information. In a transient stability program, a group of linear differential equations must be solved simultaneously to obtain the values for some variables at every instant of an observation interval.

The input and output scheme for these two programs are given as follows:

(A) Load Flow program

Specified Information

(1) The injected real power at each bus except one (referred to as the swing bus or slack bus).

(2) The desired voltage at all buses where there is an active source of reactive power (generator or synchronous condenser).

(3) Capability limitations on the injected reactive power at the buses where there is an active source of reactive power.

(4) The real and reactive demand (load) at every bus.

(5) The appropriate model for each transmission line, each transformer (including static tap settings), and each static capacitor/reactor.

(6) The bus interconnection scheme.

Determine

(1) The injected real power at the swing bus.

(2) The injected reactive power at all buses where there is an active source of reactive power.

(3) The transmission line real and reactive power flows.

(4) The real and reactive power flows through all transformers.

(5) The magnitude and phase of all bus voltages.

(6) The total system transmission losses.

(B) Transient Stability program

Specified Information

(1) The prefault network conditions including configuration, loads, and generation pattern.

(2) The faulted network condition including fault clearance information.

(3) The mathematical models for excitation and speed governor control systems and the corresponding data.

(4) A mathematical model for the synchronous machines and their corresponding data.

(5) A set of network performance equations.

Determine

(1) The machine speeds and their relative rotor angular positions throughout an observation interval.

(2) Bus terminal voltages and machine internal voltages throughout an observation interval.

(3) Bus generation powers throughout an observation interval.

1.2 Guide to the Report

This report is composed of four main parts. These parts deal with the load flow program, the transient stability program, the user's guide, and the software of the programs.

The load flow problem will be discussed in Chapter II, including introduction to the problem, classification of buses, solution technique, scheme for storing and operating on nonzero terms, program accuracy and general flow chart.

The transient stability problem will be discussed in Chapter III, including an introduction to the problem and the development and discussion of the swing equation, the machine equations, the power system equations, the excitation and speed governor control loops, the Runge-Kutta 4th order method for solving differential equations, error control and a general flow chart.

The user's guide will be described in Chapter IV, including definition of variables, input and output scheme, format type, illustrating examples, troubleshooting and the output solutions of the load flow and transient stability programs for a sample system.

The user's guide is an independent part, those who are only interested in how to use these programs may proceed directly to Chapter IV.

The software of the programs are contained in the Appendices. All the statements of these two programs are listed.

CHAPTER II

THE LOAD FLOW PROGRAM

2.1 Introduction

In this report, the load flow program is used to calculate the prefault conditions for the transient stability studies. However, this load flow program was prepared in such a way that it may be used as an independent program.

Before the discussion of load flow program, the notation to be used throughout this report will be given as follows:

P_p	real injected power at bus p.
P_{Gp}	generated real power at bus p.
P_{Lp}	real power load at bus p.
ΔP_p	the change of real injected power at bus p.
Q_p	reactive injected power at bus p.
Q_{Gp}	generated reactive power at bus p.
Q_{Lp}	reactive power load at bus p.
ΔQ_p	the change of reactive injected power at bus p.
$\dot{E}_p$	complex terminal voltage at bus p.
E_p	magnitude of $\dot{E}_p$.
ΔE_p	the change of E_p.
δ_p	phase angle of $\dot{E}_p$.
$\Delta\delta_p$	the change of δ_p.
$\dot{I}_p$	complex injected current at bus p.
I_p	magnitude of $\dot{I}_p$.
α_p	phase angle of $\dot{I}_p$.

$\dot{Y}_{pq}$ complex admittance between bus p and bus q.

Y_{pq} magnitude of $\dot{Y}_{pq}$.

θ_{pq} phase angle of $\dot{Y}_{pq}$.

Re indicates the real part of a complex quantity.

Im indicates the imaginary part of a complex quantity.

* indicates the conjugate of a complex quantity.

$$Y_{pq} = G_{pq} + jB_{pq} = Y_{pq} e^{j\theta_{pq}}$$

$$\dot{E}_p = e_p + jf_p = E_p e^{j\delta_p}$$

$$\dot{I}_p = a_p + jb_p = I_p e^{j\alpha_p}$$

As mentioned in Chapter I, the load flow program is used to solve a set of nonlinear algebriac equations simultaneously. The equations for bus p are shown as equations (2.1.1) and (2.1.2).

$$P_p = P_{Gp} - P_{Lp} = \mathrm{Re}(\dot{E}_p^* \dot{I}_p) = \mathrm{Re}(\dot{E}_p \ (\sum_{q=1}^{n} \dot{Y}_{pq} \dot{E}_q)) \tag{2.1.1}$$

$$Q_p = Q_{Gp} - Q_{Lp} = -\mathrm{Im}(\dot{E}_p^* \dot{I}_p) = -\mathrm{Im}(\dot{E}_p^* \ (\sum_{q=1}^{n} \dot{Y}_{pq} \dot{E}_q)) \tag{2.1.2}$$

where n is the number of system buses.

Obviously, both equation (2.1.1) and equation (2.1.2) are nonlinear. The main discussion of this chapter deals with solving them numerically.

Both equations (2.1.1) and (2.1.2) will be used to solve for the bus terminal voltage for a load bus, but only equation (2.1.1) will be used if the bus is a voltage control bus. The details of the bus classification scheme will be discussed in section (2.2).

Generally speaking, the solution methods for the load flow problem can be classified as either direct or iterative. The direct methods, such as the Newton Raphson method, employ the direct solution of a related linear system in the iterative algorithm. Whereas the iterative methods, such as the Gauss-Seidel method, use a scheme of successive displacement.

Digital computers have been used to solve the load flow equations for many years. The earliest programs used the Gauss-Seidel method almost exclusively (2,3,4). Alan Glen Barta developed a program based on this method (5) in 1973 for use at KSU. That program has been used extensively by faculty and students when studying the steady-state response of small electric power systems.

The load flow program described in this report is based on a solution method developed by engineers at the Bonneville Power Administration (6), which was a development of Newton Raphson method described by Van Ness (7) in 1961.

The number of iterations and the storage requirement of iterative methods increase almost linearly with respect to increases in system size, it is thus not efficient for large systems. In general, the direct methods converge in few iterations and are not subject to the ill-conditioned situation (6,7), but sometimes are not efficient for small system problems because of the relatively large storage requirement.

The main difficulty with the Newton Raphson method lies in the large storage requirements of the elimination procedure for solving the simultaneous nonlinear equations. In this report, a reordering scheme and a technique which only stores and operates on the nonzero elements in the Jacobian matrix and the bus admittance matrix are used to take advantage of the sparsity of those matrices. These schemes will be discussed later in this chapter.

2.2 Classification of Buses

In load flow problem, if the voltage magnitude E and its phase angle δ at each bus can be obtained, it is easy to substitute those results into equations (2.1.1) and (2.1.2) to solve P and Q. Evidently, the bus voltage magnitude E and the phase angle δ are the key to the load flow solution.

For each bus, there are six variables, which are P_G, P_L, Q_G, Q_L, E and δ, but only two equations. Thus, we must assign values to four variables at each bus in order to solve them.

The classification of a bus depends on which kind of specification is given for that bus. Each bus type is described as follows:

(A) Swing Bus

P_L, Q_L, E and δ are given, it is not necessary to solve equations (2.1.1) and (2.1.2) for the swing bus simultaneously with the equations for the remaining buses. These two equations are used to determine the injected real and reactive power at the swing bus after E and δ at all other buses have been determined. A generator must be connected to a swing bus.

(B) Voltage Control Bus

P_G, P_L, Q_L, E are specified, thus it is only necessary to solve for δ. Q_G can be obtained once all bus voltages are known. In this case, only equation (2.1.1) must be solved simultaneously with the equations for the remaining buses. The generated reactive power Q_G must satisfy an inequality constraint ($Q_{min} \leq Q_G \leq Q_{max}$). Q_{min} and Q_{max} represents the machine limitations and their values are assumed to be given. A generator or a synchronous condensor must be connected to a voltage control bus.

(C) Load Bus

P_G, P_L, Q_G, Q_L are given. Since both E and δ are unknowns, equation (2.1.1) and equation (2.1.2) must be solved simultaneously with the equations for the remaining buses. The voltage magnitude E must satisfy an inequality constraint ($E_{min} \leq E \leq E_{max}$), where E_{min} and E_{max} are given. Generally, but not always, there is no generator connected to a load bus.

2.3 Solution Technique

(I) Basic Method

The Newton-Raphson method is derived from the Taylor's expansion of a function. A two dimensional function is used to describe the procedure.

$$f_1(x_1,x_2) = y_1$$

$$f_2(x_1,x_2) = y_2$$

If y_1 and y_2 are given, and f_1, f_2 are nonlinear functions, the problem is to solve for x_1 and x_2. Assume that x_1^0 and x_2^0 are starting points.

$$f_1(x_1^0 + \Delta x_1, x_2^0 + \Delta x_2) = f_1(x_1^0,x_2^0) + \left.\frac{\partial f_1}{\partial x_1}\right| (x_1^0,x_2^0)\ \Delta x_1 + \left.\frac{\partial f_1}{\partial x_2}\right| (x_1^0,x_2^0)\ \Delta x_2 + \text{H.O.T.} \qquad (2.3.1)$$

$$f_2(x_1^0 + \Delta x_1, x_2^0 + \Delta x_2) = f_2(x_1^0,x_2^0) + \left.\frac{\partial f_2}{\partial x_1}\right| (x_1^0,x_2^0)\ \Delta x_1 + \left.\frac{\partial f_2}{\partial x_2}\right| (x_1^0,x_2^0)\ \Delta x_2 + \text{H.O.T.} \qquad (2.3.2)$$

If Δx_1 and Δx_2 are small enough, the higher order terms can be neglected. The equations (2.3.1) and (2.3.2) can be expressed in matrix form.

$$\begin{bmatrix} (y_1-f_1(x_1^0,x_2^0)) \\ \\ (y_2-f_2(x_1^0,x_2^0)) \end{bmatrix} = \begin{bmatrix} \left.\frac{\partial f_1}{\partial x_1}\right| (x_1^0,x_2^0) & \left.\frac{\partial f_1}{\partial x_2}\right| (x_1^0,x_2^0) \\ \\ \left.\frac{\partial f_2}{\partial x_1}\right| (x_1^0,x_2^0) & \left.\frac{\partial f_2}{\partial x_2}\right| (x_1^0,x_2^0) \end{bmatrix} \begin{bmatrix} \Delta x_1 \\ \\ \Delta x_2 \end{bmatrix} \qquad (2.3.3)$$

The coefficient matrix is the so-called Jacobian matrix. Δx_1 and Δx_2 can be easily determined from equation (2.3.3), and then added to the previous starting point (x_1^0,x_2^0) to obtain a new starting point. The procedure is continued until the process reaches a suitable terminating criterion.

In this method, the point (x_1^0,x_2^0) should be chosen in the vicinity of final result. Δx_1 and Δx_2 should be chosen small enough in order that the truncation error associated with dropping the higher order terms can be neglected. Equation (2.3.3) can be easily extended to an n dimensional case.

In the load flow problem, the total injected current at bus k is

$$\dot{I}_k = \sum_{m=1}^{n} \dot{Y}_{km} \dot{E}_m$$

The injected power at bus k is

$$P_k + jQ_k = \dot{E}_k \dot{I}_k^* = \dot{E}_k \left(\sum_{m=1}^{n} \dot{Y}_{km}^* \dot{E}_m^* \right) \qquad (2.3.4)$$

Equation (2.3.4) is a combination of equations (2.1.1) and (2.1.2). When the Newton Raphson method is applied to equation (2.3.4), equation (2.3.5) and (2.3.6) are obtained.

$$\Delta P_k = \sum_m \frac{\partial P_k}{\partial \delta_m} \Delta\delta_m + \sum_m \frac{\partial P_k}{\partial E_m} \Delta E_m \qquad (2.3.5)$$

$$\Delta Q_k = \sum_m \frac{\partial Q_k}{\partial \delta_m} \Delta\delta_m + \sum_m \frac{\partial Q_k}{\partial E_m} \Delta E_m \qquad (2.3.6)$$

The first order derivatives are all evaluated at the starting point of that iteration and their values must be calculated at each iteration. ΔP_k and ΔQ_k at each iteration are the difference between the scheduled P_k, Q_k and the P_k, Q_k calculated from the previous iteration.

In equation (2.3.5) and (2.3.6), m represents the bus number of each bus directly connected to bus k except the swing bus (including the bus k itself). The notation is simplified by writing equations (2.3.5) and (2.3.6) in the following form:

$$\Delta P_k = \sum_m H_{km} \Delta\delta_m + \sum_m N_{km} \frac{\Delta E_m}{E_m} \tag{2.3.7}$$

$$\Delta Q_k = \sum_m J_{km} \Delta\delta_m + \sum_m L_{km} \frac{\Delta E_m}{E_m} \tag{2.3.8}$$

The expressions for calculating H_{km}, J_{km}, N_{km} and L_{km} (7) are shown below. Two cases $k \neq m$ and $k=m$ should be considered.

(1) $k \neq m$

$$H_{km} = L_{km} = E_k E_m Y_{km} \sin(\delta_k - \delta_m - \theta_{km}) = a'_m f_k - b'_m e_k$$

$$N_{km} = -J_{km} = E_k E_m Y_{km} \cos(\delta_k - \delta_m - \theta_{km}) = a'_m e_k - b'_m f_k$$

where $(a'_m + jb'_m) = (e_m + jf_m)(G_{km} + jB_{km})$

(2) $k=m$

$$H_{kk} = -Q_k - B_{kk} E_k^2$$

$$L_{kk} = Q_k - B_{kk} E_k^2$$

$$N_{kk} = P_k + G_{kk} E_k^2$$

$$J_{kk} = P_k - G_{kk} E_k^2$$

As discussed in section (2.2), only voltage control buses and load buses are considered in the E and δ calculation process.

(1) A Load Bus

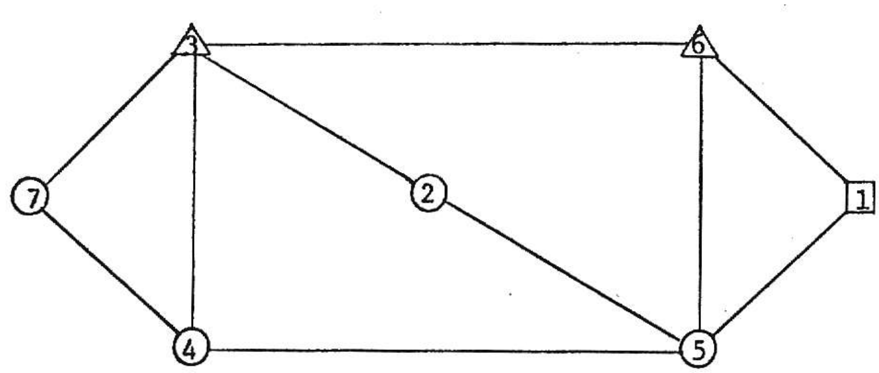
For a load bus, H, K, L, N, ΔP, ΔQ should be calculated for every iteration step. These values are used to calculate ΔE and $\Delta\delta$.

(2) A Voltage Control Bus

For a voltage control bus, only, H, N and ΔP should be calculated at every iteration step and use these values to calculate $\Delta\delta$.

(II) Jacobian Matrix

The Newton-Raphson method involves the repeated direct solution of a set of linear equations of the form of equations (2.3.5) and (2.3.6). The Jacobian matrix gives the linearized relationship between the small change in voltage magnitude and phase angle and the small change in injected real and reactive powers. For a seven-bus system as shown in Fig. 2.1, the matrix equation is as shown in equation (2.3.9).



1 Swing Bus
○ Load Bus
△ Voltage Control Bus

Fig. 2.1. SEVEN-BUS SYSTEM

$$
\begin{bmatrix} \Delta P_2 \\ \Delta Q_2 \\ \Delta P_3 \\ \Delta P_4 \\ \Delta Q_4 \\ \Delta P_5 \\ \Delta Q_5 \\ \Delta P_6 \\ \Delta P_7 \\ \Delta Q_7 \end{bmatrix}
=
\begin{bmatrix}
H_{22} N_{22} & H_{23} & & H_{25} N_{25} & & \\
J_{22} L_{22} & J_{23} & & J_{25} L_{25} & & \\
H_{32} N_{32} & H_{33} & H_{34} N_{34} & & H_{36} & H_{37} N_{37} \\
 & H_{43} & H_{44} N_{44} & H_{45} N_{45} & & H_{47} N_{47} \\
 & J_{43} & J_{44} L_{44} & J_{45} L_{45} & & J_{47} L_{47} \\
H_{52} N_{52} & & H_{54} N_{54} & H_{55} N_{55} & H_{56} & \\
J_{52} L_{52} & & J_{54} L_{54} & J_{55} L_{55} & J_{56} & \\
 & H_{63} & & H_{65} N_{65} & H_{66} & \\
 & H_{73} & H_{74} N_{74} & & & H_{77} N_{77} \\
 & J_{73} & J_{74} L_{74} & & & J_{77} L_{77}
\end{bmatrix}
\begin{bmatrix} \Delta \delta_2 \\ \Delta E_2/E_2 \\ \Delta \delta_3 \\ \Delta \delta_4 \\ \Delta E_4/E_4 \\ \Delta \delta_5 \\ \Delta E_5/E_5 \\ \Delta \delta_6 \\ \Delta \delta_7 \\ \Delta E_7/E_7 \end{bmatrix}
\qquad (2.3.9)
$$

In this equation the coefficient matrix is the Jacobian matrix.

(III) Reordering Scheme

It is necessary to arrange the set of linear equations in an order that will tend to minimize the accumulation of nonzero terms in the upper traingular matrix during the Gaussian elimination. The order needs to be determined only once for each network configuration no matter how many times the solution is iterated.

The order must be determined prior to elimination. The only information needed by the subroutine for doing this is a bus-branch connection pattern of the network. An order that would be valid for the reduction of the admittance matrix of the network is also valid for the triangularization of the related Jacobian matrix.

Tinney and Hart (6) have suggested these recordering schemes. One of these was implemented in this program. This scheme is described as follows:

> The nodes are numbered, starting with that having the fewest connected branches and ending with that having the most connected branches.
>
> The reordering subroutine OPOR is just a general sorting program.

(IV) Elimination of Jacobian Matrix and Storage of Upper Triangular Matrix

Equation (2.3.9) is formed and solved by Gaussian elimination and back-substitution. The program operates upon and stores only the nonzero elements. The Jacobian matrix is triangularized either one or two rows at a time, depending upon which type of bus it is. For a voltage control bus, there is only one row in the Jacobian matrix. For a load bus, there are two rows in the Jacobian matrix.

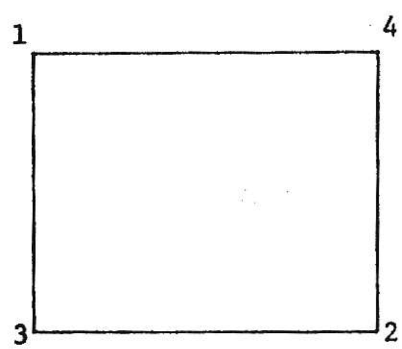
All elements to the left of the diagonal of a single or double row are eliminated by appropriate linear combinations with previously processed rows. The linear combination operates upon the nonzero elements, and the nonzero elements of the new single or double row are stored in the upper triangle. Matrix (2.3.10) shows the form of the upper triangular matrix resulting from Gaussian elimination of the Jacobian matrix for the sample 7 bus system.

The primes indicate elements that have been altered during the elimination process. The situation display in (2.3.10) is at the end of the downward operation. At this point $\Delta Q_7'$ is equal to $\Delta E_7/E_7$. The remaining voltage and magnitude and phase angle corrections can be computed by back substitution. In the programs described in this report, matrix (2.3.10) is stored in a one dimensional array JAC and some auxiliary tables are used to find the proper nonzero terms to perform the back substitution in order to obtain the corrections.

$$\begin{array}{|cc|c|cc|cc|c|cc|}
\hline
1 & H'_{22} & H'_{23} & & & H'_{25} & N'_{25} & & & \\
 & 1 & J'_{23} & & & J'_{25} & L'_{25} & & & \\
\hline
 & & 1 & H'_{34} & N'_{34} & H'_{35} & N'_{35} & H'_{36} & H'_{37} & N'_{37} \\
\hline
 & & & 1 & N'_{44} & H'_{45} & N'_{45} & H'_{46} & H'_{47} & N'_{47} \\
 & & & & 1 & J'_{45} & L'_{45} & J'_{46} & J'_{47} & L'_{47} \\
\hline
 & & & & & 1 & N'_{55} & H'_{56} & H'_{57} & L'_{57} \\
 & & & & & & 1 & J'_{56} & J'_{57} & L'_{57} \\
\hline
 & & & & & & & 1 & H'_{67} & N'_{67} \\
\hline
 & & & & & & & & 1 & N'_{77} \\
 & & & & & & & & & 1 \\
\hline
\end{array} \qquad (2.3.10)$$

(V) <u>Illustrating Examples for the Scheme of Storing and Operating Upon Only Nonzero Elements</u>

The bus admittance matrix and the Jacobian matrix of a power system are always sparse matrices. Usually for a large system, less than one tenth of their elements are nonzero elements. Therefore, if only the nonzero elements are stored and manipulated, computer memory requirements can be reduced extensively. A sample system is given to illustrate this scheme as follows:



Bus 1 Swing Bus

Bus 2 Voltage Control Bus

Bus 3,4 Load Bus

Fig. 2.2 A FOUR-BUS SAMPLE SYSTEM

There are only four buses in this system, obviously, it is easy to obtain the conventional bus admittance matrix from the network connection configuration as shown in Fig. 2.5.

$\dot{Y}_{11}$	0	$\dot{Y}_{13}$	$\dot{Y}_{14}$
0	$\dot{Y}_{22}$	$\dot{Y}_{23}$	$\dot{Y}_{24}$
$\dot{Y}_{31}$	$\dot{Y}_{32}$	$\dot{Y}_{33}$	0
$\dot{Y}_{41}$	$\dot{Y}_{42}$	0	$\dot{Y}_{44}$

The bus admittance matrix YBUS and its corresponding tables IYBUS, JYBUS used in these programs are shown as follows:

$$YBUS = \begin{pmatrix} \dot{Y}_{11} \\ \dot{Y}_{13} \\ \dot{Y}_{14} \\ \dot{Y}_{22} \\ \dot{Y}_{23} \\ \dot{Y}_{24} \\ \dot{Y}_{31} \\ \dot{Y}_{32} \\ \dot{Y}_{33} \\ \dot{Y}_{41} \\ \dot{Y}_{42} \\ \dot{Y}_{44} \end{pmatrix} \qquad IYBUS = \begin{pmatrix} 1 \\ 1 \\ 1 \\ 2 \\ 2 \\ 2 \\ 3 \\ 3 \\ 3 \\ 4 \\ 4 \\ 4 \end{pmatrix} \qquad JYBUS = \begin{pmatrix} 1 \\ 3 \\ 4 \\ 2 \\ 3 \\ 4 \\ 1 \\ 2 \\ 3 \\ 1 \\ 2 \\ 4 \end{pmatrix}$$

IYBUS indicates the row index for the corresponding elements for YBUS and JYBUS indicates the Column index for the corresponding elements for YBUS. The second elements of IYBUS and JYBUS are respectively 1 and 3, it means that the second element of YBUS must be $\dot{Y}_{13}$.

H_{22}	$H_{23}N_{23}$	$H_{24}N_{24}$
H_{32} J_{32}	$H_{33}N_{33}$ $J_{33}L_{33}$	
H_{42} J_{42}		$H_{44}N_{44}$ $J_{44}L_{44}$

The Gauss elimination process is performed one bus at a time. In the process, a working matrix WKJR and its corresponding table KWKJ must be formed in advance. For an example, these matrices for bus 3 are shown as follows:

$$\text{WKJR} = \begin{pmatrix} P_3 & H_{32} & H_{33} \\ Q_3 & J_{32} & J_{33} \\ 0 & 0 & N_{33} \\ 0 & 0 & L_{33} \end{pmatrix}$$

$$\text{KWKJ} = \begin{pmatrix} 3 & 2 & 3 \\ 2 & 3 & 0 \end{pmatrix}$$

Fig. 2.3 THE WORKING MATRIX WKJR AND ITS TABLE KWKJ FOR BUS 3

In Fig. 2.3, the 1st element in the first row of KWKJ indicates the row index of WKJR, the other elements in this row indicate the corresponding column index of WKJR. The elements in the second row of KWKJ indicate the "next location" of nonzero elements.

EXAMPLE

Examining the KWKJ shown in Fig. 2.3.

KWKJ(1,1) = 2 indicates that the working matrix WKJR belongs to bus 3.

KWKJ(2,1) = 2 indicates that the succeeding nonzero elements will be in colum 2 of WKJR, such as H_{32} and J_{32}.

KWKJ(1,2) = 2 indicates that the nonzero elements in column 2 of WKJR are related to colum 2 of the row corresponding to bus 3 in the Jacobian matrix, such as H_{32}.

KWKJ(1,3) = 3 indicates that the nonzero elements in colum 3 of WKJR are H_{33}, N_{33}, J_{33} etc.

KWKJ(2,3) = 0 indicates that no more nonzero elements exist for bus 3 after column 3 of WKJR.

The eliminated Jacobian matrix of this sample system is shown as follows:

$$JAC = \begin{bmatrix} P'_3 \\ Q'_3 \\ N'_{33} \end{bmatrix} \qquad IJAC = \begin{bmatrix} 3 \\ 3 \\ 3 \end{bmatrix} \qquad JJAC = \begin{bmatrix} 3 \\ 3 \\ 3 \end{bmatrix}$$

The primes indicate elements that have been altered from their original values in the elimination process. IJAC indicates the row index of the elements in JAC, JJAC indicates the corresponding column index.

IJAC and JJAC are used to locate the proper nonzero elements to do the back substitution until all ΔE and $\Delta\delta$ are obtained.

The scheme of storing and operating on the nonzero elements is very complicated. For large system problem, the scheme reduces the storage requirement extensively and makes the programs more flexible.

2.4 General Flow Chart for Load Flow Program

The flow chart for the load flow program described in this report is very complicated, thus only a general type can be given here. In this program, there are three subroutines which are OPOR, GGSEL, and MISMATCH. They are used to handle the following operations:

(1) OPOR: handle the reordering scheme.

(2) GGSEL: handle the Gauss elimination and back substitution process.

(3) MISMATCH: calculate the mismatches at the end of this program.

The general flow chart is shown in Fig. 2.4.

2.5 Accuracy of the Result

The last part of output of the load flow program is the mismatch. The mismatch tells how good the load flow solution is. The first value is the net injected power at swing bus, the remaining mismatch values are the differences between the total line flow from every other bus and its net injected power (Net injected power equals generated power minus load). If there is no error existing, the difference should be zero. Total mismatch are the summation of the individual mismatch. The average mismatch is the total mismatch divided by (N-1), where N is the number of system buses.

The total error of the solution for the sample systems studied has always been within $\pm 0.05\%$. It is judged to be practical in the load flow calculation.

The load flow program was used to solve four sample systems which are a 5-bus system, a 7-bus system, a 14-bus system, and a 57-bus system. The results for these sample systems are judged to be right. The solution for a 7-bus system is listed in Chapter 4.

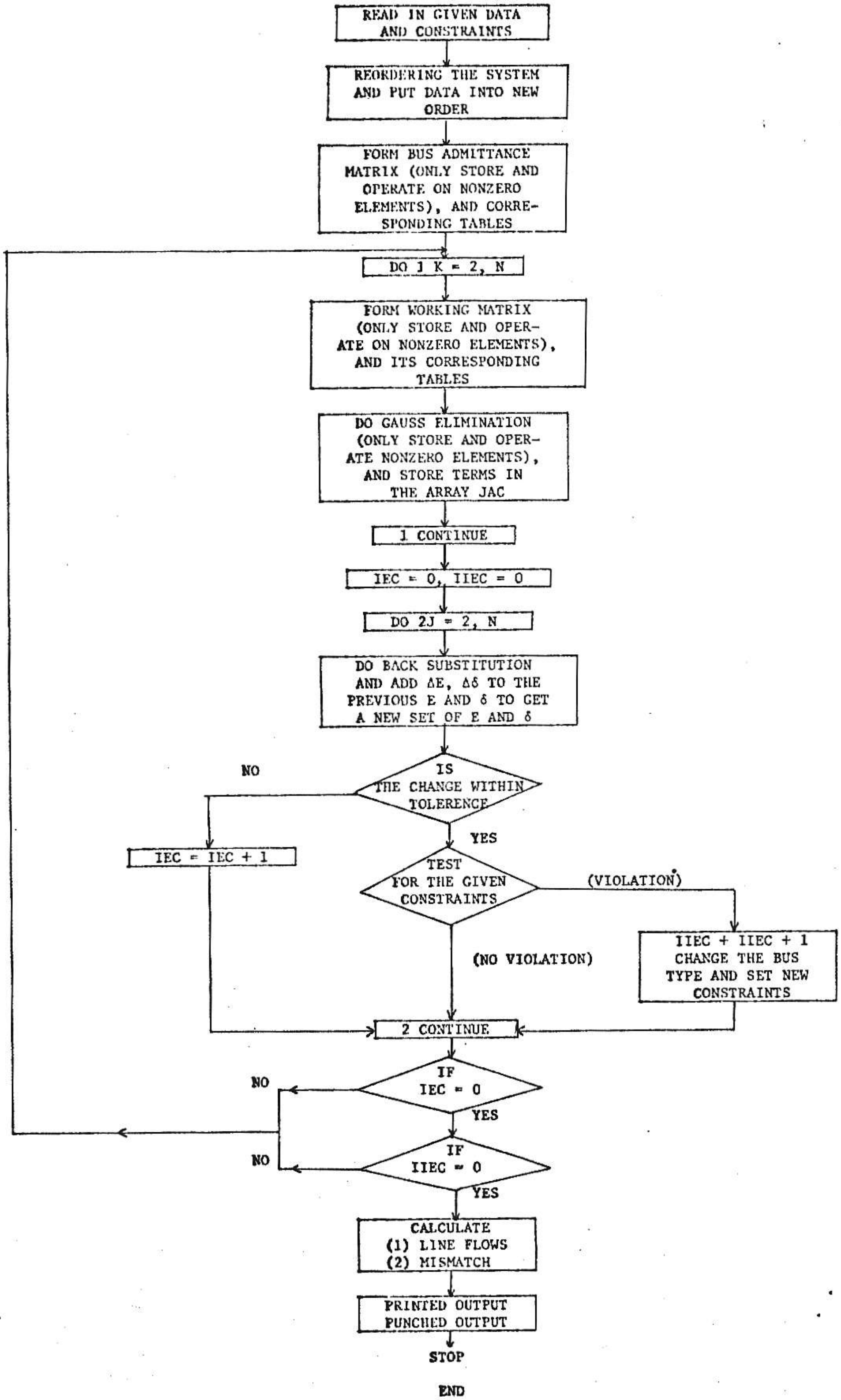


Fig. 2.4 GENERAL FLOW CHART FOR LOAD FLOW PROGRAM

CHAPTER III

3.1 Introduction

The transient stability problem involves the calculation of machine speed, internal voltages, and relative angular positions throughout a transient observation period. These quantities change during that period because of the unbalance in mechanical and electrical power.

The performance of the power system during the transient period can be obtained from the network performance equations. The performance equations used in this report are based on a bus admittance model of the network.

In transient stability studies, a load flow calculation is necessary to obtain the system conditions prior to the disturbance. In this calculation, the network is composed of system buses, transmission lines, and transformers. The network representation for transient stability studies includes, in addition to these components, equivalent circuits for the synchronous machines and static admittances to represent loads. After the load flow calculation, therefore, the admittance matrix of the network must be modified to reflect the changes in the representation of the network.

The operating characteristics of the synchronous machines, the excitation and speed governor control systems are described by sets of differential equations. The number of differential equations required for machines and control systems depends on the detail needed to represent accurately the machine and control systems performance.

A transient stability analysis is performed by combining a solution of the algebraic equations describing the network with a numerical solution of these differential equations. The solution of the network equations provides information about the bus terminal voltage and armature currents during the transient period. The Runge-Kutta 4th-order method has been applied to the solution of the differential equations in these transient stability studies.

Formulation of suitable mathematical models for the system components are initially discussed in this chapter. The solution scheme and a general flow chart of the program are then presented.

3.2 Swing Equation

In order to determine the angular displacement between the machines of a power system during transient conditions, it is necessary to solve the differential equations describing the motion of the machine rotors. The laws of mechanics related to rotational bodies, yields

$$T = \frac{WR^2}{g} \alpha \tag{3.2.1}$$

where T = algebriac sum of all applied torques, ft-lb

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

g = acceleration due to gravity, equal to 32.2 ft/sec^2

α = mechanical angular acceleration, rad/sec^2

The electrical angle θ_e is equal to the product of the mechanical angle θ_m and the number of pairs of poles, p/2, that is,

$$\theta_e = (p/2)\ \theta_m \ . \tag{3.2.2}$$

The frequency f in Hertz is

$$f = (p/2)\ \frac{rpm}{60} \ . \tag{3.2.3}$$

Then from equations (3.2.2) and (3.2.3), the electrical angle in radians is

$$\theta_e = \frac{60f}{rpm}\ \theta_m \ . \tag{3.2.4}$$

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

$$\delta = \theta_e - \omega_o t$$

where ω_o = rated synchronous speed in rad/sec

t = time in seconds.

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

$$\frac{d\delta}{dt} = \frac{d\theta_e}{dt} - \omega_o$$

and the angular acceleration is

$$\frac{d^2\delta}{dt} = \frac{d\theta_e}{dt} - \omega_o$$

and the angular acceleration is

$$\frac{d^2\delta}{dt^2} = \frac{d^2\theta_e}{dt^2} .$$

Taking the second derivative of equation (3.2.4) 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 (3.2.1), the net torque is

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

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, that is,

$$\text{Base torque} = \frac{\text{base kva } (550/0.746)}{(2)(\text{rpm}/60)}$$

where the base torque is in foot-pounds. Therefore, the torque in per unit is

$$T = \frac{(R^2/g)(2\pi/f)(\text{rpm}/60)^2(0.746/550)}{\text{base kva}} \frac{d^2\delta}{dt^2} . \tag{3.2.5}$$

The inertia constant H of a machine is defined as the kinetic energy at rated speed in kilowatt seconds per kilovolt-ampere. The kinetic energy in foot-pounds is

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

where

$$\omega_o = (2\pi) \frac{\text{rpm}}{60}$$

and rpm is the rated speed. Therefore

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

Substituting in equation (3.2.5).

$$T = \frac{H}{\pi f} \frac{d^2\delta}{dt^2} . \tag{3.2.6}$$

The torques applied to the rotor of an alternator include the mechanical input torque from the prime mover, torques due to rotational losses (friction, windage and core losses), electrical output torques, and dampling torques due to prime mover, alternator, and the power system. 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 air gap torque.

Thus equation (3.2.6) becomes

$$T_m - T_e = \frac{H}{\pi f} \frac{d^2\delta}{dt^2} . \qquad (3.2.7)$$

Since the torque and power in per unit are equal for small derivations in speed, equation (3.2.7) 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 differential equations:

$$\frac{d^2\delta}{dt^2} = \frac{d\omega}{dt} = \frac{\pi f}{H} (P_m - P_e) \qquad (3.2.8)$$

and

$$\frac{d\delta}{dt} = \frac{d\theta_e}{dt} - \omega_o \qquad (3.2.9)$$

Since the rated synchronous speed in radians per second is $2\pi f$, equation (3.2.9) becomes

$$\frac{d\delta}{dt} = \omega - 2\pi f$$

Equations (3.2.8) and (3.2.9) are used to calculate the angle δ and the speed ω for each machine at every instant during the transient period. The change of frequency Δf is very small during the transient period, therefore, $f = f_0 = 60$ Hertz is presupposed.

3.3 Machine Equations

During the transient period, the synchronous machine can be represented by a voltage source, in back of a transient reactance. This voltage source is called the machine internal voltage. The relative rotor angular position changes with time, and because of the influence of excitation control system, the magnitude of the machine internal voltage changes with time too. In this report, only the round-rotor machine is considered. In the following discussion, the armature resistance and saturation effects are neglected. In the round-rotor machine, the direct axis transient reactance, x'_d, and the quadrature axis transient reactance, x'_q, are very nearly equal (8). The equivalent circuit and the corresponding equation is shown as follows:

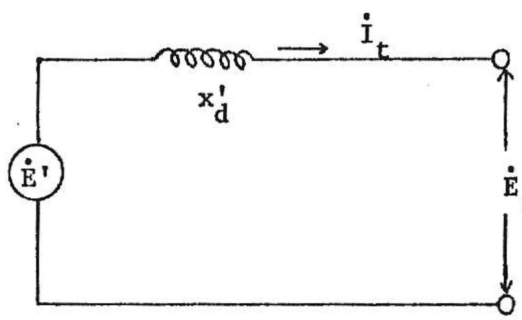


Fig. 3.1 EQUIVALENT CIRCUIT FOR ROUND-ROTOR SYNCHRONOUS MACHINE AT TRANSIENT STATE

The corresponding equation is

$$\dot{E}' = \dot{E}_t + jx'_d \dot{I}_t$$

where $\dot{E}'$ = the complex voltage behind the transient reactance

$\dot{E}_t$ = machine complex terminal voltage

$\dot{I}_d$ = machine complex terminal current

x'_d = transient reactance, typical values lie between 0.12 and 0.21 pu for two-pole turbine alternators and between 0.20 ro 0.28 pu for four-pole turbine alternator (1).

The phasor diagram of a round-rotor synchronous machine in the transient state is shown as Fig. 3.2 (9)

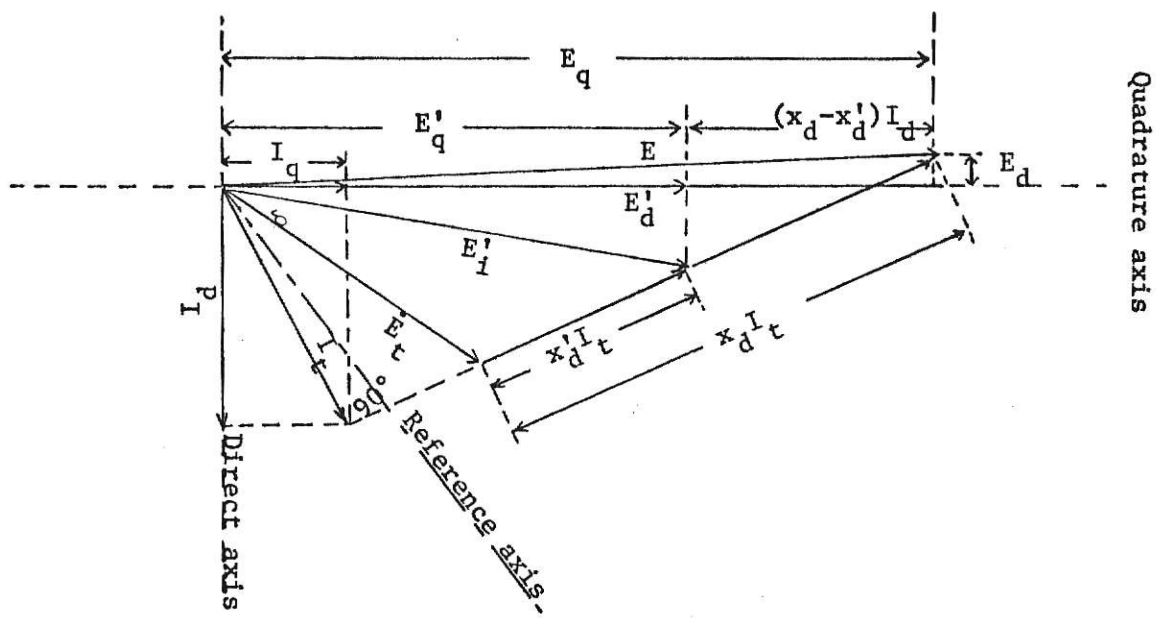


Fig. 3.2 PHASE DIAGRAM OF SYNCHRONOUS MACHINE WITH ROUND-ROTOR IN THE TRANSIENT STATE.

The following assumptions can be made (8). These assumptions are listed in their order of increasing accuracy.

(1) The magnitude of the machine internal voltage, E_i', behind direct axis transient reactance may be assumed constant; or

(2) The flux linkage of the rotor circuit on both axes may be assumed constant (that is, constant E_d' and E_q'); or

(3) The effect of decrement and excitation control system action on the flux linkage of the direct-axis rotor circuit (that is, on E_q') may be calculated, while the quadrature-axis circuit is assumed open ($E_d' = 0$); or

(4) The decrement of the rotor flux linkages of both axes and the effect of excitation control system action, if any, on the direct-axis linkages may be calculated.

All the following discussions are based on the third assumption. Based on this assumption, then $\dot{E}_i'$ is equal to the quadrature component of voltage, $\dot{E}_q$. The rate of change of E_q' is dependent on the output voltage, E_{fd}, of the excitation control system, the direct axis transient open-circuit time constant and the voltage E_I (9). The corresponding equation is

$$\frac{dE'_q}{dt} = \frac{1}{T'_{do}} (E_{fd} - E_I) \qquad (3.3.1)$$

where T'_{do} = the machine direct-axis transient open-circuit time constant

and the relation between $\dot{E}_I$ and $\dot{E}_q$ throughout the transient period is shown in the following equation

$$\dot{E}_I = \dot{E}'_q + j(x_d - x'_d)\, \dot{I}_t \ .$$

3.4 Power System Equations

(I) Representation of Loads

During the transient period, the power system loads can be represented in several ways. In this report, a static admittance representation is used (9).

The prefault current flowing into the load is

$$\dot{I}_L = \frac{P_L - jQ_L}{\dot{E}_t^*} \qquad (3.4.1)$$

where P_L and Q_L are the scheduled bus load and $\dot{E}_t$ is the calculated bus voltage. The static admittance, $\dot{Y}_L$, used to represent the bus load can be obtained from

$$\dot{Y}_L = \frac{\dot{I}_L}{\dot{E}_t} \qquad (3.4.2)$$

Substituting equation (3.4.1) into equation (3.4.2), the equation for the static admittance representation is formed

$$\dot{Y}_L = \frac{P_L - jQ_L}{(E_t)^2}$$

(II) Network Performance Equations

The network performance equations used for load flow calculation can be applied to describe the performance of the network during a transient period (9). Using the bus admittance matrix including the loads and the machines, the voltage equation for bus p is

$$\dot{Y}_{pp}\dot{E}_p = -\sum_{q=1}^{p-1} \dot{Y}_{pq}\dot{E}_q - \sum_{q=p+1}^{n} \dot{Y}_{pq}\dot{E}_q - \sum_{i=1}^{m} \dot{Y}_{pi}\dot{E}_i$$

where $\dot{E}_p$ = complex bus voltage for bus p

$\dot{E}_q$ = complex bus voltage for bus q

$\dot{E}_i$ = complex machine internal voltage

m = number of machines connected to bus p

In equation (3.4.3), bus p cannot be a faulted bus.

3.5 Excitation and Speed Governor Control Systems

(I) Representation of Excitation Control System

There are several differential types of excitation control systems, however, only those which are described as a "continuously acting regulator and excitor" (9) are considered in this report.

The excitation control system provides the proper field voltage to maintain a desired system voltage, usually at the high voltage bus of the power plant. A convenient way to represent the control system is to use a block diagram that relates by means of the transfer functions and the input, output variables of the principal components of the system as shown in

Fig. 3.3 (9). The excitation control system discussed here is composed of the regulator, the amplifier, the exciter and a stabilizing loop. The differential equations relating the input and output variables of these components are respectively

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

$$\frac{dE^{iii}}{dt} = \frac{1}{T_a}\left(K_a\left(E^{v} + \frac{E_0^{iii}}{K_a} - E^{iv}\right) - E^{iii}\right)$$

$$\frac{dE_{fd}}{dt} = \frac{1}{T_e}(E^{ii} - K_e E_{fd}) \qquad (3.5.1)$$

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

where E_s = scheduled reference voltage in per unit

E_0^{iii} = output voltage of the amplifier in per unit prior to the fault

T_r = regulator time constant in seconds

K_a = amplifier gain

T_a = amplifier time constant in seconds

K_e = exciter gain

T_e = exciter time constant in seconds

K_f = stabilizing loop gain

T_f = stabilizing loop time constant in seconds

and the intermediate variables are denoted by 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 demagnetizing effect due to saturation in the exciter. This is determined from

$$E^{vi} = A \exp(B \cdot E_{fd})$$

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

To include the effect of the excitation control system, equations (3.5.1) should be solved simultaneously with equation (3.3.1) describing the machine.

The typical value for constants of excitation systems in operation today on 3600 rpm/min steam turbine alternators (10) are shown as follows:

SYMBOL	SELF-EXCITED EXCITERS, COMMUTATOR OR SILCON DIOIDE, WITH AMPLIDYNE VOLTAGE REGULATOR	SELF-EXCITED COMMUTATOR EXCITER WITH MAG-A-STAT VOLTAGE REGULATOR	ROTATING RECTIFIER EXCITER WITH STATIC VOLTAGE REGULATOR
T_e	0.0 to 0.06	0.0	0.0
K_a	25 to 50	400	400
T_a	0.06 to 0.20	0.05	0.02
K_f	0.01 to 0.08	0.04	0.03
K_e	-0.05	-0.17	1.0
T_e	0.5	0.95	0.8

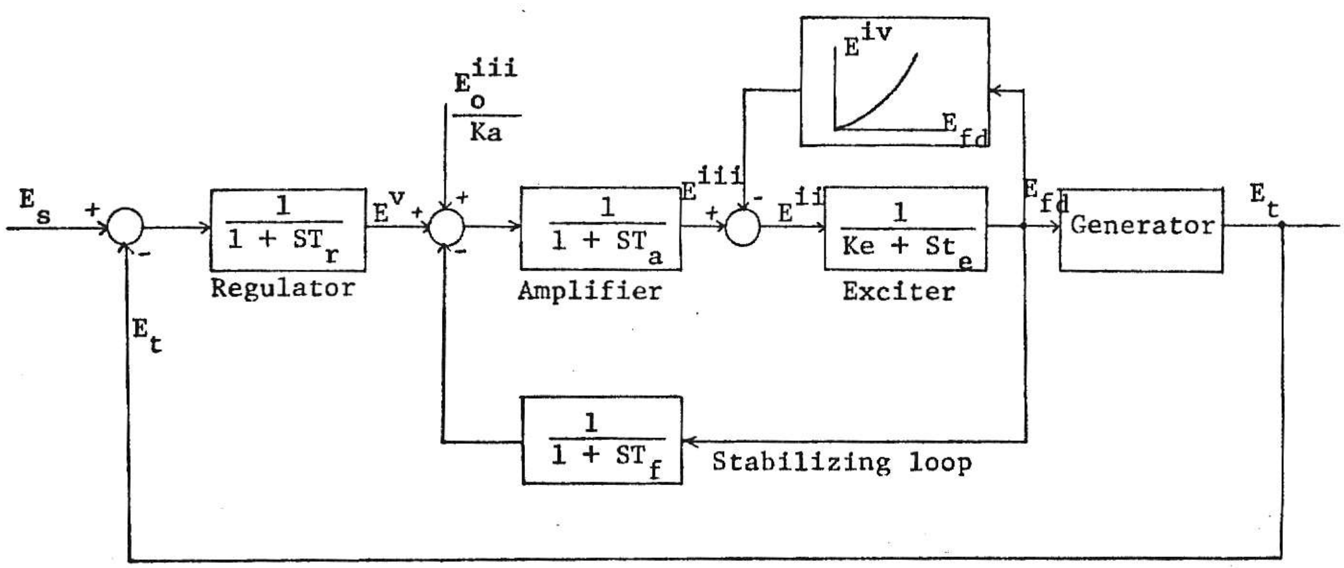


Fig. 3.3 BLOCK DIAGRAM OF CONTINUOUSLY ACTING EXCITER CONTROL SYSTEM

(II) Representation of Speed Governor Control System

The manner in which the speed governor control system is represented is similar to that used to represent the excitation control system. The block diagram is shown as Fig. 3.4 and the describing differential equations (9) are

$$\frac{dP_m}{dt} = \frac{1}{T_s} (P_m^i - P_m)$$

$$\frac{dP_m^i}{dt} = \frac{1}{T_c} (P_m^{ii} - P_m^i) \qquad (3.5.2)$$

where T_s = steam system time constant in seconds

T_c = control system time constant in seconds

P_m = mechanical power in per unit

and the intermediate variables are denoted 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 the following:

$$P_m^{ii} = 0 \qquad \text{if } P_m^{iii} \leq 0$$

$$P_m^{ii} = P_m^{iii} \qquad \text{if } 0 < P_m^{iii} < P_{max}$$

$$P_m^{ii} = P_{max} \qquad \text{if } P_m^{iii} \geq P_{max}$$

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

$$P_m^{iii} = P_{m(0)} - P_m^{iv}$$

where $P_{m(0)}$ is the initial mechanical power. The intermediate variable P_m^{iv} is

$$P_m^{iv} = \frac{1}{R} (\frac{\omega_0 - \omega}{2\pi f}) \pm DB_T)$$

where R is the speed regulation of the unit in per unit and DB_T is the dead band travel. When ω is greater than ω_0, the sign of DB_T is "+", otherwise it is "-". DB_T is the speed change required to overcome the dead band of the governor system.

Equation (3.5.2) and equations (3.2.8) and (3.2.9) should be solved simultaneously to include the effect of speed governor control system. The value of T_s, T_c, R and DB_T (11) used in this report is

SYMBOL	VALUE
T_s	0.3 sec.
T_c	0.08 sec.
R	-0.04
DB_T	0.0006

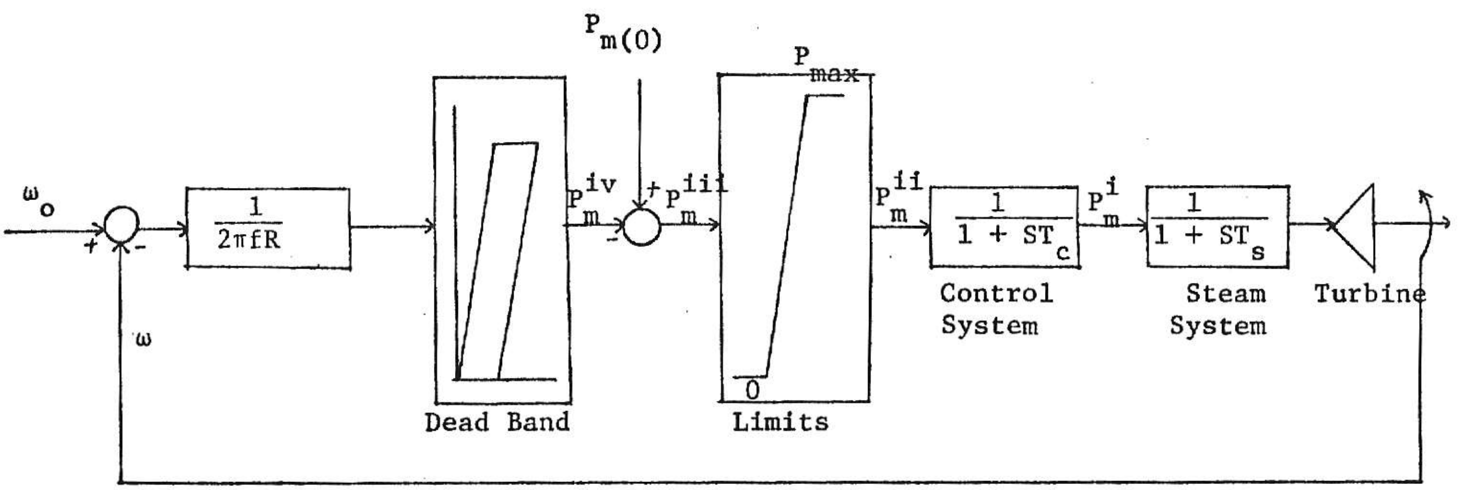


Fig. 3.4 BLOCK DIAGRAM FOR A REPRESENTATION OF SPEED GOVERNOR CONTROL SYSTEM

3.6 Runge-Kutta Fourth-Order Method for Solving Differential Equations

The subroutine RKGS for the Runge-Kutta 4th-order method is based on a built-in subroutine of KSU Computer Center, with some modifications added to adapt it to the needs of the transient stability program.

The purpose of the Runge-Kutta 4th-order method is to obtain an approximate solution of a system of 1st-order ordinary differential equations with given initial conditions. It is a 4th-order integration procedure which is stable and self-starting; that is, only the functional values at a single previous point are required to obtain the functional values ahead.

For each machine, nine 1st-order differential equations must be solved. They are listed as follows in the order used in the transient stability program.

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

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

(3) $$\frac{dP_m}{dt} = \frac{1}{T_s} (P^i_m - P_m)$$

(4) $$\frac{dP^i_m}{dt} = \frac{1}{T_c} (P^{ii}_m - P^i_m)$$

(5) $$\frac{dE'_q}{dt} = \frac{1}{T'_{do}} (E_{fd} - E_I)$$

(6) $$\frac{dE_{fd}}{dt} = \frac{1}{T_e} (E^{ii} - K_e E_{fd})$$

(7) $$\frac{dE^{iii}}{dt} = \frac{1}{T_a} (K_a(E^v + \frac{E^{iii}_0}{K_a} - E^{iv}) - E^{iii})$$

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

(9) $$\frac{dE^{iv}}{dt} = \frac{1}{T_f} (K_f \frac{dE_{fd}}{dt} - E^{iv})$$

In the subroutine RKGS, a modified output scheme is used to give the result at every desired time instant during the transient period. Subroutine FCT is used to calculate the derivatives from those differential equations one machine at a time. If there are n machines, the process will be repeated n times to handle 9n 1st-order differential equations. Subroutine OUTP supplies the output format type, the calculation of the injected power and the local load supplied at each bus throughout the transient observation interval.

In the subroutine RKGS, control of accuracy and adjustment of step size h_1 is done by comparison of results due to double and single step size $2h_1$ and h_1. If the difference between these two results exceeds the given error tolerance, the step size is reduced to one-half of the previous value and the comparison will be done again until the difference is within the given error tolerance.

3.6 General Flow Chart

The flow chart for the transient stability program described in this report is very complicated, only a general type can be given here. In this program, there are four subroutines which are FORM, RKGS, FCT, OUTP. They are used to handle the following schemes:

(1) FORM: used to solve for the bus terminal voltages throughout the transient observation interval.

(2) RKGS: subroutine for Runge-Kutta 4th-order method.

(3) FCT : used to calculate the derivatives from the differential equations.

(4) OUTP: this subroutine supplies the output format type and the calculation of the injected power and the local load supplied at each bus.

The general flow chart is shown in Fig. 3.5.

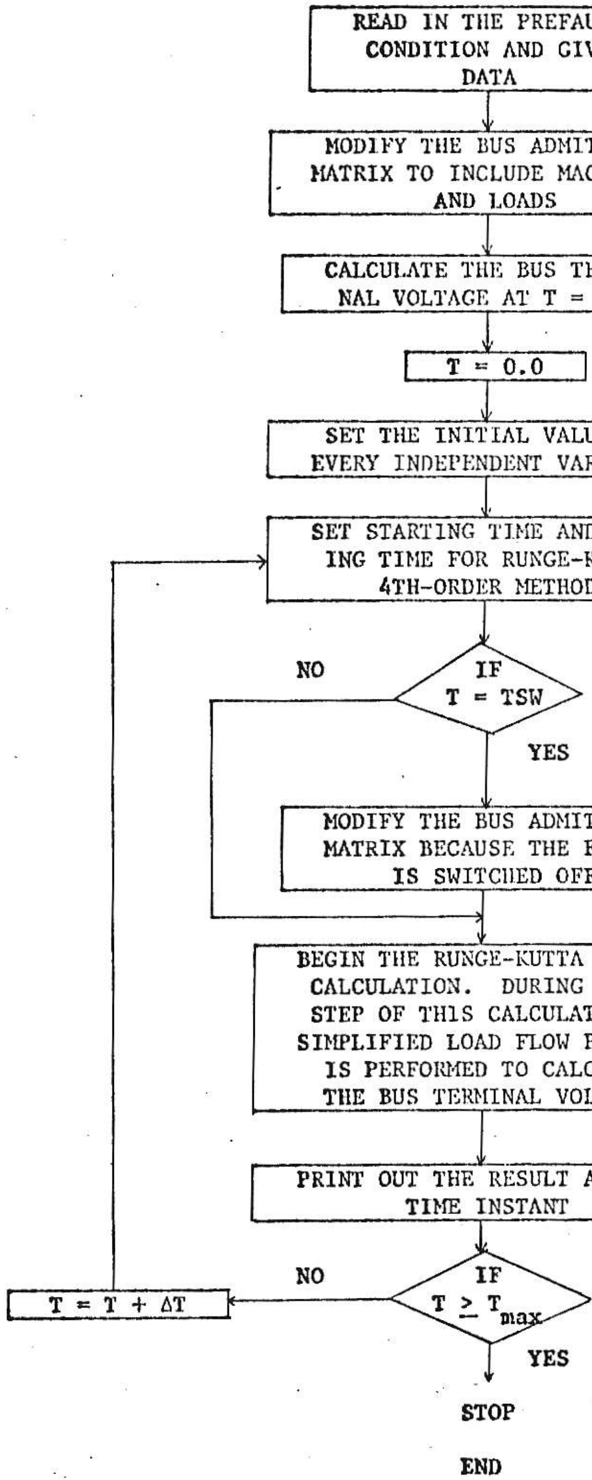


Fig. 3.5 GENERAL FLOW CHART FOR THE TRANSIENT STABILITY PROGRAM

3.7 Accuracy of the Result

In the subroutine RKGS, control of accuracy and adjustment of step size h_1 is done by comparison of results due to double and single size $2h_1$ and h_1. If the difference between these two results exceeds the given error tolerance, the step size is reduced to one-half of the previous value. This process will keep on until the difference is within the given error tolerance.

The error tolerance will be given by the user. Its value will dominate the accuracy of the result.

The transient stability program was used to solve two sample systems which are a 7-bus system and a 57-bus system. The results for these two sample systems are judged to be right. The solution for a 7-bus system is listed in Chapter 4.

CHAPTER IV

USER'S GUIDE

(I) Nomenclature of Load Flow and Transient Stability Programs

Symbol	Quantity
A1	Exciter saturation characteristic constant
B1	Exciter saturation characteristic constant
BC	Complex current
BCJ	Complex current
BM	Number of voltage control buses
BN	Index of system buses
BN1	Index of buses where a static capacitor/reactor is connected
CC	Susceptance of the static capacitor/reactor
CJGBC	Conjugate of complex current
CJGV	Conjugate of complex voltage
CMVAR	Static injected power
DBT	Dead band travel of governor system
DDEL	Change in the phase angle of bus voltage
DE	Change in bus voltage magnitude
DELTA	Phase angle of bus voltage
DELTAA	Phase angle of swing bus voltage
DELTT	Step size used in Runge-Kutta 4th order method
DP	Change in real bus power
DQ	Change in reactive bus power
EB	The index of the ending bus of a line
EB1	The index of the ending bus of a faulted line

Symbol	Quantity
FB	The index of the faulted buses
H	Machine inertia constant
IJAC	The row index table for the nonzero elements in the eliminated upper triangular matrix JAC
ITER	The number of iteration steps used in load flow program
ITER1	The allowed iteration steps used in load flow program
IYBUS	The row index table for the nonzero elements in the Bus Admittance matrix YBUS
JAC	A one dimensional array where the nonzero elements in the eliminated Jacobian matrix are stored
JJAC	The column index table for the nonzero elements in JAC
JYBUS	The column index table for the nonzero elements in the Bus Admittance matrix YBUS
KA	The amplifier gain of the excitation control loop
KE	The exciter gain of the excitation control loop
KF	The stabilizing loop gain of the excitation control loop
LENGTH	The length of the line
LNHFR	A variable used to indicate what type of output is desired
M	The number of machines
MAB	The index of machine buses
MAGV	The magnitude of the swing bus voltage
N	The number of buses
NBASE	New base power used
NC	the number of the static capacitors/reactors
NFB	The number of faulted buses
NFBL	The number of faulted buses
NL	The number of lines

Symbol	Quantity
NOCL	The table used in the Gauss elimination and back substitution processes
NTABI	The table used in the reordering scheme
OBASE	Old base power used
P	Bus injected real power
PA	Calculated bus injected real power
PG	Bus generated real power
PL	The real load at each bus
Q	Bus injected reactive power
QA	Calculated bus injected real power
QG	Bus generated real power
QL	The reactive load at each bus
QMAX	The maximum reactive power constraint at the voltage control bus
QMIN	The minimum reactive power constraint at the voltage control bus
R	The speed regulation of governor system
SB	The index of the starting bus of a line
ST	A variable which indicates total or one-half shunt admittance used
SERV	Series line admittance
SERZ	Series line impedance
SHTY	Line shunt admittance
T	Time
TA	Amplifier time constant of the excitation control loop
TC	Speed control system time constant
TDOP	Machine open-circuit time constant
TE	Exciter time constant
TF	Stabilizing loop time constant

Symbol	Quantity
TMAX	Fault clearing time
TR	Regulator time constant of excitation control loop
TS	Steam system time constant of speed governor control loop
TSW	Switching time
V	Complex bus voltage
VMAX	Maximum voltage constraint of a load bus
VMIN	Minimum voltage constraint of a load bus
VSPEC	Specified voltage magnitude of a voltage control bus
WKJR	Working matrix in the Gauss elimination process
XDOP	Machine transient reactance
YBUS	The bus admittance matrix in which only the nonzero elements are stored
YSHT	Line shunt admittance
ZSER	Series line impedance

(II) General Relation Between Load Flow and Transient Stability Programs

The programs described in this report are the load flow program and the transient stability program. The transient stability program must be used on the basis of a given initial static power flow condition which is a solution of the load flow program. However, the load flow program was also prepared to be used as an independent program. The general output and input relationships between these two programs are shown in Fig. 4.1.

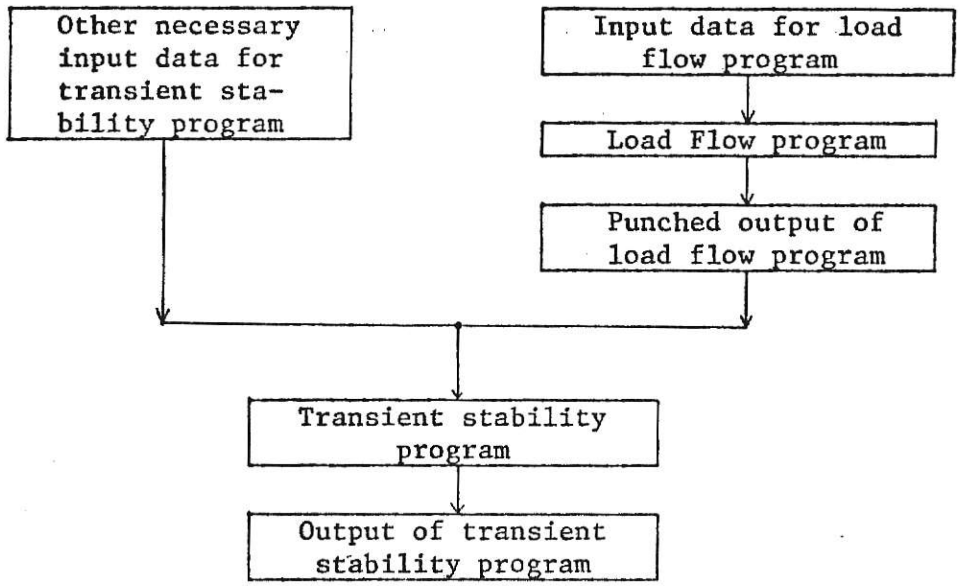


Fig. 4.1 GENERAL RELATION BETWEEN LOAD FLOW PROGRAM AND TRANSIENT STABILITY PROGRAM

If the load flow program is used as an independent program, only printed output is required. Otherwise, both printed output and punched outputs are required, the punched output will be used as a part of input data for the transient stability program, and the printed output will be used to show the prefault condition to the user.

The description for load flow program and transient stability program will be given respectively in part (III) and part (IV) of this chapter.

(III) Load Flow Program (SLFNR)

(A) Program Description

SLFNR is a Fortran program formulated using the Newton Raphson method. The program is used to calculate the static power flow condition of a power system.

Input to the program consists of

(1) System parameters
(2) Static capacitors
(3) Transmission line parameters
(4) Transformer line parameters
(5) Voltage control bus parameters
(6) Swing bus parameters
(7) Load bus parameters

All the impedances, line charging admittances, static capacitor/reactor susceptances, and voltage magnitudes are in per unit on a known MVA base (old base). All powers are in megawatts and megavars. The angles are in radians.

Normal output consists of

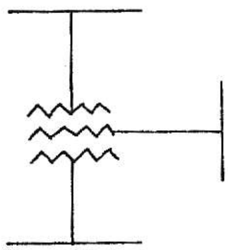
(1) Input data
(2) Load flow solution
(3) System totals
(4) Mismatch

(B) Program Input

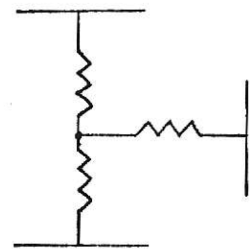
SLFNR uses a fixed format input. The following steps are used in preparing the input data cards.

STEP I Identify the system

Variable LNHFR is used to indicate what type of output that is desired. If LNHFR is equal to 1, both printed and punched outputs will be given. If LNHFR is set to 0, only printed output will be given. Number the buses in a numerical order where bus 1 is the swing bus, the swing bus must have a generator; bus 2 to MB are voltage control buses, the voltage control bus must have either a generator or a synchronous condenser; bus (MB+1) to N are the load buses. Generally, there is no generator or synchronous condenser connected to a load bus. If the bus is a voltage control bus, its bus index must carry a negative sign. Also in counting buses, the three winding transformer is considered to have a bus located at its midpoint (See example below). Number the lines consecutively from 1 to NL, where each transmission line counts as one line; each two-winding transformer counts as two lines; and each three-winding transformer counts as three lines (See below).



3 WINDING TRANSFORMER



EQUIVALENT CIRCUIT
3 LINES, 4 BUSES

The remaining steps will describe the data, its order, and data format. The data cards are placed in the following order.

(1) System parameter cards
(2) Transmission line and transformer line cards
(3) Static capacitor/reactor cards (if any)
(4) Swing bus cards
(5) Voltage control bus cards
(6) Load bus cards

STEP 2 System Parameter Cards

The first card is for the variable LNHFR; its format is (I1). The second card consists of the tolerance (TOLE), allowed number of iteration steps (ITER1); its format is (F10.5,I3). The third card consists of the number of lines (NL), number of buses (NB), number of static capacitors/reactors (NC), old base (OBASE), new base (NBASE), and the line shunt admittance (ST); its format is (5I2,2F10.5). The remaining cards of this class are for the index of buses (BN(I),I=1,NB), the format for each card is (8I3).

EXAMPLE: A system has 14 buses, 20 lines, 4 voltage control buses, 1 static capacitor. Old base used is 100 MVA, new base used is 100 MVA too, the tolerance used is 0.001, the allowed iteration step is 25, line shunt admittance is given as one-half of the total line shunt admittance, and both printed and punched outputs are required.

LNHFR
1
↑
Col. 1

(Note: If only printed output is required, input LNHFR as 0)

TOLE	ITER1
0000.001	25
↑	↑
Col's 1	12

NL	NB	BM	NC	ST	OBASE	NBASE
20	14	4	1	0	100.	100.
↑	↑	↑	↑	↑	↑	↑
Col's 1	3	6	8	10	12	22

(Note If the total line shunt admittance is used, input nonzero integer for ST)

BN(I),I=1,8

1	-2	-3	-4	-5	6	7	8
↑	↑	↑	↑	↑	↑	↑	↑
Col's 3	5	8	11	14	18	21	24

(Note: the index of a voltage control bus must carry a negative sign)

STEP 3 Transmission Line and Transformer Line Cards

Each of these cards is for one single line, it consists of the starting bus index (SB), ending bus index (EB), series impedance per unit length (ZSER), shunt admittance per unit length (YSHT), tap setting (TR), length of the line (LENGTH), and a variable TS which indicates the type of the line (if TS is equal to zero, it is a transmission line, otherwise, it is a transformer line). The format of each card is (2I3,4F10.5,F5.3, F5.1,I1).

EXAMPLE: A transformer line is connected from bus 6 to bus 7, the series impedance per unit length is 0.0+j0.20912, the shunt admittance per unit length is 0.0+j0.0, the length of the line is 1 unit length, the tap setting is 0.978.

SB	EB	ZSER		YSHT		TR	LENGTH	TS
6	7	0.0	0.20912	0.0	0.0	0.978	-1.0	1
↑	↑	↑	↑	↑	↑	↑	↑	↑
Col's 3	6	10	21	30	40	47	53	57

(Note: If the line is a transmission line, input a negative real number for TR. If the length of the line is 1 unit length, input a negative real number for LENGTH. Input TS as 0 for a transmission line)

STEP 4 Static Capacitor/Reactor Cards (if any)

Each of these cards is for one static capacitor/reactor, it consists of the index of the bus where the static capacitor/reactor is connected, and the susceptance of the static capacitor/reactor (CC). Its format is (I5,F10.5).

EXAMPLE: A static capacitor is connected to bus 9, and its susceptance is 0.19000.

BNL	CC
9	0.190
↑	↑
Col's 5	9

STEP 5 Swing Bus Cards

The first card consists of the real load (P_L) and the reactive load (Q_L) at the swing bus, its format is (2F10.5). The second cards consists of the voltage magnitude (MAGV) and its phase angle (DELTAA) at the swing bus, the format os this card is (2F10.5) also.

EXAMPLE: The magnitude and its phase angle at a swing bus are respectively 1.06 pu and 0.0 radian. The real load and reactive load at this bus are respectively 0.0 MW and 0.0 MVAR.

P_L	Q_L
0.00	0.00
↑	↑
Col's 4	14

MAGV	DELTAA
1.06000	0.000
↑	↑
Col's 4	14

STEP 6 Voltage Control Bus Cards

Each of these cards is for one voltage control bus; it consists of the specified voltage magnitude (VSPEC), the maximum generated reactive power at this bus (QMAX), the minimum generated reactive power at this bus (QMIN), the real load at this bus (PL), the reactive load at this bus (Q_L) and the generated real power at this bus (P_G); its format is (6F10.5).

EXAMPLE: The specified voltage magnitude of a voltage control bus is 1.045 pu; its constraints of maximum and minimum generated reactive powers are respectively 50 MVAR and -40 MVAR; its real and reactive loads are respectively 21.7 MW and 12.7 MVAR; its generated real power is 40.0 MW.

VSPEC	QMIN	QMAX	PL	PG	QL
1.045	-40.0	50.0	21.7	40.0	12.7
↑	↑	↑	↑	↑	↑
Col's 4	12	23	33	43	53

STEP 7 Load Bus Cards

Each of these cards is for one load bus, it consists of the generated real power at this bus (PG), the generated reactive power at this bus (QG), the real load at this bus (PL), the reactive load at this bus (QL), the maximum constraint of bus voltage magnitude (VMAX), the minimum constraint of bus voltage magnitude (VMIN); its format is (6F10.5).

EXAMPLE: The generated real and reactive powers at a load bus are respectively 0.0 MW and 0.0 MVAR, the real load and reactive load at this bus are respectively 30.0 MW and 15.0 MVAR, the maximum and minimum constraints of voltage magnitude at this bus are respectively 1.5 pu and 0.7 pu.

PG	QG	PL	QL	VMAX	VMIN
0.0	0.0	30.0	15.0	1.5	0.7
↑	↑	↑	↑	↑	↑
Col's 4	14	23	33	44	54

STEP 8 Combine all the data cards in the order described in Step 1.

(C) Program Output

The program output consists of the input data, the load flow solution, system totals, and the mismatch.

The input data is the data the user supplied. This section of the output is used for troubleshooting.

The load flow solution gives the number of iterations for convergence, and the base MVA value for the output. At each bus the pu voltage magnitude, phase angle (in degrees), real and reactive generated powers, real and reactive line flows in MW and MVAR. The positive values of real and/or reactive power indicate the power flow towards the ending bus, whereas the negative values indicate flow away from the ending bus. If one desires to calculate the losses in a line, one simply goes to the two buses to which the line is connected and notes that the line flow is given twice. Each bus is used as the reference in turn, therefore the line flows are negative of each other. The sum of the line flows is the line loss.

The system totals consist of total generation, load, injected power, and total losses. The total generation is simply calculated by adding the real and reactive generation at each bus. The static injected power and load are calculated similarly. The total losses are calculated by adding the total generation and the total injected power by static capacitors or reactors and substracting the total load.

The last part of the putout is the mismatch. The mismatch tells how good the load flow solution is. The first value is the swing bus net power which is calculated by simply summing the line flows at bus 1. The remaining mismatch values are calculated by subtracting the total line flows from a bus from the net power at the bus. (Net power equals generation minus load.) Total mismatch is calculated by adding the individual mismatches. The average is the total mismatch divided by (N-1).

(D) Troubleshooting

The input data listed in the output of the load flow program makes it convenient for users to troubleshoot. If no input listing is printed out, then one either has the input cards in improper order or does not have the proper number of cards. Also values in the incorrect columns of data cards may cause no listing.

If the program does not converge in the allowed number of iteration steps, one must make sure that the constraints (Q_{max}, Q_{min}, V_{max}, V_{min}) are given properly.

(IV) Transient Stability Program (TSRK)

(A) Program Description

TSRK is also a Fortran program which calculate the bus terminal voltage, machine speed, relative rotor angular position, machine internal voltage, and bus injected power for a power system throughout a transient observation period.

Input to the program consists of

(1) Prefault condition, which is the punched output of the load flow program.

(2) Fault condition parameters.

(3) Machine parameters.

(4) Control loop parameters.

All the time constants are in seconds, machine inertia and transient reactance are in per unit on a known MVA base (old base).

Normal output consists of

(1) Input data.

(2) Initial faulted condition.

(3) Machine internal voltage throughout an observation interval.

(4) Machine speed and its relative rotor angular position throughout and observation interval.

(5) Bus terminal voltage and injected power throughout an observation interval.

(B) Program Input

TSRK uses a fixed format input. The following steps are used in preparing the input data cards.

STEP 1 Identify the System

Determine the number of machines (M), number of faults (NFB), fault location, fault clearing time, switching time, step size (DELTT) used in Runge-Kutta 4th order method, error tolerance (TOLE) used in Runge-Kutta 4th order method. The remaining steps will describe the data, its order, and data format, the data cards are placed in the following order.

(1) The prefault condition cards.

(2) Machine parameter cards.

(3) Fault condition cards.

(4) Control loop cards.

(5) Runge-Kutta 4th order method card.

STEP 2 Prefault Condition Cards

The prefault condition cards are the punched output of the load flow program, they consist of the loads, the prefault injected power at each bus, the prefault bus terminal voltage, the prefault bus admittance matrix (YBUS) and its corresponding tables (IYBUS, JYBUS), the tables for the reordering scheme, and the number of lines (NL) of the system in the prefault condition.

STEP 3 Machine Parameter Cards

The first card consists of the number of machines (M) and the machine open-circuit time constant (TDOP); its format is (I3,F10.5). Each of the remaining machine parameter cards is for one single machine, it consists of the index of the bus where the machine is connected (MAB), the transient reactance of that machine (XDP), and the inertia constant of this machine (H); the format of each card is (I3,2F10.5).

EXAMPLE: There is one machine in a system, the open-circuit time constant of that machine is 0.01 seconds. The machine is connected to bus 2, the transient reactance of the machine is 0.1 pu, and its inertia is 5 pu.

M	TDOP
1	0.01
↑	↑
Col's 3	7

MAB	XDP	H
2	0.1	5.0
↑	↑	↑
Col's 3	7	17

STEP 4 Fault Condition Cards

The first card consists of the number of faulted buses (NFB), the number of faulted lines (NFBL), the fault clearing time (TMAX), and the switching time (TSW); its format is (2I3,2F10.5). The remaining fault condition cards can be divided into two parts. Each card of the first part is for one single faulted bus. It consists of the index of the faulted bus (FB); its format is (I3). Each card of the second part is for one single faulted line. It consists of the index of the starting bus (SB1) of the faulted line and the index of the ending bus (EB1) of this faulted line; its format is (2I3).

EXAMPLE: A three phase to ground fault occurs at bus 3, one transmission line connected from bus 3 to bus 6 is involved, the fault will be cleared after 0.5 seconds, and the fault switching time is 0.3 seconds.

NFB	NFBL	TMAX	TSW
1	1	0.50	0.30
↑	↑	↑	↑
Col's 3	6	10	20

FB

3
↑
Col's 3

SB1	EB1
3	6
↑	↑
Col's 3	6

STEP 5 Control Loop Parameter Cards

The first card consists of steam system time constant (TS), speed control system time constant (TC), the speed regulation of the governor system in pu (R), the dead band travel of the governor system (DBT), and the maximum turbine capability (PMAX); its format is (5F10.5). The second card consists of the regulator time constant (TR) of the excitation control loop, the amplifier time constant (TA) of the excitation control loop, the amplifier gain (KA), the exciter time constant (TE), and the exciter gain (KE); its format is (5F10.5). The third card consists of the stabilizing loop time constant (TF) of the excitation control loop, the stabilizing loop time constant (KF), and the exciter saturation characteristic constants (A1) and (B1); its format is (4F10.5).

EXAMPLE: An electrical power system has the excitation and speed governor control loops, their parameters are as follows:

1. speed governor control loop
   TS = 0.3 sec. TC = 0.08 sec. R = -0.04, DBT = 0.0006
   PMAX = 1.1 pu.
2. excitation control loop
   TR = 0.03 sec, TA = 0.1 sec, KA = 30.0, KF = 0.05, TF = 0.6 sec,
   KE = -0.05, TE = 0.5 sec, A1 = 1.2, B1 = 1.1

TS	TC	R	DBT	PMAX
0.3	0.03	-0.04	0.0006	1.1
↑	↑	↑	↑	↑
Col's 4	14	23	34	44

TR	TA	KA	TE	KE
0.03	0.1	30.0	0.5	-0.05
↑	↑	↑	↑	↑
Col's 4	14	23	34	43

TF	KF	A1	B1
0.6	0.05	1.2	1.1
↑	↑	↑	↑
Col's 14	14	24	34

STEP 6 Runge-Kutta 4th-order Method Card

This card consists of the step size used in Runge-Kutta 4th-order method (DELTT) and the error tolerance used in Runge-Kutta 4th-order method (PRMT(4)); its format is (2F10.5).

EXAMPLE: If DELTT is equal to 0.01 seconds and PRMT(4) is assigned to 0.1.

DELTT	PRMT(4)
0.01	0.1
↑	↑
Col's 4	14

(C) Program Output

The program output consists of the input data, initial faulted condition and the solution throughout a transient observation interval.

The input data listing in the program output consists of the number of machines, the index of machine buses, the number of faulted buses, the index of faulted buses, the number of faulted lines, the index of the starting buses and the ending buses of the faulted lines, the machine parameters, the control loop parameters, the step size used in Runge-Kutta 4th-order method, and the error tolerance used in Runge-Kutta 4th-order method.

The initial faulted condition consists of the terminal voltage at each bus right after the fault occurs, the internal voltage for each machine right after the fault occurs.

The solution throughout a transient observation interval consists of the internal voltage for each machine, the terminal voltage at each bus, the injected real and reactive powers at each bus, and the local load supplied at each bus throughout the observation interval.

(D) Troubleshooting

TSRK uses the fixed format input, it is necessary to make sure that the input cards are placed in the proper order and the input data on each card is punched at the right position.

If there is no printed transient state solution in the program output, it is better to ascertain that the step size used is not too small and the error tolerance used is not too small to be practical.

(V) Solutions for a 7-Bus System

The set of programs were used to solve the transient stability problem for several sample systems. Because the large volume of data involved only the solution for a 7-bus system are included in this report.

The programs listing are included in the Appendices. The load flow program is listed in Appendix A and the transient stability program is listed in Appendix B.

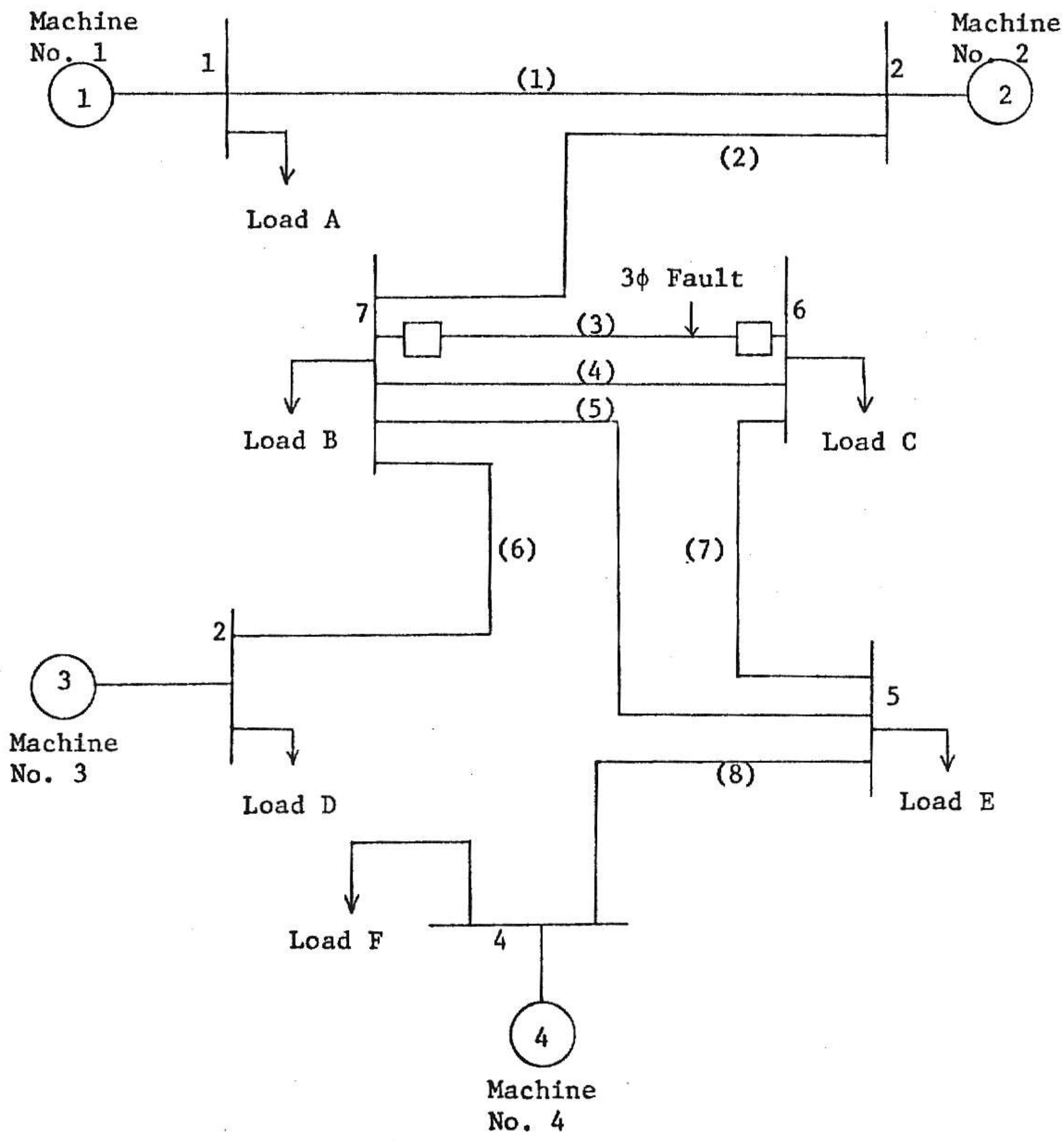


Fig. 4.2 TOPOLOGY OF THE SEVEN-BUS SAMPLE SYSTEM

ILLEGIBLE DOCUMENT

THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

THIS IS THE BEST COPY AVAILABLE

I N P U T D A T A

NO. OF LINES(NL) = 8   NO. OF BUSES(NB) = 7   NO. OF CAPACITORS/REACTOR(NC) = 0

NO. OF VOLTAGE CONTROL BUSES (BM) = 3

BASE FOR INPUTTED DATA(OLD BASE) = 100. MVA   BASE FOR OUTPUT(NEW BASE) = 100. MVA

TOLERANCE FOR CONVERGENCE = 0.001000   MAXIMUM NO. OF ITERATIONS ALLOWED = 11

SWING BUS VOLTAGE MAGNITUDE = 1.12700 PU   SWING BUS PHASE = 18.72 DEGREES

TRANSMISSION LINE DATA (OLD BASE)
Y SHUNT IS ONE-HALF OF THE TOTAL LINE CHARGING ADMITTANCE

SB	EB	Z SERIES R	Z SERIES X	Y SHUNT G	Y SHUNT B	LENGTH
1	-2	0.13100	0.79800	0.00000	0.00000	1.0
-2	7	0.01720	0.16400	0.00000	0.00000	1.0
6	7	0.01290	0.06880	0.00000	0.00000	1.0
5	7	0.01290	0.06380	0.00000	0.00000	1.0
7	5	0.05520	0.20300	0.00000	0.00000	1.0
-3	7	0.10160	0.37900	0.00000	0.00000	1.0
5	6	0.75300	1.27000	0.00000	0.00000	1.0
-4	5	0.06900	0.14400	0.00000	0.00000	1.0

TOTAL TRANSMISSION LINES = 8

VOLTAGE CONTROL BUS DATA

BUS	VSPEC PU	QMIN MVAR	QMAX MVAR
2	1.095	-50.000	150.000
3	0.973	-50.000	150.000
4	0.942	-50.000	150.000

SCHEDULED BUS POWERS

BUS	GENERATION MW	GENERATION MVAR	LOAD MW	LOAD MVAR
1	UNSPECIFIED	UNSPECIFIED	62.260	2.444
2	119.070	UNSPECIFIED	0.000	0.000
3	33.140	UNSPECIFIED	70.000	47.300
4	73.570	UNSPECIFIED	83.300	50.500
5	0.000	0.000	6.500	2.510
6	0.000	0.000	10.180	9.200
7	0.000	0.000	15.750	17.000

NEWTON-RAPHSON TECHNIQUE CONVERGED IN 4 ITERATIONS. ALL VALUES ON 100. MVA BASE

		VOLTAGE MAGNITUDE PU	DELTA(DEGS)		GENERATION MW	GENERATION MVAR	LOAD MW	LOAD MVAR	INJECTED POWER (STATIC) MVAR
BUS	1	1.127	18.7200		86.109	4.837	62.260	2.444	
		2	23.849	2.393					
BUS	2	1.095	9.9959		119.070	63.716	0.000	0.000	
		1	-23.256	1.215					
		7	142.326	62.500					
BUS	3	0.973	-10.3449		33.140	53.057	70.000	47.300	
		7	-36.860	5.757					
BUS	4	0.941	-15.2370		23.570	64.950	83.300	50.500	
		5	-59.730	14.450					
BUS	5	0.969	-9.1952		0.000	0.000	6.500	2.510	
		7	-59.890	5.293					
		6	-9.279	0.507					
		4	62.670	-8.315					
BUS	6	0.995	-2.0914		0.000	0.000	10.180	9.200	
		7	-9.853	-4.931					
		7	-9.853	-4.931					
		5	9.526	0.663					
BUS	7	1.000	-1.7377		0.000	0.000	18.750	17.000	
		2	-138.860	-29.450					
		6	9.869	5.015					
		6	9.869	5.015					
		5	62.017	2.602					
		3	38.355	-0.181					

TOTALS	MW	MVAR
GENERATION	261.889	186.560
STATIC CAP/REACTORS		0.000
LOAD	250.990	128.954
LINE LOSSES	10.899	57.605

MISMACHES

	23.849	2.393
	0.000	-0.000
	0.000	-0.000
	-0.000	0.000
	-0.000	-0.000
	0.000	0.001
	-0.000	0.002
TOTAL MISMACH	0.000	0.003
AVERAGE MISMACH	0.000	0.001

FORM N14110

```
                                 I N P U T   D A T A

NO. OF MACHINES(M)=      4     NO. OF FAULTED BUSES(NFB)=     1      NO. OF FAULTED LINES(NFBL)=     1
MACHINE BUSES ARE:  BUS   1
                    BUS   2
                    BUS   3
                    BUS   4
FAULTED BUSES ARE:  BUS   6
FAULTED LINES ARE:  STARTING BUS   6     ENDING BUS   7
THE THREE PHASE TO GROUND FAULTS HAPPEN AT TIME(T)= 0.0 SECONDS
THE FAULT WILL BE CLEARED AT TIME(T)=   0.500 SECONDS
THE FAULT WILL BE SWITCHED OFF AT TIME(T)=   0.300 SECONDS

** DATA FOR MACHINES**
THE MACHINE AT BUS   1 ; TRANSIENT REACTANCE=    0.13000 PU
THE MACHINE AT BUS   2 ; TRANSIENT REACTANCE=    0.15000 PU
THE MACHINE AT BUS   3 ; TRANSIENT REACTANCE=    0.28000 PU
THE MACHINE AT BUS   4 ; TRANSIENT REACTANCE=    0.25900 PU
THE MACHINE AT BUS   1 ; THE INERTIA CONSTANT(H)=    5.49000 PU
THE MACHINE AT BUS   2 ; THE INERTIA CONSTANT(H)=    7.65000 PU
THE MACHINE AT BUS   3 ; THE INERTIA CONSTANT(H)=    5.50000 PU
THE MACHINE AT BUS   4 ; THE INERTIA CONSTANT(H)=    4.69000 PU

** DATA FOR EXCITATION SYSTEMS **
REGULATOR TIME CONSTANT(TR)=   0.03000     AMPLIFIER TIME CONSTANT(TA)=   0.12000
EXCITER TIME CONSTANT(TE)=   0.50000     STABILIZING LOOP TIME CONSTANT(TF)=   0.65000
AMPLIFIER GAIN(KA)=  35.00000     EXCITER GAIN(KE)=  -0.05000
STABILIZING LOOP GAIN=   0.04500

** DATA FOR SPEED GOVERNOR CONTROL SYSTEM **
STEAM SYSTEM TIME CONSTANT(TS)=   0.30000     CONTROL SYSTEM TIME CONSTANT(TC)=   0.08000

** TIME INCREMENT USED(DELTT)=    0.01000
ERROR TOLERENCE USED(PRMT(4))=    0.50000
```

INITIAL CONDITIONS

```
TERMINAL VOLTAGE OF EVERY BUS
TERMINAL VOLTAGE AT BUS   1 =   1.01846   0.35702
TERMINAL VOLTAGE AT BUS   4 =   0.58137  -0.25939
TERMINAL VOLTAGE AT BUS   3 =   0.64837  -0.17888
TERMINAL VOLTAGE AT BUS   6 =   0.00000   0.00000
TERMINAL VOLTAGE AT BUS   2 =   0.72241   0.18654
TERMINAL VOLTAGE AT BUS   5 =   0.39718  -0.11940
TERMINAL VOLTAGE AT BUS   7 =   0.19140  -0.00030

INTERNAL VOLTAGE FOR MACHINE AT BUS   1 =   1.04079   0.45756

INTERNAL VOLTAGE FOR MACHINE AT BUS   2 =   1.13602   0.36585

INTERNAL VOLTAGE FOR MACHINE AT BUS   3 =   1.12418  -0.10822

INTERNAL VOLTAGE FOR MACHINE AT BUS   4 =   1.09783  -0.23184
```

THE RESULT FOR EVERY 0.02 SEC IS AS FOLLOWS

```
THE RESULT AT TIME(T)=    0.00000 SECONDS
THE MACHINE AT BUS   1
ITS INTERNAL VOLTAGE MAGNITUDE=     1.13692      ANGULAR POSITION OF THE ROTOR=   23.73186 DEGREES
ITS MACHINE SPEED=  376.99090 RADIANS PER SECOND
THE MACHINE AT BUS   2
ITS INTERNAL VOLTAGE MAGNITUDE=     1.19348      ANGULAR POSITION OF THE ROTOR=   17.85100 DEGREES
ITS MACHINE SPEED=  376.99090 RADIANS PER SECOND
THE MACHINE AT BUS   3
ITS INTERNAL VOLTAGE MAGNITUDE=     1.12938      ANGULAR POSITION OF THE ROTOR=   -5.49881 DEGREES
ITS MACHINE SPEED=  376.99090 RADIANS PER SECOND
THE MACHINE AT BUS   4
ITS INTERNAL VOLTAGE MAGNITUDE=     1.12204      ANGULAR POSITION OF THE ROTOR=  -11.92439 DEGREES
ITS MACHINE SPEED=  376.99090 RADIANS PER SECOND
```

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.079	19.3178	15.549	42.858	57.093	2.241
BUS	2	0.746	14.4793	34.924	221.498	0.000	-0.000
BUS	3	0.673	-15.4234	13.281	83.045	33.476	22.620
BUS	4	0.637	-24.0452	19.325	90.081	38.085	23.089
BUS	5	0.415	-16.7321	-1.192	-0.460	1.192	0.460
BUS	6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS	7	0.191	-0.0910	-0.687	-0.623	0.687	0.623

```
THE RESULT AT TIME(T)=    0.02000 SECONDS
THE MACHINE AT BUS   1
ITS INTERNAL VOLTAGE MAGNITUDE=     1.13472      ANGULAR POSITION OF THE ROTOR=   23.78453 DEGREES
ITS MACHINE SPEED=  377.08390 RADIANS PER SECOND
THE MACHINE AT BUS   2
ITS INTERNAL VOLTAGE MAGNITUDE=     1.18720      ANGULAR POSITION OF THE ROTOR=   18.08804 DEGREES
ITS MACHINE SPEED=  377.40500 RADIANS PER SECOND
THE MACHINE AT BUS   3
ITS INTERNAL VOLTAGE MAGNITUDE=     1.12682      ANGULAR POSITION OF THE ROTOR=   -5.55266 DEGREES
ITS MACHINE SPEED=  376.99740 RADIANS PER SECOND
THE MACHINE AT BUS   4
ITS INTERNAL VOLTAGE MAGNITUDE=     1.11931      ANGULAR POSITION OF THE ROTOR=  -12.08280 DEGREES
ITS MACHINE SPEED=  376.71530 RADIANS PER SECOND
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		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.077	19.3845	15.271	42.942	56.841	2.231
BUS	2	0.743	14.6781	34.956	219.079	0.000	-0.000
BUS	3	0.671	-15.4692	13.190	82.705	33.305	22.505
BUS	4	0.635	-24.1893	19.663	89.688	37.872	22.959

BUS	5	0.413	-16.8415	-1.184	-0.457	1.184	0.457
BUS	6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS	7	0.191	-0.0259	-0.681	-0.617	0.681	0.617

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THE RESULT AT TIME(T)=     0.04000 SECONDS
THE MACHINE AT BUS    1
ITS INTERNAL VOLTAGE MAGNITUDE=      1.13253      ANGULAR POSITION OF THE ROTOR=   23.94635 DEGREES
ITS MACHINE SPEED=  377.18130 RADIANS PER SECOND
THE MACHINE AT BUS    2
ITS INTERNAL VOLTAGE MAGNITUDE=      1.18108      ANGULAR POSITION OF THE ROTOR=   18.79791 DEGREES
ITS MACHINE SPEED=  377.81540 RADIANS PER SECOND
THE MACHINE AT BUS    3
ITS INTERNAL VOLTAGE MAGNITUDE=      1.12435      ANGULAR POSITION OF THE ROTOR=   -5.71240 DEGREES
ITS MACHINE SPEED=  376.30630 RADIANS PER SECOND
THE MACHINE AT BUS    4
ITS INTERNAL VOLTAGE MAGNITUDE=      1.11666      ANGULAR POSITION OF THE ROTOR=  -12.55503 DEGREES
ITS MACHINE SPEED=  376.44330 RADIANS PER SECOND
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		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.074	19.5876	14.551	43.067	56.591	2.221
BUS	2	0.739	15.2754	35.749	216.708	0.000	-0.000
BUS	3	0.669	-15.5964	12.993	82.427	33.121	22.330
BUS	4	0.633	-24.6095	19.348	89.395	37.626	22.810
BUS	5	0.412	-17.1459	-1.174	-0.454	1.174	0.454
BUS	6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS	7	0.189	0.1977	-0.673	-0.611	0.673	0.610

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THE RESULT AT TIME(T)=     0.06000 SECONDS
THE MACHINE AT BUS    1
ITS INTERNAL VOLTAGE MAGNITUDE=      1.13040      ANGULAR POSITION OF THE ROTOR=   24.22464 DEGREES
ITS MACHINE SPEED=  377.28780 RADIANS PER SECOND
THE MACHINE AT BUS    2
ITS INTERNAL VOLTAGE MAGNITUDE=      1.17524      ANGULAR POSITION OF THE ROTOR=   19.97429 DEGREES
ITS MACHINE SPEED=  373.21870 RADIANS PER SECOND
THE MACHINE AT BUS    3
ITS INTERNAL VOLTAGE MAGNITUDE=      1.12206      ANGULAR POSITION OF THE ROTOR=   -5.97508 DEGREES
ITS MACHINE SPEED=  376.71900 RADIANS PER SECOND
THE MACHINE AT BUS    4
ITS INTERNAL VOLTAGE MAGNITUDE=      1.11421      ANGULAR POSITION OF THE ROTOR=  -13.33597 DEGREES
ITS MACHINE SPEED=  376.17670 RADIANS PER SECOND
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		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.072	19.9331	13.418	43.240	56.344	2.212
BUS	2	0.735	16.2659	37.266	214.433	0.000	-0.000

BUS	3	0.667	-15.8033	12.702	82.225	32.923	22.250
BUS	4	0.630	-25.3028	18.884	89.215	37.354	22.645
BUS	5	0.410	-17.6568	-1.163	-0.449	1.163	0.449
BUS	6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS	7	0.183	0.5781	-0.664	-0.602	0.664	0.602

THE RESULT AT TIME(T)= 0.08000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12834 ANGULAR POSITION OF THE ROTOR= 24.63014 DEGREES
ITS MACHINE SPEED= 377.40420 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.16979 ANGULAR POSITION OF THE ROTOR= 21.60767 DEGREES
ITS MACHINE SPEED= 378.61230 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12008 ANGULAR POSITION OF THE ROTOR= -6.33679 DEGREES
ITS MACHINE SPEED= 376.63350 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11209 ANGULAR POSITION OF THE ROTOR= -14.41876 DEGREES
ITS MACHINE SPEED= 375.91690 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	MVAR	LOCAL LOAD SUPPLIED MW	MVAR
BUS	1	1.070	20.4300	11.905	43.468	56.102	2.202
BUS	2	0.732	17.6437	39.455	212.306	0.000	-0.000
BUS	3	0.665	-16.0878	12.329	82.116	32.731	22.117
BUS	4	0.629	-26.2650	18.298	89.165	37.061	22.468
BUS	5	0.407	-18.3619	-1.149	-0.444	1.149	0.444
BUS	6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS	7	0.187	1.1134	-0.653	-0.592	0.653	0.592

THE RESULT AT TIME(T)= 0.10000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12637 ANGULAR POSITION OF THE ROTOR= 25.17645 DEGREES
ITS MACHINE SPEED= 377.53390 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.16485 ANGULAR POSITION OF THE ROTOR= 23.68408 DEGREES
ITS MACHINE SPEED= 378.99160 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11848 ANGULAR POSITION OF THE ROTOR= -6.79306 DEGREES
ITS MACHINE SPEED= 376.55290 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11038 ANGULAR POSITION OF THE ROTOR= -15.79466 DEGREES
ITS MACHINE SPEED= 375.66550 RADIANS PER SECOND

VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	MVAR	LOCAL LOAD SUPPLIED MW	MVAR

FORM N1411D

BUS	1	1.068	21.0896	10.057	43.766	55.864	2.193
BUS	2	0.728	19.4006	42.246	210.367	0.000	-0.000
BUS	3	0.663	-16.4482	11.889	82.112	32.533	21.983
BUS	4	0.625	-27.4955	17.621	89.257	36.751	22.290
BUS	5	0.405	-19.2660	-1.134	-0.438	1.134	0.438
BUS	6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS	7	0.135	1.8012	-0.640	-0.581	0.640	0.581

THE RESULT AT TIME(T)= 0.12000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12451 ANGULAR POSITION OF THE ROTOR= 25.87967 DEGREES
ITS MACHINE SPEED= 377.67840 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.16046 ANGULAR POSITION OF THE ROTOR= 26.18597 DEGREES
ITS MACHINE SPEED= 379.35420 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11734 ANGULAR POSITION OF THE ROTOR= -7.33909 DEGREES
ITS MACHINE SPEED= 376.47700 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.10915 ANGULAR POSITION OF THE ROTOR= -17.45313 DEGREES
ITS MACHINE SPEED= 375.42380 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.065	21.9251	7.921	44.149	55.629	2.184
BUS	2	0.725	21.5264	45.555	208.647	0.000	-0.000
BUS	3	0.661	-16.8829	11.400	82.224	32.336	21.850
BUS	4	0.623	-28.5871	16.885	89.496	36.424	22.082
BUS	5	0.401	-20.3708	-1.116	-0.431	1.116	0.431
BUS	6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS	7	0.183	2.6385	-0.625	-0.567	0.625	0.567

THE RESULT AT TIME(T)= 0.14000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12277 ANGULAR POSITION OF THE ROTOR= 26.75810 DEGREES
ITS MACHINE SPEED= 377.83980 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.15663 ANGULAR POSITION OF THE ROTOR= 29.09236 DEGREES
ITS MACHINE SPEED= 379.69720 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11666 ANGULAR POSITION OF THE ROTOR= -7.96904 DEGREES
ITS MACHINE SPEED= 376.40640 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.10842 ANGULAR POSITION OF THE ROTOR= -19.38275 DEGREES
ITS MACHINE SPEED= 375.19230 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.063	22.9518	5.554	44.635	55.395	2.175
BUS	2	0.721	24.0093	49.276	207.157	-0.000	-0.000
BUS	3	0.659	-17.3898	10.892	82.453	32.136	21.715
BUS	4	0.620	-30.7373	16.129	89.878	36.077	21.871
BUS	5	0.398	-21.6805	-1.096	-0.423	1.096	0.423
BUS	6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS	7	0.180	3.6223	-0.608	-0.551	0.608	0.551

THE RESULT AT TIME(T)= 0.16000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12115 ANGULAR POSITION OF THE ROTOR= 27.83136 DEGREES
ITS MACHINE SPEED= 378.01870 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.15335 ANGULAR POSITION OF THE ROTOR= 32.37973 DEGREES
ITS MACHINE SPEED= 380.01900 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11643 ANGULAR POSITION OF THE ROTOR= -8.67696 DEGREES
ITS MACHINE SPEED= 376.34100 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.10819 ANGULAR POSITION OF THE ROTOR= -21.57088 DEGREES
ITS MACHINE SPEED= 374.57260 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.061	24.1855	3.014	45.238	55.160	2.165
BUS	2	0.718	26.9367	53.291	205.897	0.000	-0.000
BUS	3	0.657	-17.9678	10.354	82.797	31.932	21.577
BUS	4	0.616	-32.7429	15.395	90.395	35.708	21.648
BUS	5	0.393	-23.2015	-1.073	-0.414	1.073	0.414
BUS	6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS	7	0.177	4.7502	-0.587	-0.532	0.587	0.532

THE RESULT AT TIME(T)= 0.18000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11966 ANGULAR POSITION OF THE ROTOR= 29.12038 DEGREES
ITS MACHINE SPEED= 378.21650 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.15056 ANGULAR POSITION OF THE ROTOR= 36.02287 DEGREES
ITS MACHINE SPEED= 380.31780 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11662 ANGULAR POSITION OF THE ROTOR= -9.45663 DEGREES
ITS MACHINE SPEED= 376.28120 RADIANS PER SECOND

THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.10843 ANGULAR POSITION OF THE ROTOR= -24.00409 DEGREES
ITS MACHINE SPEED= 374.76460 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.058	25.6437	0.364	45.968	54.921	2.156
BUS	2	0.714	29.9961	57.466	204.361	0.000	-0.000
BUS	3	0.655	-18.6157	9.841	83.249	31.717	21.432
BUS	4	0.613	-35.0009	14.730	91.031	35.314	21.409
BUS	5	0.339	-24.9431	-1.046	-0.404	1.046	0.404
BUS	6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS	7	0.173	6.0206	-0.563	-0.510	0.563	0.510

THE RESULT AT TIME(T)= 0.20000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11830 ANGULAR POSITION OF THE ROTOR= 30.64679 DEGREES
ITS MACHINE SPEED= 378.43310 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.14820 ANGULAR POSITION OF THE ROTOR= 39.99471 DEGREES
ITS MACHINE SPEED= 390.59220 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11719 ANGULAR POSITION OF THE ROTOR= -10.30171 DEGREES
ITS MACHINE SPEED= 376.22700 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.10909 ANGULAR POSITION OF THE ROTOR= -26.66895 DEGREES
ITS MACHINE SPEED= 374.56830 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.056	27.3440	-2.336	46.331	54.678	2.146
BUS	2	0.739	33.4739	61.656	204.036	0.000	-0.000
BUS	3	0.652	-19.3331	9.368	83.798	31.488	21.277
BUS	4	0.609	-37.5058	14.184	91.763	34.893	21.154
BUS	5	0.333	-26.9184	-1.016	-0.392	1.016	0.392
BUS	6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS	7	0.169	7.4323	-0.535	-0.485	0.535	0.485

THE RESULT AT TIME(T)= 0.22000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11705 ANGULAR POSITION OF THE ROTOR= 32.43205 DEGREES
ITS MACHINE SPEED= 378.66820 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.14620 ANGULAR POSITION OF THE ROTOR= 44.26677 DEGREES

ITS MACHINE SPEED= 380.84220 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11806 ANGULAR POSITION OF THE ROTOR= -11.20575 DEGREES
ITS MACHINE SPEED= 376.17820 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11012 ANGULAR POSITION OF THE ROTOR= -29.55222 DEGREES
ITS MACHINE SPEED= 374.38330 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	MVAR	LOCAL LOAD SUPPLIED MW	MVAR
BUS	1	1.054	29.3040	-5.022	47.822	54.430	2.137
BUS	2	0.705	37.2565	65.713	203.408	0.000	-0.000
BUS	3	0.650	-20.1195	8.961	84.432	31.240	21.109
BUS	4	0.605	-40.2689	13.809	92.567	34.445	20.882
BUS	5	0.377	-29.1450	-0.983	-0.380	0.983	0.379
BUS	6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS	7	0.164	8.9901	-0.504	-0.457	0.504	0.457

THE RESULT AT TIME(T)= 0.24000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11591 ANGULAR POSITION OF THE ROTOR= 34.49707 DEGREES
ITS MACHINE SPEED= 378.92130 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.14451 ANGULAR POSITION OF THE ROTOR= 48.81189 DEGREES
ITS MACHINE SPEED= 381.06880 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11920 ANGULAR POSITION OF THE ROTOR= -12.16279 DEGREES
ITS MACHINE SPEED= 376.13450 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11147 ANGULAR POSITION OF THE ROTOR= -32.64183 DEGREES
ITS MACHINE SPEED= 374.20820 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	MVAR	LOCAL LOAD SUPPLIED MW	MVAR
BUS	1	1.051	31.5411	-7.640	48.931	54.176	2.127
BUS	2	0.700	41.3318	69.488	202.966	0.000	-0.000
BUS	3	0.647	-20.9756	8.647	85.134	30.971	20.928
BUS	4	0.601	-43.2786	13.654	93.414	33.973	20.596
BUS	5	0.369	-31.6451	-0.946	-0.365	0.946	0.365
BUS	6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS	7	0.158	10.6964	-0.469	-0.425	0.469	0.425

THE RESULT AT TIME(T)= 0.26000 SECONDS
THE MACHINE AT BUS 1

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ITS INTERNAL VOLTAGE MAGNITUDE=    1.11489     ANGULAR POSITION OF THE ROTOR=   36.86220 DEGREES
ITS MACHINE SPEED=  379.19160 RADIANS PER SECOND
THE MACHINE AT BUS   2
ITS INTERNAL VOLTAGE MAGNITUDE=    1.14308     ANGULAR POSITION OF THE ROTOR=   53.60432 DEGREES
ITS MACHINE SPEED=  381.27410 RADIANS PER SECOND
THE MACHINE AT BUS   3
ITS INTERNAL VOLTAGE MAGNITUDE=    1.12053     ANGULAR POSITION OF THE ROTOR=  -13.16705 DEGREES
ITS MACHINE SPEED=  376.09570 RADIANS PER SECOND
THE MACHINE AT BUS   4
ITS INTERNAL VOLTAGE MAGNITUDE=    1.11310     ANGULAR POSITION OF THE ROTOR=  -35.92664 DEGREES
ITS MACHINE SPEED=  374.04220 RADIANS PER SECOND
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	VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	MVAR	LOCAL LOAD SUPPLIED MW	MVAR
BUS 1	1.049	34.0724	-10.141	50.139	53.919	2.117
BUS 2	0.594	45.6394	72.345	202.704	0.000	-0.000
BUS 3	0.644	-21.9020	8.453	85.890	30.678	20.730
BUS 4	0.597	-46.5404	13.767	94.276	33.484	20.299
BUS 5	0.362	-34.4457	-0.906	-0.350	0.906	0.350
BUS 6	0.000	0.0000	0.000	-0.000	0.000	-0.000
BUS 7	0.152	12.5635	-0.431	-0.391	0.431	0.391

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THE RESULT AT TIME(T)=    0.28000 SECONDS
THE MACHINE AT BUS   1
ITS INTERNAL VOLTAGE MAGNITUDE=    1.11396     ANGULAR POSITION OF THE ROTOR=   39.54623 DEGREES
ITS MACHINE SPEED=  379.47770 RADIANS PER SECOND
THE MACHINE AT BUS   2
ITS INTERNAL VOLTAGE MAGNITUDE=    1.14189     ANGULAR POSITION OF THE ROTOR=   58.62001 DEGREES
ITS MACHINE SPEED=  381.45940 RADIANS PER SECOND
THE MACHINE AT BUS   3
ITS INTERNAL VOLTAGE MAGNITUDE=    1.12202     ANGULAR POSITION OF THE ROTOR=  -14.21335 DEGREES
ITS MACHINE SPEED=  376.06100 RADIANS PER SECOND
THE MACHINE AT BUS   4
ITS INTERNAL VOLTAGE MAGNITUDE=    1.11497     ANGULAR POSITION OF THE ROTOR=  -39.39751 DEGREES
ITS MACHINE SPEED=  373.88300 RADIANS PER SECOND
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	VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	MVAR	LOCAL LOAD SUPPLIED MW	MVAR
BUS 1	1.046	36.9140	-12.488	51.421	53.661	2.106
BUS 2	0.688	50.3200	75.660	202.618	0.000	-0.000
BUS 3	0.641	-22.9001	8.405	86.684	30.363	20.517
BUS 4	0.592	-50.0567	14.139	95.123	32.989	19.999
BUS 5	0.353	-37.5794	-0.864	-0.334	0.864	0.334
BUS 6	0.000	0.0000	0.000	-0.000	0.000	-0.000

BUS	7	0.144	14.6096	-0.390	-0.353	0.390	0.353

THE RESULT AT TIME(T)= 0.30000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11314 ANGULAR POSITION OF THE ROTOR= 42.56622 DEGREES
ITS MACHINE SPEED= 379.77780 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.14093 ANGULAR POSITION OF THE ROTOR= 63.83762 DEGREES
ITS MACHINE SPEED= 381.62740 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12364 ANGULAR POSITION OF THE ROTOR= -15.29752 DEGREES
ITS MACHINE SPEED= 376.07920 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11707 ANGULAR POSITION OF THE ROTOR= -43.04793 DEGREES
ITS MACHINE SPEED= 373.72850 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.076	39.4589	-6.817	27.069	56.764	2.228
BUS	2	0.888	44.8572	219.583	113.189	0.000	-0.000
BUS	3	0.815	-14.3015	-54.820	56.611	49.136	33.202
BUS	4	0.698	-35.8868	-33.360	82.786	45.817	27.776
BUS	5	0.661	-13.2993	-3.024	-1.168	3.023	1.168
BUS	6	0.690	11.8271	-4.893	-4.422	4.893	4.422
BUS	7	0.700	13.4054	-9.194	-8.337	9.194	8.336

THE RESULT AT TIME(T)= 0.32000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11269 ANGULAR POSITION OF THE ROTOR= 45.89320 DEGREES
ITS MACHINE SPEED= 380.01260 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.13861 ANGULAR POSITION OF THE ROTOR= 68.84285 DEGREES
ITS MACHINE SPEED= 381.09270 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12563 ANGULAR POSITION OF THE ROTOR= -16.24208 DEGREES
ITS MACHINE SPEED= 376.30510 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11360 ANGULAR POSITION OF THE ROTOR= -46.48480 DEGREES
ITS MACHINE SPEED= 374.25360 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.072	42.3920	-8.271	30.364	56.295	2.210
BUS	2	0.861	49.4722	216.954	122.206	0.000	-0.000
BUS	3	0.794	-15.1039	-52.977	62.484	46.638	31.514
BUS	4	0.668	-39.4162	-77.422	88.614	41.924	25.416

BUS	5	0.614	-14.5182	-2.612	-1.008	2.611	1.008
BUS	6	0.644	13.7584	-4.261	-3.851	4.261	3.851
BUS	7	0.654	15.4737	-8.030	-7.281	8.030	7.280

THE RESULT AT TIME(T)= 0.34000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11228 ANGULAR POSITION OF THE ROTOR= 49.49335 DEGREES
ITS MACHINE SPEED= 380.25310 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.13637 ANGULAR POSITION OF THE ROTOR= 73.24258 DEGREES
ITS MACHINE SPEED= 380.57270 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12758 ANGULAR POSITION OF THE ROTOR= -16.86807 DEGREES
ITS MACHINE SPEED= 376.58440 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12022 ANGULAR POSITION OF THE ROTOR= -49.32787 DEGREES
ITS MACHINE SPEED= 374.76290 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.068	46.5344	-8.739	33.001	55.907	2.195
BUS	2	0.839	53.7793	211.731	130.098	0.000	-0.000
BUS	3	0.776	-15.7242	-50.739	67.378	44.504	30.072
BUS	4	0.642	-42.6523	-71.084	93.115	38.784	23.513
BUS	5	0.572	-15.7004	-2.269	-0.876	2.269	0.876
BUS	6	0.602	15.5882	-3.730	-3.371	3.729	3.370
BUS	7	0.613	17.5336	-7.049	-6.391	7.049	6.391

THE RESULT AT TIME(T)= 0.36000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11137 ANGULAR POSITION OF THE ROTOR= 53.36787 DEGREES
ITS MACHINE SPEED= 380.49070 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.13425 ANGULAR POSITION OF THE ROTOR= 77.05984 DEGREES
ITS MACHINE SPEED= 380.07730 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12945 ANGULAR POSITION OF THE ROTOR= -17.17528 DEGREES
ITS MACHINE SPEED= 376.86100 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12191 ANGULAR POSITION OF THE ROTOR= -51.60027 DEGREES
ITS MACHINE SPEED= 375.24920 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.065	50.3892	-8.269	34.950	55.603	2.183
BUS	2	0.820	57.7411	205.152	136.838	0.000	-0.000

BUS	3	0.760	-16.1193	-48.382	71.363	42.733	28.875
BUS	4	0.672	-45.5037	-64.912	96.536	36.314	22.015
BUS	5	0.536	-16.7876	-1.991	-0.769	1.990	0.769
BUS	6	0.566	17.6085	-3.294	-2.977	3.294	2.977
BUS	7	0.577	19.5746	-6.245	-5.663	6.245	5.663

```
THE RESULT AT TIME(T)=     0.39000 SECONDS
THE MACHINE AT BUS   1
ITS INTERNAL VOLTAGE MAGNITUDE=     1.11146      ANGULAR POSITION OF THE ROTOR=   57.50992 DEGREES
ITS MACHINE SPEED=  380.71390 RADIANS PER SECOND
THE MACHINE AT BUS   2
ITS INTERNAL VOLTAGE MAGNITUDE=     1.13224      ANGULAR POSITION OF THE ROTOR=   80.32669 DEGREES
ITS MACHINE SPEED=  379.61250 RADIANS PER SECOND
THE MACHINE AT BUS   3
ITS INTERNAL VOLTAGE MAGNITUDE=     1.13122      ANGULAR POSITION OF THE ROTOR=  -17.16788 DEGREES
ITS MACHINE SPEED=  377.13330 RADIANS PER SECOND
THE MACHINE AT BUS   4
ITS INTERNAL VOLTAGE MAGNITUDE=     1.12368      ANGULAR POSITION OF THE ROTOR=  -53.32968 DEGREES
ITS MACHINE SPEED=  375.71020 RADIANS PER SECOND
```

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.063	54.4518	-6.898	36.236	55.380	2.174
BUS	2	0.805	61.3320	197.810	142.430	0.000	-0.000
BUS	3	0.747	-16.2551	-46.114	74.540	41.305	27.910
BUS	4	0.605	-47.8949	-59.279	99.111	34.413	20.863
BUS	5	0.505	-17.7149	-1.770	-0.683	1.770	0.683
BUS	6	0.535	19.5069	-2.946	-2.662	2.945	2.662
BUS	7	0.547	21.5815	-5.603	-5.080	5.603	5.080

```
THE RESULT AT TIME(T)=     0.40000 SECONDS
THE MACHINE AT BUS   1
ITS INTERNAL VOLTAGE MAGNITUDE=     1.11104      ANGULAR POSITION OF THE ROTOR=   61.90474 DEGREES
ITS MACHINE SPEED=  380.93110 RADIANS PER SECOND
THE MACHINE AT BUS   2
ITS INTERNAL VOLTAGE MAGNITUDE=     1.13037      ANGULAR POSITION OF THE ROTOR=   83.08003 DEGREES
ITS MACHINE SPEED=  379.18160 RADIANS PER SECOND
THE MACHINE AT BUS   3
ITS INTERNAL VOLTAGE MAGNITUDE=     1.13238      ANGULAR POSITION OF THE ROTOR=  -16.85173 DEGREES
ITS MACHINE SPEED=  377.39960 RADIANS PER SECOND
THE MACHINE AT BUS   4
ITS INTERNAL VOLTAGE MAGNITUDE=     1.12551      ANGULAR POSITION OF THE ROTOR=  -54.54573 DEGREES
ITS MACHINE SPEED=  376.14550 RADIANS PER SECOND
```

VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR

BUS	1	1.061	58.7092	-4.659	36.931	55.225	2.168
BUS	2	0.794	64.5385	190.179	147.124	0.000	-0.000
BUS	3	0.737	-16.1061	-44.076	77.015	40.195	27.160
BUS	4	0.592	-49.7709	-54.414	101.046	32.983	19.996
BUS	5	0.430	-18.4162	-1.599	-0.617	1.599	0.617
BUS	6	0.510	21.3665	-2.675	-2.417	2.675	2.417
BUS	7	0.522	23.5350	-5.104	-4.627	5.104	4.627

THE RESULT AT TIME(T)= 0.42000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11058 ANGULAR POSITION OF THE ROTOR= 66.52992 DEGREES
ITS MACHINE SPEED= 381.12030 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12865 ANGULAR POSITION OF THE ROTOR= 85.35945 DEGREES
ITS MACHINE SPEED= 378.78560 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.13444 ANGULAR POSITION OF THE ROTOR= -16.23404 DEGREES
ITS MACHINE SPEED= 377.65560 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12740 ANGULAR POSITION OF THE ROTOR= -55.27684 DEGREES
ITS MACHINE SPEED= 376.55710 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	INJECTED POWER MVAR	LOCAL LOAD SUPPLIED MW	LOCAL LOAD SUPPLIED MVAR
BUS	1	1.060	63.1412	-1.575	37.133	55.125	2.164
BUS	2	0.785	67.3575	192.567	150.892	0.000	-0.000
BUS	3	0.729	-15.6569	-42.353	73.883	39.376	26.607
BUS	4	0.583	-51.0965	-50.438	102.505	31.939	19.363
BUS	5	0.461	-18.8304	-1.470	-0.568	1.470	0.568
BUS	6	0.490	23.1669	-2.472	-2.234	2.472	2.234
BUS	7	0.502	25.4126	-4.729	-4.288	4.729	4.288

THE RESULT AT TIME(T)= 0.44000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.11007 ANGULAR POSITION OF THE ROTOR= 71.35538 DEGREES
ITS MACHINE SPEED= 381.27950 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12708 ANGULAR POSITION OF THE ROTOR= 87.20329 DEGREES
ITS MACHINE SPEED= 378.42480 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.13591 ANGULAR POSITION OF THE ROTOR= -15.32218 DEGREES
ITS MACHINE SPEED= 377.91300 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12935 ANGULAR POSITION OF THE ROTOR= -55.54845 DEGREES
ITS MACHINE SPEED= 376.94820 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	MVAR	LOCAL LOAD SUPPLIED MW	MVAR
BUS	1	1.060	67.7200	2.321	36.965	55.061	2.161
BUS	2	0.779	69.7951	175.172	153.905	0.000	-0.000
BUS	3	0.724	-14.8997	-40.990	80.229	38.824	26.234
BUS	4	0.576	-51.8537	-47.406	103.614	31.212	18.922
BUS	5	0.446	-18.9054	-1.378	-0.532	1.378	0.532
BUS	6	0.476	24.8862	-2.328	-2.103	2.327	2.103
BUS	7	0.488	27.1911	-4.463	-4.047	4.463	4.047

THE RESULT AT TIME(T)= 0.46000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.10949 ANGULAR POSITION OF THE ROTOR= 76.34360 DEGREES
ITS MACHINE SPEED= 381.40330 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12568 ANGULAR POSITION OF THE ROTOR= 83.65767 DEGREES
ITS MACHINE SPEED= 378.05880 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.13730 ANGULAR POSITION OF THE ROTOR= -14.12328 DEGREES
ITS MACHINE SPEED= 378.16060 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.13134 ANGULAR POSITION OF THE ROTOR= -55.38126 DEGREES
ITS MACHINE SPEED= 377.32320 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	MVAR	LOCAL LOAD SUPPLIED MW	MVAR
BUS	1	1.059	72.4115	6.986	36.562	55.011	2.159
BUS	2	0.775	71.3636	168.117	156.273	0.000	-0.000
BUS	3	0.721	-13.3340	-39.998	81.115	38.518	26.077
BUS	4	0.572	-52.0364	-45.329	104.462	30.750	18.642
BUS	5	0.436	-18.6068	-1.316	-0.508	1.316	0.508
BUS	6	0.466	26.5041	-2.234	-2.019	2.234	2.019
BUS	7	0.478	28.3437	-4.292	-3.891	4.292	3.892

THE RESULT AT TIME(T)= 0.43000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.10384 ANGULAR POSITION OF THE ROTOR= 81.45132 DEGREES
ITS MACHINE SPEED= 391.48700 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12445 ANGULAR POSITION OF THE ROTOR= 89.75584 DEGREES
ITS MACHINE SPEED= 377.80590 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.13864 ANGULAR POSITION OF THE ROTOR= -12.64385 DEGREES
ITS MACHINE SPEED= 378.40280 RADIANS PER SECOND

THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.13338 ANGULAR POSITION OF THE ROTOR= -54.79141 DEGREES
ITS MACHINE SPEED= 377.68700 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	MVAR	LOCAL LOAD SUPPLIED MW	MVAR
BUS	1	1.059	77.1769	12.356	36.061	54.956	2.157
BUS	2	0.773	73.5803	161.488	158.089	0.000	-0.000
BUS	3	0.721	-12.4644	-39.362	81.599	38.444	25.977
BUS	4	0.570	-51.6474	-44.195	105.110	30.518	18.501
BUS	5	0.430	-17.9102	-1.233	-0.495	1.283	0.495
BUS	6	0.461	28.0054	-2.187	-1.976	2.187	1.976
BUS	7	0.474	30.3737	-4.205	-3.813	4.205	3.813

THE RESULT AT TIME(T)= 0.50000 SECONDS
THE MACHINE AT BUS 1
ITS INTERNAL VOLTAGE MAGNITUDE= 1.10809 ANGULAR POSITION OF THE ROTOR= 86.62964 DEGREES
ITS MACHINE SPEED= 381.52530 RADIANS PER SECOND
THE MACHINE AT BUS 2
ITS INTERNAL VOLTAGE MAGNITUDE= 1.12339 ANGULAR POSITION OF THE ROTOR= 90.53613 DEGREES
ITS MACHINE SPEED= 377.54410 RADIANS PER SECOND
THE MACHINE AT BUS 3
ITS INTERNAL VOLTAGE MAGNITUDE= 1.13995 ANGULAR POSITION OF THE ROTOR= -10.88990 DEGREES
ITS MACHINE SPEED= 378.63980 RADIANS PER SECOND
THE MACHINE AT BUS 4
ITS INTERNAL VOLTAGE MAGNITUDE= 1.13544 ANGULAR POSITION OF THE ROTOR= -53.78911 DEGREES
ITS MACHINE SPEED= 378.04410 RADIANS PER SECOND

		VOLTAGE MAGNITUDE PU	DELTA(DEGREES)	INJECTED POWER MW	MVAR	LOCAL LOAD SUPPLIED MW	MVAR
BUS	1	1.058	81.9728	13.345	35.593	54.875	2.154
BUS	2	0.773	74.9632	155.351	159.420	0.000	-0.000
BUS	3	0.722	-10.7996	-39.054	81.680	38.590	26.076
BUS	4	0.570	-50.6935	-43.981	105.590	30.495	18.487
BUS	5	0.429	-16.8101	-1.274	-0.492	1.274	0.492
BUS	6	0.461	29.3317	-2.180	-1.970	2.180	1.970
BUS	7	0.473	31.7554	-4.195	-3.804	4.195	3.804

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APPENDIX A

(Program Listing for SLFNR)

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                C ***************************************
                C LOAD FLOW PROGRAM (NEWTON RAPHSON METHOD)*
                C ***************************************
0001                COMPLEX*8 SERY(100),SERZ(100),SHTY(100),YSHT(100),VA(60),
                   1ZSER(100),YBUS(300),CMPLX,CONJG,S(100),R(100),AMM,BMM,TMM,
                   2V(60),HV,NYV,BC,AK,BKL,CPQ,CJV,CJGBC,YV,BCJ,CJGV,TG,TLD,TL
0002                REAL LENGTH(100),TR(100),OBASE,NBASE,CC(60),ABS,CMVAR(20),
                   1MAGV,DELTAA,DELTA(60),PL(60),QL(60),PG(60),
                   2QG(60),VSPEC(60),QMIN(60),QMAX(60),P(60),Q(60),VMIN(60),
                   3VMAX(60),PA(60),QA(60),AJ,BJ,FK,FK,WKJR(4,40),
                   4JAC(800),TOLE,DP(60),DQ(60),DDEL(60),DE(60),E(60),DJ,
                   5CAVJ
0003                INTEGER SB(100),EB(100),NL,NB,NC,BN1(60),MB,BM,LG(30),IYBUS(300),
                   1KTABI(60,3),NTABI(60,3),NOET,SUM,KJ(20),L(60),BN(60),TS(100),ST,
                   2JYBUS(300),IABS,JJAC(800),IJAC(60,2),KWKJ(2,40),NOCL(2,59),LK(60)
0004            120 FORMAT(F10.5,I3)
0005            100 FORMAT(5I2,2F10.5)
0006            102 FORMAT(I5,F10.5)
0007            106 FORMAT(2I3,4F10.5,F5.3,F5.1,I1)
0008            108 FORMAT(8I3)
0009                READ(5,333) LNHER
0010            333 FORMAT(I1)
0011                READ(5,120) TOLE,ITER1
0012                READ(5,100) NL,NB,BM,NC,ST,OBASE,NBASE
0013                MB=BM+1
0014                READ(5,108) (BN(I),I=1,NB)
0015                DO 2 I=1,NL
0016                READ(5,106) SB(I),EB(I),ZSER(I),YSHT(I),TR(I),LENGTH(I),TS(I)
0017                ZSER(I)=ZSER(I)*NBASE/OBASE
0018                YSHT(I)=YSHT(I)*OBASE/NBASE
0019                IF(TR(I).LE.0) TR(I)=1.0
0020                TR(I)=1./TR(I)
0021                IF(LENGTH(I).LE.0) LENGTH(I)=1.0
0022                SHTY(I)=YSHT(I)*LENGTH(I)
0023                IF(ST.NE.0) SHTY(I)=SHTY(I)/2.
0024                SERZ(I)=ZSER(I)*LENGTH(I)
0025              2 SERY(I)=1./SERZ(I)
0026                CALL ORDR(SB,EB,NL,NB,BN,KTABI,NTABI,NOET)
0027                DO 3 I=1,NOET
0028              3 YBUS(I)=CMPLX(0.,0.)
0029                IF(NC.LE.0) GO TO 1
0030                DO 4 I=1,NC
0031                READ(5,102) BN1(I),CC(I)
0032                CC(I)=CC(I)*OBASE/NBASE
0033                K=IABS(KTABI(BN1(I),3))
0034                KC=1
0035                K1=K-1
0036                DO 5 I1=1,K1
0037                IF (K.EQ.1) GO TO 6
0038              5 KC=KC+NTABI(I1,2)
0039              6 YBUS(KC)=CMPLX(0.0,CC(I))
0040              4 CONTINUE
0041              1 CONTINUE
0042                NUM=0
0043                DO 7 I=1,NB
0044                NUM=NUM+1
0045                IC=0
0046                I1=NTABI(I,3)
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            DO 8 J=1,NL
            IF(SB(J).EQ.I1) GO TO 9
            IF(EB(J).NE.I1) GO TO 8
            NK=SB(J)
            IC=IC+1
            LG(IC)=IABS(NK)
            GO TO 10
      9     NK=EB(J)
            IC=IC+1
            LG(IC)=IABS(NK)
     10     CONTINUE
            IF(IC.EQ.1) GO TO 8888
            IC1=IC-1
            DO 11 IJ=1,IC1
            IF(LG(IJ).NE.LG(IC)) GO TO 11
            IAA=1
            IF(I.EQ.1) GO TO 8887
            I2=I-1
            DO 8886 K=1,I2
   8886     IAA=IAA+NTABI(K,2)
   8887     IA=NUM
            DO 8885 L1=IAA,IA
            NKA=IABS(NK)
            IF(JYBUS(L1).EQ.KTABI(NKA,3)) GO TO 8884
   8885     CONTINUE
   8884     YBUS(L1)=YBUS(L1)-(SERY(J)*TR(J))
            GO TO 12
     11     CONTINUE
   8888     NUM=NUM+1
            IYBUS(NUM)=NTABI(I,1)
            NKB=LG(IC)
            JYBUS(NUM)=KTABI(NKB,3)
            YBUS(NUM)=YBUS(NUM)-SERY(J)*TR(J)
     12     NNN=1
            IF(I.EQ.1) GO TO 13
            III=I-1
            DO 14 KJ1=1,III
     14     NNN=NNN+NTABI(KJ1,2)
     13     IYBUS(NNN)=NTABI(I,1)
            JYBUS(NNN)=NTABI(I,1)
            IF(SB(J).EQ.I1) GO TO 15
            YBUS(NNN)=YBUS(NNN)+SERY(J)+SHTY(J)
            GO TO 8
     15     YBUS(NNN)=YBUS(NNN)+(SERY(J)+SHTY(J))*TR(J)*TR(J)
      8     CONTINUE
      7     CONTINUE
   1222     FORMAT(2F10.5)
    104     FORMAT(2F10.5)
    110     FORMAT(6F10.5)
    112     FORMAT(6F10.5)
            READ(5,1222) PL(1),QL(1)
            READ(5,104) MAGV,DELTAA
            DELTA(1)=DELTAA*ARSIN(1.0)/90.0
            V(1)=MAGV*CMPLX(COS(DELTA(1)),SIN(DELTA(1)))
            IF(MB.EQ.1) GO TO 1999
            DO 16 I=2,MB
     16     READ(5,110) VSPEC(I),QMIN(I),QMAX(I),PL(I),PG(I),QL(I)
   1999     MB1=MB+1
```

```
      DO 17 I=MB1,NB
   17 READ(5,112) PG(I),QG(I),PL(I),QL(I),VMAX(I),VMIN(I)
      CALL INPUT(ZSER,YSHT,LENGTH,TS,TR,ST,PG,QG,PL,
     1QL,VMAX,VMIN,QMAX,QMIN,VSPEC,CC,SA,EB,NL,NB,BN,MB,NC,
     2ITER1,ITER,TOLE,DELTAA,MAGV,DBASE,NBASE,BN1,BM)
      PL(I)=PL(I)/NBASE
      QL(I)=QL(I)/NBASE
      IF(MB.EQ.1) GO TO 85
      DO 370 I=2,MB
      QA(I)=QMIN(I)
  370 PA(I)=QMAX(I)
      DO 86 I=2,MB
      NOR=IABS(KTABI(I,3))
      VSPEC(NOR)=VSPEC(I)
      QMIN(NOR)=(QA(I)-QL(I))/NBASE
      QMAX(NOR)=(PA(I)-QL(I))/NBASE
      P(NOR)=(PG(I)-PL(I))/NBASE
      DELTA(NOR)=0.0
   86 V(NOR)=VSPEC(NOR)*CMPLX(1.0,0.0)
   85 MB1=MB+1
      DO 87 I=MB1,NB
      NOR=IABS(KTABI(I,3))
      P(NOR)=(PG(I)-PL(I))/NBASE
      Q(NOR)=(QG(I)-QL(I))/NBASE
      VMAX(NOR)=VMAX(I)
      VMIN(NOR)=VMIN(I)
      DELTA(NOR)=0.0
   87 V(NOR)=CMPLX(1.0,0.0)
      DO 371 I=2,NB
      PA(I)=PL(I)
  371 QA(I)=QL(I)
      DO 372 I=2,NB
      NOR=IABS(KTABI(I,3))
      PL(NOR)=PA(I)/NBASE
  372 QL(NOR)=QA(I)/NBASE
      ITER=0
      DO 987 I=1,NB
      IF(NTABI(I,1).GT.0) GO TO 9879
      LK(I)=0
      GO TO 987
 9879 LK(I)=1
  987 CONTINUE
11111 CONTINUE
      IEC=0
      DO 26 K=2,NB
      KK=NTABI(K,1)
      NOET5=1
      BC=CMPLX(0.0,0.0)
      K1=K-1
      DO 27 I=1,K1
   27 NOET5=NOET5+NTABI(I,2)
      NOET6=NOET5+NTABI(K,2)-1
      DO 28 L4=1,NB
      DO 29 L1=NOET5,NOET6
      IAJY=IABS(JYBUS(L1))
      IF(IAJY.EQ.L4) GO TO 8881
      IF(L1.EQ.NOET6) GO TO 28
   29 CONTINUE
```

```
 8891 YV=YBUS(L1)*V(L4)
      BC=BC+YV
   28 CONTINUE
      CJGBC=CONJG(BC)
      PA(K)=REAL(V(K)*CJGBC)
      QA(K)=AIMAG(V(K)*CJGBC)
      IF(NTABI(K,1).GT.0) GO TO 8891
      DP(K)=P(K)-PA(K)
      IF(ABS(DP(K)).LE.TOLE) GO TO 8880
      IFC=IFC+1
 8880 NCOUNT=1
      DO 30 J=2,NB
      DO 31 KJ1=NOET5,NOET6
      IAJY=IABS(JYBUS(KJ1))
      IF(IAJY.EQ.J) GO TO 8879
      IF(KJ1.EQ.NOET6) GO TO 30
   31 CONTINUE
 8879 NCOUNT=NCOUNT+1
      IF(J.EQ.K) GO TO 8878
      BCJ=V(J)*YBUS(KJ1)
      IF(NTABI(J,1).GT.0) GO TO 8877
      AJ=REAL(BCJ)
      BJ=AIMAG(BCJ)
      EK=REAL(V(K))
      FK=AIMAG(V(K))
      WKJR(1,NCOUNT)=AJ*FK-BJ*EK
      WKJR(2,NCOUNT)=0.0
      WKJR(3,NCOUNT)=0.0
      WKJR(4,NCOUNT)=0.0
      GO TO 8872
 8877 AJ=REAL(BCJ)
      BJ=AIMAG(BCJ)
      EK=REAL(V(K))
      FK=AIMAG(V(K))
      WKJR(1,NCOUNT)=AJ*FK-BJ*EK
      WKJR(2,NCOUNT)=0.0
      WKJR(3,NCOUNT)=AJ*EK+BJ*FK
      WKJR(4,NCOUNT)=0.0
      GO TO 8872
 8878 BKJ=AIMAG(YBUS(NOET5))
      WKJR(1,NCOUNT)=-QA(K)-BKJ*CABS(V(K))*CABS(V(K))
      WKJR(2,NCOUNT)=0.0
      WKJR(3,NCOUNT)=0.0
      WKJR(4,NCOUNT)=0.0
 8872 KWKJ(1,NCOUNT)=NTABI(J,1)
      KWKJ(2,NCOUNT)=NCOUNT+1
   30 CONTINUE
      KWKJ(2,NCOUNT)=0
      K1=K-1
      NOCL(1,K1)=NTABI(K,1)
      NOCL(2,K1)=NCOUNT
      WKJR(1,1)=DP(K)
      WKJR(2,1)=0.
      WKJR(3,1)=0.
      WKJR(4,1)=0.
      KWKJ(1,1)=NTABI(K,1)
      KWKJ(2,1)=2
      CALL GSEL(K,KK,WKJR,KWKJ,NOCL,JAC,IJAC,JJAC,JNG)
```

```
      GO TO 26
 8391 DP(K)=P(K)-PA(K)
      DQ(K)=Q(K)-QA(K)
      IF(ABS(DP(K)).GT.TOLE) GO TO 8371
      IF(ABS(DQ(K)).LE.TOLE) GO TO 8370
 8871 IEC=IEC+1
 8370 NCOUNT=1
      DO 32 J=2,NB
      DO 33 KJ1=NOET5,NOET6
      IAJY=IABS(JYBUS(KJ1))
      IF(IAJY.EQ.J) GO TO 8865
      IF(KJ1.EQ.NOET6) GO TO 32
   33 CONTINUE
 8865 NCOUNT=NCOUNT+1
      IF(J.EQ.K) GO TO 8864
      BCJ=V(J)*YBUS(KJ1)
      IF(NTABI(J,1).GT.0) GO TO 8863
      AJ=REAL(BCJ)
      BJ=AIMAG(BCJ)
      EK=REAL(V(K))
      FK=AIMAG(V(K))
      WKJR(1,NCOUNT)=AJ*FK-BJ*EK
      WKJR(2,NCOUNT)=-(AJ*EK+BJ*FK)
      WKJR(3,NCOUNT)=0.0
      WKJR(4,NCOUNT)=0.0
      GO TO 8862
 8863 AJ=REAL(BCJ)
      BJ=AIMAG(BCJ)
      EK=REAL(V(K))
      FK=AIMAG(V(K))
      WKJR(1,NCOUNT)=AJ*FK-BJ*EK
      WKJR(2,NCOUNT)=-(AJ*EK+BJ*FK)
      WKJR(3,NCOUNT)=-WKJR(2,NCOUNT)
      WKJR(4,NCOUNT)=WKJR(1,NCOUNT)
      GO TO 8862
 8864 GKJ=REAL(YBUS(NOET5))
      BKJ=AIMAG(YBUS(NOET5))
      WKJR(1,NCOUNT)=-QA(K)-BKJ*(CABS(V(K))**2)
      WKJR(2,NCOUNT)=PA(K)-GKJ*(CABS(V(K))**2)
      WKJR(3,NCOUNT)=PA(K)+GKJ*(CABS(V(K))**2)
      WKJR(4,NCOUNT)=QA(K)-BKJ*(CABS(V(K))**2)
 8862 KWKJ(1,NCOUNT)=NTABI(J,1)
      KWKJ(2,NCOUNT)=NCOUNT+1
   32 CONTINUE
      KWKJ(2,NCOUNT)=0
      K1=K-1
      NOCL(1,K1)=NTABI(K,1)
      NOCL(2,K1)=NCOUNT
      WKJR(1,1)=DP(K)
      WKJR(2,1)=DQ(K)
      WKJR(3,1)=0.0
      WKJR(4,1)=0.0
      KWKJ(1,1)=NTABI(K,1)
      KWKJ(2,1)=2
      CALL GSEL(K,KK,WKJR,KWKJ,NOCL,JAC,IJAC,JJAC,JNG)
   26 CONTINUE
      ITER=ITER+1
      IF(ITER.GT.ITER1) GO TO 1975
```

```
            DO 34 K=2,NB
            J=(NB+2)-K
            ML=K-1
            IF(NTABI(J,1).GT.0) GO TO 8861
            J1=J-1
            KSL=IJAC(J1,2)
            IF(ML.NE.1) GO TO 8860
            DDEL(J)=JAC(KSL)
            GO TO 3555
      8860 KEL=IJAC(J,2)-1
            DDEL(J)=JAC(KSL)
            ML1=ML-1
            DO 35 I=1,ML1
            IX=(NB-ML1)+I
            KSL1=KSL+1
            IF(NTABI(IX,1).GT.0) GO TO 8859
            NIX=-IX
            DO 36 L1=KSL1,KEL
            IF(JJAC(L1).EQ.NIX) GO TO 8858
            IAJJ=IABS(JJAC(L1))
            IF(IAJJ.GT.IX) GO TO 35
        36 CONTINUE
            GO TO 35
      8858 DDEL(J)=DDEL(J)-JAC(L1)*DDEL(IX)
            GO TO 35
      8859 CONTINUE
            DO 37 L4=KSL1,KEL
            L1=L4+1
            IF(JJAC(L4).EQ.IX) GO TO 8857
            IAJJ=IABS(JJAC(L4))
            IF(IAJJ.GT.IX) GO TO 35
        37 CONTINUE
            GO TO 35
      8857 DDEL(J)=DDEL(J)-(JAC(L1)*DE(IX)/(E(IX)-DE(IX)))-
           1(JAC(L4)*DDEL(IX))
        35 CONTINUE
      3555 DELTA(J)=ATAN2(AIMAG(V(J)),REAL(V(J)))
            DELTA(J)=DELTA(J)+DDEL(J)
            DJ=DELTA(J)
            V(J)=VSPEC(J)*CMPLX(COS(DJ),SIN(DJ))
            GO TO 34
      8861 J1=J-1
            KSL=IJAC(J1,2)
            CAVJ=CABS(V(J))
            DDEL(J)=JAC(KSL)
            KSL1=KSL+1
            DF(J)=JAC(KSL1)
            IF(ML.EQ.1) GO TO 3888
            KEL=IJAC(J,2)-1
            ML1=ML-1
            DO 39 I=1,ML1
            IX=(NB-ML1)+I
            IF(NTABI(IX,1).GT.0) GO TO 8856
            KSL4=KSL+4
            DO 39 L1=KSL4,KEL
            NIX=-IX
            IF(JJAC(L1).EQ.NIX) GO TO 8855
            IAJJ=IABS(JJAC(L1))
```

```
0334          IF(IAJJ.GT.IX) GO TO 38
0335       39 CONTINUE
0336          GO TO 33
0337     8855 DE(J)=DE(J)-(JAC(L1)*DDEL(IX))
0338          L2=L1-1
0339          DDEL(J)=DDEL(J)-(JAC(L2)*DDEL(IX))
0340          GO TO 38
0341     8856 CONTINUE
0342          KSL4=KSL+3
0343          DO 40 L1=KSL4,KEL
0344          IF(JJAC(L1).EQ.IX) GO TO 8854
0345          IAJJ=IABS(JJAC(L1))
0346          IF(IAJJ.GT.IX) GO TO 38
0347       40 CONTINUE
0348          GO TO 38
0349     8854 L4=L1+1
0350          L2=L1+2
0351          L3=L1+3
0352          DDEL(J)=DDEL(J)-(JAC(L1)*DDEL(IX))-(JAC(L2)*DE(IX)/
             1(E(IX)-DE(IX)))
0353          DE(J)=DE(J)-(JAC(L4)*DDEL(IX))-(JAC(L3)*DE(IX)/
             1(E(IX)-DE(IX)))
0354       38 CONTINUE
0355     3888 KSL2=KSL+2
0356          DE(J)=DE(J)*CABS(V(J))
0357          DDEL(J)=DDEL(J)-(JAC(KSL2)*DE(J)/CABS(V(J)))
0358          E(J)=DE(J)+CABS(V(J))
0359          DELTA(J)=ATAN2(AIMAG(V(J)),REAL(V(J)))
0360          DELTA(J)=DELTA(J)+DDEL(J)
0361          DJ=DELTA(J)
0362          V(J)=E(J)*CMPLX(COS(DJ),SIN(DJ))
0363       34 CONTINUE
0364          IIEC=0
0365          DO 41 I=2,NB
0366          IF(NTABI(I,1).GT.0) GO TO 46
0367          ISY=1
0368          BC=CMPLX(0.,0.)
0369          I1=I-1
0370          DO 43 M1=1,I1
0371       43 ISY=ISY+NTABI(M1,2)
0372          IEY=ISY-1+NTABI(I,2)
0373          DO 42 M=1,NB
0374          DO 44 IY=ISY,IEY
0375          IAJJ=IABS(JYBUS(IY))
0376          IF(IAJJ.EQ.M) GO TO 8852
0377          IF(IY.EQ.IEY) GO TO 42
0378          GO TO 44
0379     8852 BC=BC+YBUS(IY)*V(M)
0380       44 CONTINUE
0381       42 CONTINUE
0382          CJGV=CONJG(V(I))
0383          CA(I)=-AIMAG(BC*CJGV)
0384          IF(QA(I).GE.QMAX(I)) GO TO 8851
0385          IF(QA(I).LE.QMIN(I)) GO TO 8850
0386          GO TO 41
0387     8851 Q(I)=QMAX(I)
0388          GO TO 8949
0389     8850 Q(I)=QMIN(I)
```

```
 8949 NTABI(I,1)=-NTABI(I,1)
      NTABI(I,3)=-NTABI(I,3)
      IF(LK(I).NE.0) GO TO 213
      VMAX(I)=VSPEC(I)+0.00001
      VMIN(I)=VSPEC(I)-0.00001
  213 CONTINUE
      GO TO 1111
   46 IF(CABS(V(I)).GT.VMAX(I)) GO TO 1956
      IF(CABS(V(I)).LT.VMIN(I)) GO TO 211
      GO TO 41
 1956 VSPEC(I)=VMAX(I)
      V(I)=VSPEC(I)*CMPLX(COS(DELTA(I)),SIN(DELTA(I)))
      GO TO 212
  211 VSPEC(I)=VMIN(I)
      V(I)=VSPEC(I)*CMPLX(COS(DELTA(I)),SIN(DELTA(I)))
  212 NTABI(I,1)=-NTABI(I,1)
      NTABI(I,3)=-NTABI(I,3)
      IF(LK(I).EQ.0) GO TO 215
      QMAX(I)=Q(I)+0.00001
      QMIN(I)=Q(I)-0.00001
  215 CONTINUE
 1111 IIEC=IIEC+1
   41 CONTINUE
12345 FORMAT(2I5)
      IF(IIEC.NE.0) GO TO 11111
      IF(IEC.NE.0) GO TO 11111
 1975 CONTINUE
      IF(LNMER.EQ.0) GO TO 319
      WRITE(7,399) NL
  399 FORMAT(I3)
      WRITE(7,360) (SERY(I),SHTY(I),I=1,NL)
  360 FORMAT(4F10.5)
      WRITE(7,365) (SB(I),EB(I),I=1,NL)
  365 FORMAT(2I3)
      WRITE(7,366) (TR(I),I=1,NL)
  366 FORMAT(2F10.5)
      WRITE(7,300) NBASE,OBASE
  300 FORMAT(2F10.5)
      WRITE(7,301) NB,NDET
  301 FORMAT(2I3)
      WRITE(7,303) (V(I),I=1,NB)
  303 FORMAT(2F10.5)
      WRITE(7,302) (PL(I),QL(I),I=1,NB)
  302 FORMAT(2F10.5)
  319 CONTINUE
 1110 FORMAT('1',////T30,'FAILED TO CONVERGE IN',I4,'ITERATIONS')
 1112 FORMAT('1',T20,'NEWTON-RAPHSON TECHNIQUE CONVERGED IN',I4,1X,
     1'ITERATIONS.  ALL VALUES ON',F6.0,1X,'MVA BASE'//)
 1116 FORMAT('0',T31,'VOLTAGE',T111,'INJECTED POWER'/T30,'MAGNITUDE',
     1T42,'DELTA(DEGS)',T64,'GENERATION',T95,'LOAD',T114,'(STATIC)'/
     2T33,'PU',T60,'MW',T74,'MVAR',T88,'MW',T102,'MVAR',T116,'MVAR')
 1118 FORMAT('0',T20,'BUS',I5,2X,F7.3,5X,F9.4,5X,F9.3,5X,F9.3,5X,F9.3,
     15X,F9.3,5X,F9.3)
 1120 FORMAT(' ',T30,I5,2X,F9.3,2X,F9.3,2X,F9.3,2X,'TAP',1X,F5.3)
 1122 FORMAT(' ',T30,I5,2X,F9.3,2X,F9.3)
 1124 FORMAT('1'//T48,'TOTALS',28X,'MW',11X,'MVAR'//T42,'GENERATION',24X
     1,F11.3,2X,F11.3)
 1126 FORMAT('0',T42,'STATIC CAP/REACTORS',28X,F11.3)
```

```
 1128 FORMAT('0',T42,'LOAD',30X,F11.3,2X,F11.3)
 1130 FORMAT('0',T42,'LINE LOSSES',23X,F11.3,2X,F11.3)
      IF(ITER.LE.ITER1) GO TO 51
      WRITE(6,1110) ITER
      GO TO 52
   51 DO 53 I=1,NB
      BC=CMPLX(0.0,0.0)
      ISY=1
      IF(I.EQ.1) GO TO 55
      II=I-1
      DO 54 MI=1,II
   54 ISY=ISY+NTABI(MI,2)
   55 IEY=ISY-1+NTABI(I,2)
      DO 56 M=1,NB
      DO 57 IY=ISY,IEY
      IAJJ=IABS(JYBUS(IY))
      IF(IAJJ.EQ.M) GO TO 58
      IF(IY.EQ.IEY) GO TO 56
   57 CONTINUE
   58 BC=BC+YBUS(IY)*V(M)
   56 CONTINUE
      CJGV=CONJG(V(I))
      P(I)=REAL(BC*CJGV)
      Q(I)=-AIMAG(BC*CJGV)
   53 CONTINUE
      IF(LNBER.EQ.0) GO TO 321
      WRITE(7,304) (P(I),Q(I),I=1,NB)
  304 FORMAT(2F10.5)
      WRITE(7,305) ((KTABI(I,J),J=1,3),I=1,NB)
  305 FORMAT(3I3)
      WRITE(7,306) ((NTABI(I,J),J=1,3),I=1,NB)
  306 FORMAT(3I3)
      WRITE(7,307) (YBUS(I),I=1,NOET)
  307 FORMAT(6F10.5)
      WRITE(7,308) (IYBUS(I),JYBUS(I),I=1,NOET)
  308 FORMAT(2I3)
  321 CONTINUE
      DO 311 I=1,NB
      P(I)=P(I)*NBASE
      Q(I)=Q(I)*NBASE
      PL(I)=PL(I)*NBASE
  311 QL(I)=QL(I)*NBASE
      DO 78 I=1,NB
      PA(I)=P(I)
      QA(I)=Q(I)
   78 VA(I)=V(I)
      DO 73 I=1,NB
      IJ=IABS(KTABI(I,3))
      V(I)=VA(IJ)
      P(I)=PA(IJ)
   73 Q(I)=QA(IJ)
      DO 312 I=1,NB
      PA(I)=PL(I)
  312 QA(I)=QL(I)
      DO 313 I=1,NB
      IJ=IABS(KTABI(I,3))
      PL(I)=PA(IJ)
  313 QL(I)=QA(IJ)
```

```
      WRITE(6,1112) ITER,NBASE
      WRITE(6,1116)
      DO 63 I=1,MB
   63 QG(I)=Q(I)+QL(I)
      PG(I)=P(I)+PL(I)
      DO 59 I=1,NB
      DELTAA=ATAN2(AIMAG(V(I)),REAL(V(I)))*90.0/ARSIN(1.0)
      MAGV=CABS(V(I))
      IF(NC.EQ.0) GO TO 61
      DO 60 J=1,NC
      IF(I.EQ.BN1(J)) GO TO 62
   60 CONTINUE
      GO TO 61
   62 CMVAR(J)=(MAGV**2)*CC(J)*NBASE
      WRITE(6,1118) I,MAGV,DELTAA,PG(I),QG(I),PL(I),QL(I),CMVAR(J)
      GO TO 64
   61 WRITE(6,1118) I,MAGV,DELTAA,PG(I),QG(I),PL(I),QL(I)
   64 DO 65 J=1,NL
      L1=IABS(SB(J))
      M=IABS(EB(J))
      IF(L1.EQ.I) GO TO 66
      IF(M.EQ.I) GO TO 67
      GO TO 65
   66 IF(TS(J).EQ.0) GO TO 68
      S(J)=V(L1)*CONJG(V(L1)*TR(J)*(TR(J)-1.)*SERY(J))*NBASE
     1+(V(L1))*CONJG((V(L1)-V(M))*TR(J)*SERY(J))*NBASE
      GO TO 69
   68 S(J)=(V(L1)*CONJG((V(L1)-V(M))*SERY(J)+V(L1)*(SHTY(J)))))*NBASE
      GO TO 69
   67 IF(TS(J).EQ.0) GO TO 70
      R(J)=V(M)*CONJG(V(M)*(1.-TR(J))*SERY(J))*NBASE+
     1(V(M))*CONJG((V(M)-V(L1))*TR(J)*SERY(J))*NBASE
      GO TO 69
   70 R(J)=(V(M)*CONJG((V(M)-V(L1))*SERY(J)+V(M)*(SHTY(J)))))*NBASE
   69 CONTINUE
      IF(M.EQ.I) GO TO 71
      IF(TS(J).EQ.0) GO TO 72
      TR(J)=1./TR(J)
      WRITE(6,1120) M,S(J),TR(J)
      TR(J)=1./TR(J)
      GO TO 65
   72 WRITE(6,1122) M,S(J)
      GO TO 65
   71 WRITE(6,1122) L1,R(J)
   65 CONTINUE
   59 CONTINUE
      TG=CMPLX(0.0,0.0)
      TCR=0.0
      TL=CMPLX(0.0,0.0)
      TLD=CMPLX(0.0,0.0)
      IF(NC.EQ.0) GO TO 330
      DO 75 J=1,NC
      TCR=TCR+CMVAR(J)
   75 CONTINUE
  330 CONTINUE
      DO 74 I=1,NB
      TG=TG+CMPLX(PG(I),QG(I))
      TLD=TLD+CMPLX(PL(I),QL(I))
```

```
      IF(NC.EQ.0) GO TO 355
      DO 84 J=1,NC
      IF(BN1(J).EQ.I) GO TO 76
   84 CONTINUE
  355 CONTINUE
      TL=TL+CMPLX(P(I),Q(I))
      GO TO 74
   76 TL=TL+CMPLX(P(I),Q(I))+CMPLX(0.0,CMVAR(J))
   74 CONTINUE
      WRITE(6,1124) TG
      WRITE(6,1126) TCR
      WRITE(6,1128) TLD
      WRITE(6,1130) TL
      CALL MISMAT(SB,EB,S,R,P,Q,CMVAR,NB,BN1,NL,NC,BM,MB)
   52 CONTINUE
      STOP
      END
```

```
    8 NDET=0
      DO 11 I=1,NB
   11 NDET=NDET+KTABI(I,2)
      DO 10 I=2,NB
      DO 9 K=2,NB
      N9=IABS(KTABI(K,3))
      IF(N9.EQ.1) GO TO 12
    9 CONTINUE
   12 NTABI(I,1)=KTABI(K,3)
      NTABI(I,2)=KTABI(K,2)
      NTABI(I,3)=KTABI(K,1)
   10 CONTINUE
      NTABI(1,1)=1
      NTABI(1,2)=KTABI(1,2)
      NTABI(1,3)=1
      RETURN
      END
```

```
      SUBROUTINE OPOR(SB,EB,NL,NB,BN,KTABI,NTABI,NOET)
      INTEGER SB(100),EB(100),NL,NB,BN(60),KTABI(60,3),
     1NTABI(60,3),NOET,SUM,KJ(20),L(60),IABS
      DO 60 I=1,NB
      SUM=1
      NOVP=0
      DO 50 K=1,NL
      N1=IABS(SB(K))
      N2=IABS(EB(K))
      IF(N1.EQ.I) GO TO 1
      IF(N2.EQ.I) GO TO 2
      GO TO 50
    1 NOVP=NOVP+1
      KJ(NOVP)=EB(K)
      GO TO 3
    2 NOVP=NOVP+1
      KJ(NOVP)=SB(K)
    3 CONTINUE
      IF(NOVP.EQ.1) GO TO 88
      DO 51 KJJ=1,NOVP
      IF(KJJ.EQ.NOVP) GO TO 51
      N3=KJ(KJJ)
      N4=KJ(NOVP)
      IF(N3.EQ.N4) GO TO 50
   51 CONTINUE
   88 SUM=SUM+1
   50 CONTINUE
      KTABI(I,2)=SUM
      KTABI(I,1)=BN(I)
   60 CONTINUE
      KTABI(1,3)=1
      DO 4 K=2,NB
      L(K)=0
    4 CONTINUE
      LLL=1
      DO 9999 LB=2,NB
      DO 30 M=2,NB
      N5=L(M)
      IF(N5.EQ.0) GO TO 5
   30 CONTINUE
    5 IAA=KTABI(M,2)
      DO 20 I=2,NB
      N6=L(I)
      IF(N6.EQ.1) GO TO 20
      N7=KTABI(I,2)
      IF(N7.GT.IAA) GO TO 20
      KK=I
      IAA=KTABI(I,2)
   20 CONTINUE
      LLL=LLL+1
      L(KK)=L(KK)+1
      N8=KTABI(KK,1)
      IF(N8.GT.0) GO TO 6
      KTABI(KK,3)=-LLL
      GO TO 7
    6 KTABI(KK,3)=LLL
    7 CONTINUE
 9999 CONTINUE
```

```
      SUBROUTINE GSEL(K,KK,WKJR,KWKJ,NOCL,JAC,IJAC,JJAC,JNG)
      REAL WKJR(4,40),JAC(900)
      INTEGER KWKJ(2,40),JJAC(800),IJAC(60,2),NOCL(2,59)
      EQUIVALENCE(KA,K3)
      EQUIVALENCE(NG,NNG)
      IF(K.NE.2) GO TO 1114
      IF(KK.LT.0) GO TO 1
      KA=3
      A=((WKJR(3,2)/WKJR(1,2))*(-WKJR(2,2)))+WKJR(4,2)
      JAC(1)=WKJR(1,1)/WKJR(1,2)
      JAC(2)=(WKJR(2,2)*(-JAC(1))+WKJR(2,1))/A
      JAC(3)=WKJR(3,2)/WKJR(1,2)
      JJAC(1)=KK
      JJAC(2)=KK
      JJAC(3)=KK
      IJAC(1,1)=KK
      IJAC(1,2)=1
      NN=NOCL(2,1)
      DO 10 I=3,NN
      KW=KWKJ(1,I)
      IF(KW.LT.0) GO TO 2
      KA=KA+1
      JAC(KA)=WKJR(1,I)/WKJR(1,2)
      JJAC(KA)=KWKJ(1,I)
      KA=KA+1
      KAA=KA-1
      JAC(KA)=(-JAC(KAA)*WKJR(2,2)+WKJR(2,I))/A
      JJAC(KA)=KWKJ(1,I)
      KA=KA+1
      JAC(KA)=WKJR(3,I)/WKJR(1,2)
      JJAC(KA)=KWKJ(1,I)
      KA=KA+1
      KAA=KA-1
      JAC(KA)=(-JAC(KAA)*WKJR(2,2)+WKJR(4,I))/A
      JJAC(KA)=KWKJ(1,I)
      GO TO 10
    2 KA=KA+1
      JAC(KA)=WKJR(1,I)/WKJR(1,2)
      JJAC(KA)=KWKJ(1,I)
      KA=KA+1
      KAA=KA-1
      JAC(KA)=(-JAC(KAA)*WKJR(2,2)+WKJR(2,I))/A
      JJAC(KA)=KWKJ(1,I)
   10 CONTINUE
      JNG=KA
      GO TO 1000
    1 KA=1
      JAC(1)=WKJR(1,1)/WKJR(1,2)
      JJAC(1)=KK
      IJAC(1,1)=KK
      IJAC(1,2)=1
      NN=NOCL(2,1)
      DO 9 I=3,NN
      KW=KWKJ(1,I)
      IF(KW.LT.0) GO TO 3
      KA=KA+1
      JAC(KA)=WKJR(1,I)/WKJR(1,2)
      JJAC(KA)=KWKJ(1,I)
```

```
            KA=KA+1
            JAC(KA)=WKJR(3,I)/WKJR(1,2)
            JJAC(KA)=KWKJ(1,I)
            GO TO 9
          3 KA=KA+1
            JAC(KA)=WKJR(1,I)/WKJR(1,2)
            JJAC(KA)=KWKJ(1,I)
          9 CONTINUE
            JNG=KA
            GO TO 1000
       1114 CONTINUE
            IF(KK.GT.0) GO TO 2225
      C PAGE ONE OF BEGH BRANCH
            LOCT=1
            KC=K-1
            NG=NOCL(2,KC)
            DO 20 I=2,NG
            II=KWKJ(2,LOCT)
            KWA=IABS(KWKJ(1,II))
            KWB=KWA-K
            IF(KWB.EQ.0) GO TO 777
            L=IABS(KWKJ(1,II))
            KW=KWKJ(1,II)
            IF(KW.LT.0) GO TO 7
            L1=L-1
            IGA=IABS(L-K)
            IS=IJAC(L1,2)+3
            IF(IGA.EQ.1) GO TO 557
            IE=IJAC(L,2)-1
            GO TO 558
        557 IE=JNG
        558 IS1=IS-1
            ISA=IS-2
            ISB=IS-3
            B=WKJR(3,II)-JAC(IS1)*WKJR(1,II)
            WKJR(1,1)=WKJR(1,1)-JAC(ISB)*WKJR(1,II)-JAC(ISA)*B
            LA=II
            DO 40 KA=IS,IE
            JC=JJAC(KA)
            IF(JC.GT.0) GO TO 8
      C PAGE TWO OF BEGH BRANCHES
            NEXT=KWKJ(2,LA)
            IF(NEXT.EQ.0) GO TO 12
            N=IABS(KWKJ(1,NEXT))
            JJ=IABS(JJAC(KA))
            JJN=JJ-N
            IF(JJN-0) 12,97,13
         97 KAA=KA+1
            WKJR(1,NEXT)=WKJR(1,NEXT)-JAC(KA)*WKJR(1,II)-JAC(KAA)*B
            LA=NEXT
            KB=KB+1
            GO TO 40
         12 NOCL(2,KC)=NOCL(2,KC)+1
            NN=NOCL(2,KC)
            KAA=KA+1
            WKJR(1,NN)=-(JAC(KA)*WKJR(1,II))-(JAC(KAA)*B)
            WKJR(2,NN)=0.0
            WKJR(3,NN)=0.0
```

```
              WKJR(4,NN)=0.0
              KWKJ(1,NN)=JJAC(KA)
              NM=NOCL(2,KC)-1
              DO 22 N=2,NM
              KWA=KWKJ(2,N)
              IF(KWA.EQ.0) GO TO 120
           22 CONTINUE
          120 KW1=IABS(KWKJ(1,N))
              JJ1=IABS(JJAC(KA))
              KJ1=KW1-JJ1
              IF(KJ1.GT.0) GO TO 222
              KWKJ(2,N)=NN
              KWKJ(2,NN)=0
        C PAGE THREE OF BEGH BRANCHES
              GO TO 2222
          222 CONTINUE
              NN1=NN-1
              DO 23 M=2,NN1
              MA=KWKJ(2,M)
              IF(MA.NE.0) GO TO 1960
              GO TO 23
         1960 KW1=IABS(KWKJ(1,M))
              KW2=IABS(KWKJ(1,MA))
              JK1=JJ1-KW1
              JK2=JJ1-KW2
              IF(JK1.LT.0) GO TO 23
              IF(JK2.GT.0) GO TO 23
              KWKJ(2,NN)=MA
              KWKJ(2,M)=NN
              GO TO 2222
           23 CONTINUE
         2222 KB=KB+1
              NNG=NNG+1
              GO TO 40
           13 KB=KB-1
              LA=NEXT
              GO TO 40
            8 NEXT=KWKJ(2,LA)
              IF(NEXT.EQ.0) GO TO 14
              N=IABS(KWKJ(1,NEXT))
              JJ=IABS(JJAC(KA))
              JJN=JJ-N
        C PAGE FOUR OF BEGH BRANCHES
              IF(JJN-0) 14,15,16
           15 KAA=KA+1
              WKJR(1,NEXT)=WKJR(1,NEXT)-(JAC(KA)*WKJR(1,II))-(JAC(KAA)*B)
              KB=KB+2
              KAA=KA+1
              WKJR(3,NEXT)=WKJR(3,NEXT)-(JAC(KA)*WKJR(1,II))-(JAC(KAA)*B)
              KB=KB+1
              LA=NEXT
              GO TO 40
           16 KB=KB-1
              LA=NEXT
              GO TO 40
           14 NOCL(2,KC)=NOCL(2,KC)+1
              NN=NOCL(2,KC)
              KAA=KA+1
```

```
      WKJR(1,NN)=-JAC(KA)*WKJR(1,II)-JAC(KAA)*3
      WKJR(2,NN)=0.0
      WKJR(4,NN)=0.0
      KWKJ(1,NN)=JJAC(KA)
      NM=NOCL(2,KC)-1
      DO 32 N=2,NM
      KWA=KWKJ(2,N)
      IF(KWA.EQ.0) GO TO 121
   32 CONTINUE
  121 KW1=IABS(KWKJ(1,N))
      JJ1=IABS(JJAC(KA))
      KJ1=KW1-JJ1
      IF(KJ1.GT.0) GO TO 322
      KWKJ(2,N)=NN
C PAGE FIVE OF BEGH BRANCHES
      KWKJ(2,NN)=0
      GO TO 3222
  322 CONTINUE
      NN1=NN-1
      DO 33 M=2,NN1
      MA=KWKJ(2,M)
      IF(MA.NE.0) GO TO 1961
      GO TO 33
 1961 KW1=IABS(KWKJ(1,M))
      KW2=IABS(KWKJ(1,MA))
      JK1=JJ1-KW1
      JK2=JJ1-KW2
      IF(JK1.LT.0) GO TO 33
      IF(JK2.GT.0) GO TO 33
      KWKJ(2,NN)=MA
      KWKJ(2,M)=NN
      GO TO 3222
   33 CONTINUE
 3222 KB=KB+2
      KAA=KA+1
      WKJR(3,NN)=-(JAC(KA)*WKJR(1,II))-JAC(KAA)*B
      KB=KB+1
      NNG=NNG+1
   40 CONTINUE
      LOCT=II
      GO TO 20
C PAGE SIX OF BEGH BRANCHES
    7 L1=L-1
      IGA=IABS(L-K)
      IS=IJAC(L1,2)+1
      IF(IGA.EQ.1) GO TO 555
      IF=IJAC(L,2)-1
      GO TO 556
  555 IF=JNG
  556 IS1=IS-1
      WKJR(1,1)=WKJR(1,1)-JAC(IS1)*WKJR(1,II)
      LA=II
      DO30 KA=IS,IF
      JC=JJAC(KA)
      IF(JC.GT.0) GO TO 28
      NEXT=KWKJ(2,LA)
      IF(NEXT.EQ.0) GO TO 34
      N=IABS(KWKJ(1,NEXT))
```

```
      JJ=IABS(JJAC(KA))
      JJN=JJ-N
      IF(JJN-0) 34,35,36
   35 WKJR(1,NEXT)=WKJR(1,NEXT)-JAC(KA)*WKJR(1,II)
      LA=NEXT
      GO TO 30
   36 LA=NEXT
      KB=KB-1
      GO TO 30
   34 NOCL(2,KC)=NOCL(2,KC)+1
      NN=NOCL(2,KC)
      WKJR(1,NN)=-JAC(KA)*WKJR(1,II)
      WKJR(2,NN)=0.0
      WKJR(3,NN)=0.0
      WKJR(4,NN)=0.0
C PAGE SEVENOF BFGH BRANCHES
      KWKJ(1,NN)=JJAC(KA)
      NM=NOCL(2,KC)-1
      DO 42 N=2,NM
      KWA=KWKJ(2,N)
      IF(KWA.EQ.0) GO TO 122
   42 CONTINUE
  122 KW1=IABS(KWKJ(1,N))
      JJ1=IABS(JJAC(KA))
      KJ1=KW1-JJ1
      IF(KJ1.GT.0) GO TO 422
      KWKJ(2,N)=NN
      KWKJ(2,NN)=0
      GO TO 4222
  422 CONTINUE
      NN1=NN-1
      DO 43 M=2,NN1
      MA=KWKJ(2,M)
      IF(MA.NE.0) GO TO 1962
      GO TO 43
 1962 KW1=IABS(KWKJ(1,M))
      KW2=IABS(KWKJ(1,MA))
      JK1=JJ1-KW1
      JK2=JJ1-KW2
      IF(JK1.LT.0) GO TO 43
      IF(JK2.GT.0) GO TO 43
      KWKJ(2,NN)=MA
      KWKJ(2,M)=NN
      GO TO 4222
C PAGE EIGHT OF BFGH BRANCHES
   43 CONTINUE
 4222 CONTINUE
      NNG=NNG+1
      GO TO 30
   28 NEXT=KWKJ(2,LA)
      IF(NEXT.EQ.0) GO TO 44
      N=IABS(KWKJ(1,NEXT))
      JJ=IABS(JJAC(KA))
      JJN=JJ-N
      IF(JJN-0) 44,45,46
   45 WKJR(1,NEXT)=WKJR(1,NEXT)-JAC(KA)*WKJR(1,II)
      KB=KB+1
      WKJR(3,NEXT)=WKJR(3,NEXT)-JAC(KA)*WKJR(1,II)
```

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FORTRAN IV G LEVEL  21                GSEL              DATE = 75305          17/33/58              PAGE 0006

              LA=NEXT
              GO TO 30
           46 KB=KB-1
              LA=NEXT
              GO TO 30
           44 NOCL(2,KC)=NOCL(2,KC)+1
              NN=NOCL(2,KC)
              WKJR(1,NN)=-JAC(KA)*WKJR(1,II)
              WKJR(2,NN)=0.0
              WKJR(4,NN)=0.0
              KWKJ(1,NN)=JJAC(KA)
              NM=NOCL(2,KC)-1
              DO 52 N=2,NM
              KWA=KWKJ(2,N)
              IF(KWA.EQ.0) GO TO 123
C PAGE NINE OF BEGH BRANCHES
           52 CONTINUE
          123 KW1=IABS(KWKJ(1,N))
              JJ1=IABS(JJAC(KA))
              KJ1=KW1-JJ1
              IF(KJ1.GT.0) GO TO 522
              KWKJ(2,N)=NN
              KWKJ(2,NN)=0
              GO TO 5222
          522 CONTINUE
              NN1=NN-1
              DO 53 M=2,NN1
              MA=KWKJ(2,M)
              IF(MA.NE.0) GO TO 1963
              GO TO 53
         1963 KW1=IABS(KWKJ(1,M))
              KW2=IABS(KWKJ(1,MA))
              JK1=JJ1-KW1
              JK2=JJ1-KW2
              IF(JK1.LT.0) GO TO 53
              IF(JK2.GT.0) GO TO 53
              KWKJ(2,NN)=MA
              KWKJ(2,M)=NN
              GO TO 5222
           53 CONTINUE
         5222 KB=KB+1
              WKJR(3,NN)=-JAC(KA)*WKJR(1,II)
              NNG=NNG+1
           30 CONTINUE
          201 LOCT=II
           20 CONTINUE
         2225 CONTINUE
C PAGE ONE OF BFIJ BRANCHES
              LOCT=1
              KC=K-1
              NG=NOCL(2,KC)
              DO 21 I=2,NG
              II=KWKJ(2,LOCT)
              KWA=IABS(KWKJ(1,II))
              KWB=KWA-K
              IF(KWB.EQ.0) GO TO 888
              L=KWA
              KW=KWKJ(1,II)
```

```
      IF(KW.LT.0) GO TO 667
      L1=L-1
      IGA=IABS(L-K)
      IS=IJAC(L1,2)+3
      IF(IGA.EQ.1) GO TO 551
      IE=IJAC(L,2)-1
      GO TO 552
  551 IE=JNG
  552 IS1=IS-1
      ISA=IS-2
      ISB=IS-3
      B=WKJR(4,II)-JAC(IS1)*WKJR(2,II)
      A=WKJR(3,II)-JAC(IS1)*WKJR(1,II)
      WKJR(1,1)=WKJR(1,1)-JAC(ISB)*WKJR(1,II)-JAC(ISA)*A
      WKJR(2,1)=WKJR(2,1)-JAC(ISB)*WKJR(2,II)-JAC(ISA)*B
      LA=II
      DO41 KA=IS,IE
C PAGE TWO OF BEIJ BRANCHES
      JC=JJAC(KA)
      IF(JC.GT.0) GO TO 889
      NEXT=KWKJ(2,LA)
      IF(NEXT.EQ.0) GO TO 62
      N=IABS(KWKJ(1,NEXT))
      JJ=IABS(JJAC(KA))
      JJN=JJ-N
      IF(JJN-0) 62,69,63
   69 KAA=KA+1
      WKJR(1,NEXT)=WKJR(1,NEXT)-(JAC(KA)*WKJR(1,II))-(JAC(KAA)*A)
      WKJR(2,NEXT)=WKJR(2,NEXT)-(JAC(KA)*WKJR(2,II))-(JAC(KAA)*B)
      KB=KB+1
      LA=NEXT
      GO TO 41
   62 NOCL(2,KC)=NOCL(2,KC)+1
      NN=NOCL(2,KC)
      KAA=KA+1
      WKJR(1,NN)=-(JAC(KA)*WKJR(1,II))-(JAC(KAA)*A)
      WKJR(2,NN)=-(JAC(KA)*WKJR(2,II))-(JAC(KAA)*B)
      WKJR(3,NN)=0.0
      WKJR(4,NN)=0.0
      KB=KB+1
      KWKJ(1,NN)=JJAC(KA)
      NM=NOCL(2,KC)-1
      DO 220 N=2,NM
      KWA=KWKJ(2,N)
      IF(KWA.EQ.0) GO TO 124
  220 CONTINUE
C PAGE THREE OF BEIJ BRANCHES
  124 KWI=IABS(KWKJ(1,N))
      JJ1=IABS(JJAC(KA))
      KJ1=KWI-JJ1
      IF (KJ1.GT.0) GO TO 223
      KWKJ(2,N)=NN
      KWKJ(2,NN)=0
      GO TO 2223
  223 CONTINUE
      NN1=NN-1
      DO 230 M=2,NN1
      MA=KWKJ(2,M)
```

```
            IF(MA.NE.0) GO TO 1964
            GO TO 230
       1964 KW1=IABS(KWKJ(1,M))
            KW2=IABS(KWKJ(1,MA))
            JK1=JJ1-KW1
            JK2=JJ1-KW2
            IF(JK1.LT.0) GO TO 230
            IF(JK2.GT.0) GO TO 230
            KWKJ(2,NN)=MA
            KWKJ(2,M)=NN
            GO TO 2223
        230 CONTINUE
       2223 CONTINUE
            NNG=NNG+1
            GO TO 41
         63 KB=KB-1
C PAGE FOUR OF BFIJ BRANCHES
            LA=NEXT
            GO TO 41
        889 NEXT=KWKJ(2,LA)
            IF(NEXT.EQ.0) GO TO 80
            N=IABS(KWKJ(1,NEXT))
            JJ=IABS(JJAC(KA))
            JJN=JJ-N
            IF(JJN-0) 80,81,82
         81 KAA=KA+1
            WKJR(1,NEXT)=WKJR(1,NEXT)-(JAC(KA)*WKJR(1,II))-(JAC(KAA)*A)
            WKJR(2,NEXT)=WKJR(2,NEXT)-(JAC(KA)*WKJR(2,II))-(JAC(KAA)*B)
            KB=KB+2
            KAA=KA+1
            WKJR(3,NEXT)=WKJR(3,NEXT)-(JAC(KA)*WKJR(1,II))-(JAC(KAA)*A)
            WKJR(4,NEXT)=WKJR(4,NEXT)-(JAC(KA)*WKJR(2,II))-(JAC(KAA)*B)
            KB=KB+1
            LA=NEXT
            GO TO 41
         82 KB=KB-1
            LA=NEXT
            GO TO 41
         80 NOCL(2,KC)=NOCL(2,KC)+1
            NN=NOCL(2,KC)
            KAA=KA+1
            WKJR(1,NN)=-(JAC(KA)*WKJR(1,II))-(JAC(KAA)*A)
C PAGE FIVE OF BFIJ BRANCHES
            WKJR(2,NN)=-(JAC(KA)*WKJR(2,II))-(JAC(KAA)*B)
            KB=KB+2
            KAA=KA+1
            WKJR(3,NN)=-(JAC(KA)*WKJR(1,II))-(JAC(KAA)*A)
            WKJR(4,NN)=-(JAC(KA)*WKJR(2,II))-(JAC(KAA)*B)
            KB=KB+1
            KWKJ(1,NN)=JJAC(KA)
            NM=NOCL(2,KC)-1
            DO 822 N=2,NM
            KWA=KWKJ(2,N)
            IF(KWA.EQ.0) GO TO 125
        822 CONTINUE
        125 KW1=IABS(KWKJ(1,N))
            JJ1=IABS(JJAC(KA))
            KJ1=KW1-JJ1
```

```
            IF(KJ1.GT.0) GO TO 8222
            KWKJ(2,N)=NN
            KWKJ(2,NN)=0
            GO TO 8223
      8222 CONTINUE
            NN1=NN-1
            DO 84 M=2,NN1
            MA=KWKJ(2,M)
            IF(MA.NE.0) GO TO 1965
            GO TO 84
      1965 KW1=IABS(KWKJ(1,M))
            KW2=IABS(KWKJ(1,MA))
     C PAGE SIX OF BFIJ BRANCHES
            JK1=JJ1-KW1
            JK2=JJ1-KW2
            IF(JK1.LT.0) GO TO 84
            IF(JK2.GT.0) GO TO 84
            KWKJ(2,NN)=MA
            KWKJ(2,M)=NN
            GO TO 8223
        84 CONTINUE
      8223 CONTINUE
            NNG=NNG+1
        41 CONTINUE
            LOCT=II
            GO TO 21
       667 L1=L-1
            IGA=IABS(L-K)
            IS=IJAC(L1,2)+1
            IF(IGA.EQ.1) GO TO 553
            IE=IJAC(L,2)-1
            GO TO 554
       553 IE=JNG
       554 IS1=IS-1
            WKJR(1,1)=WKJR(1,1)-JAC(IS1)*WKJR(1,II)
            WKJR(2,1)=WKJR(2,1) -JAC(IS1)*WKJR(2,II)
            LA=II
            DO 91 KA=IS,IE
            JC=JJAC(KA)
            IF(JC.GT.0) GO TO 92
            NEXT=KWKJ(2,LA)
            IF(NEXT.EQ.0) GO TO 900
            N=IABS(KWKJ(1,NEXT))
     C PAGE SEVEN OF BFIJ BRANCHES
            JJ=IABS(JJAC(KA))
            JJN=JJ-N
            IF(JJN-0) 900,901,902
       901 WKJR(1,NEXT)=WKJR(1,NEXT)-JAC(KA)*WKJR(1,II)
            WKJR(2,NEXT)=WKJR(2,NEXT)-JAC(KA)*WKJR(2,II)
            LA=NEXT
            GO TO 91
       902 KB=KB-1
            LA=NEXT
            GO TO 91
       900 NOCL(2,KC)=NOCL(2,KC)+1
            NN=NOCL(2,KC)
            WKJR(1,NN)=-JAC(KA)*WKJR(1,II)
            WKJR(2,NN)=-JAC(KA)*WKJR(2,II)
```

```
0507          WKJR(3,NN)=0.0
0508          WKJR(4,NN)=0.0
0509          KWKJ(1,NN)=JJAC(KA)
0510          NM=NOCL(2,KC)-1
0511          DO 903 N=2,NM
0512          KWA=KWKJ(2,N)
0513          IF(KWA.EQ.0) GO TO 126
0514      903 CONTINUE
0515      126 KW1=IABS(KWKJ(1,N))
0516          JJ1=IABS(JJAC(KA))
0517          KJ1=KW1-JJ1
0518          IF(KJ1.GT.0) GO TO 904
0519          KWKJ(2,N)=NN
0520          KWKJ(2,NN)=0
        C PAGE EIGHT OF BFIJ BRANCHES
0521          GO TO 905
0522      904 CONTINUE
0523          NN1=NN-1
0524          DO 906 M=2,NN1
0525          MA=KWKJ(2,M)
0526          IF(MA.NE.0) GO TO 1966
0527          GO TO 906
0528     1966 KW1=IABS(KWKJ(1,M))
0529          KW2=IABS(KWKJ(1,MA))
0530          JK1=JJ1-KW1
0531          JK2=JJ1-KW2
0532          IF(JK1.LT.0) GO TO 906
0533          IF(JK2.GT.0) GO TO 906
0534          KWKJ(2,NN)=MA
0535          KWKJ(2,M)=NN
0536          GO TO 905
0537      906 CONTINUE
0538      905 CONTINUE
0539          NNG=NNG+1
0540          GO TO 91
0541       92 NEXT=KWKJ(2,LA)
0542          IF(NEXT.EQ.0) GO TO 907
0543          N=IABS(KWKJ(1,NEXT))
0544          JJ=IABS(JJAC(KA))
0545          JJN=JJ-N
0546          IF(JJN-0) 907,908,909
0547      908 WKJR(1,NEXT)=WKJR(1,NEXT)-JAC(KA)*WKJR(1,II)
0548          KAA=KA+1
        C PAGE NINE OF BFIJ BRANCHES
0549          WKJR(3,NEXT)=WKJR(3,NEXT)-JAC(KAA)*WKJR(1,II)
0550          WKJR(2,NEXT)=WKJR(2,NEXT)-JAC(KA)*WKJR(2,II)
0551          WKJR(4,NEXT)=WKJR(4,NEXT)-JAC(KAA)*WKJR(2,II)
0552          KB=KB+1
0553          LA=NEXT
0554          GO TO 91
0555      909 KB=KB-1
0556          LA=NEXT
0557          GO TO 91
0558      907 NOCL(2,KC)=NOCL(2,KC)+1
0559          NN=NOCL(2,KC)
0560          WKJR(1,NN)=-JAC(KA)*WKJR(1,II)
0561          WKJR(2,NN)=-JAC(KA)*WKJR(2,II)
0562          KAA=KA+1
```

```
      WKJR(3,NN)=-JAC(KAA)*WKJR(1,II)
      WKJR(4,NN)=-JAC(KAA)*WKJR(2,II)
      KWKJ(1,NN)=JJAC(KA)
      NM=NOCL(2,KC)-1
      DO 910 N=2,NM
      KWA=KWKJ(2,N)
      IF(KWA.EQ.0) GO TO 129
  910 CONTINUE
  129 KW1=IABS(KWKJ(1,N))
      JJ1=IABS(JJAC(KA))
      KJ1=KW1-JJ1
      IF(KJ1.GT.0) GO TO 911
C PAGE TEN OF BFIJ BRANCHES
      KWKJ(2,N)=NN
      KWKJ(2,NN)=0
      GO TO 912
  911 CONTINUE
      NN1=NN-1
      DO 913 M=2,NN1
      MA=KWKJ(2,M)
      IF(MA.NE.0) GO TO 1967
      GO TO 913
 1967 KW1=IABS(KWKJ(1,M))
      KW2=IABS(KWKJ(1,MA))
      JK1=JJ1-KW1
      JK2=JJ1-KW2
      IF(JK1.LT.0) GO TO 913
      IF(JK2.GT.0) GO TO 913
      KWKJ(2,NN)=MA
      KWKJ(2,M)=NN
      GO TO 912
  913 CONTINUE
  912 KB=KB+1
      NNG=NNG+1
   91 CONTINUE
  211 LOCT=II
   21 CONTINUE
C PAGE ONE OF Y BRANCH
  888 A=(-WKJR(3,II)/WKJR(1,II))*WKJR(2,II)+WKJR(4,II)
      KA=JNG+1
      IJAC(KC,1)=KK
      IJAC(KC,2)=KA
      JAC(KA)=WKJR(1,1)/WKJR(1,II)
      JJAC(KA)=KK
      KA=KA+1
      KAA=KA-1
      JAC(KA)=(-JAC(KAA)*WKJR(2,II)+WKJR(2,1))/A
      JJAC(KA)=KK
      KA=KA+1
      JAC(KA)=WKJR(3,II)/WKJR(1,II)
      JJAC(KA)=KK
      IB=II
      NN=NOCL(2,KC)
      DO 101 IT=1,NN
      IB=KWKJ(2,IB)
      JNG=KA
      IF(IB.EQ.0) GO TO 1000
      KW=KWKJ(1,IB)
```

```
      IF(KW.LT.0) GO TO 5
      KA=KA+1
      JAC(KA)=WKJR(1,IB)/WKJR(1,II)
      JJAC(KA)=KWKJ(1,IB)
      KA2=KA+2
C PAGE TWO OF Y BRANCH
      JAC(KA2)=WKJR(3,IB)/WKJR(1,II)
      JJAC(KA2)=KWKJ(1,IB)
      KA=KA+1
      KAA=KA-1
      JAC(KA)=(-JAC(KAA)*WKJR(2,II)+WKJR(2,IB))/A
      JJAC(KA)=KWKJ(1,IB)
      KA=KA+2
      KAA=KA-1
      JAC(KA)=(-JAC(KAA)*WKJR(2,II)+WKJR(4,IB))/A
      JJAC(KA)=KWKJ(1,IB)
      GO TO 101
    5 KA=KA+1
      JAC(KA)=WKJR(1,IB)/WKJR(1,II)
      JJAC(KA)=KWKJ(1,IB)
      KA=KA+1
      KAA=KA-1
      JAC(KA)=(-JAC(KAA)*WKJR(2,II)+WKJR(2,IB))/A
      JJAC(KA)=KWKJ(1,IB)
  101 CONTINUE
      GO TO 1000
C PAGE ONE OF X BRANCH
  777 KA=JNG+1
      IJAC(KC,1)=KK
      IJAC(KC,2)=KA
      JAC(KA)=WKJR(1,1)/WKJR(1,II)
      JJAC(KA)=KK
      IB=II
      NN=NOCL(2,KC)
      DO 100 IT=1,NN
      IB=KWKJ(2,IB)
      JNG=KA
      IF(IB.EQ.0) GO TO 1000
      KW=KWKJ(1,IB)
      IF(KW.LT.0) GO TO 4
      KA=KA+1
      JAC(KA)=WKJR(1,IB)/WKJR(1,II)
      JJAC(KA)=KWKJ(1,IB)
      KA=KA+1
      JAC(KA)=WKJR(3,IB)/WKJR(1,II)
      JJAC(KA)=KWKJ(1,IB)
      GO TO 100
    4 KA=KA+1
      JAC(KA)=WKJR(1,IB)/WKJR(1,II)
      JJAC(KA)=KWKJ(1,IB)
  100 CONTINUE
 1000 CONTINUE
      RETURN
      END
```

```
0001          SUBROUTINE INPUT(ZSER,YSHT,LENGTH,TS,TR,ST,PG,QG,PL,
             1QL,VMAX,VMIN,QMAX,QMIN,VSPEC,CC,SB,EB,NL,NG,BN,MB,NC,
             2ITER1,ITER,TOLE,DELTAA,MAGV,OBASE,NBASE,BN1,BM)
0002          COMPLEX*8 ZSER(100),YSHT(100)
0003          REAL LENGTH(100),PG(60),PL(60),QG(60),QL(60),
             1VSPEC(60),QMIN(60),QMAX(60),VMAX(60),VMIN(60),CC(60),MAGV,
             2DELTAA,TOLE,TR(100),OBASE,NBASE
0004          INTEGER SB(100),EB(100),BN(60),BM,BN1(60),TS(100),ST
0005      100 FORMAT('1'//T57,'I N P U T  D A T A'/)
0006      102 FORMAT('0',T20,'NO. OF LINES(NL) =',I5,5X,'NO. OF BUSES(NB) =',
             1I5,5X,'NO. OF CAPACITORS/REACTOR(NC) =',I5,//T20,
             2'NO. OF VOLTAGE CONTROL BUSES (BM) =',I5//T20,
             3'BASE FOR INPUTTED DATA(OLD BASE) =',1X,F6.0,1X,'MVA',5X,
             4'BASE FOR OUTPUT(NEW BASE) =',1X,F6.0,1X,'MVA')
0007      104 FORMAT('0',T20,'TOLERANCE FOR CONVERGENCE =',F9.6,5X,
             1'MAXIMUM NO. OF ITERATIONS ALLOWED =',I4)
0008      106 FORMAT('0',T20,'SWING BUS VOLTAGE MAGNITUDE =',F10.5,1X,'PU',5X,
             1'SWING BUS PHASE =',F7.2,1X,'DEGREES'//)
0009      108 FORMAT('0',T20,'STATIC CAPACITORS/REACTOR (OLD BASE)'//T20,
             1'BUS',5X,'SUSCEPTANCE'/)
0010      110 FORMAT(' ',T17,I5,5X,F10.5)
0011      112 FORMAT('0'//T20,'TRANSMISSION LINE DATA (OLD BASE)'/T20,
             1'Y SHUNT IS TOTAL LINE CHARGING ADMITTANCE'/T20,'SB',5X,
             2'EB',14X,'Z SERIES',19X,'Y SHUNT',11X,'LENGTH'/T40,'R',11X,'X',
             314X,'G',11X,'B'/)
0012      113 FORMAT('0'//T20,'TRANSMISSION LINE DATA (OLD BASE)'/T20,
             1'Y SHUNT IS ONE-HALF OF THE TOTAL LINE CHARGING ADMITTANCE'/T20,
             2'SB',5X,'EB',14X,'Z SERIES',19X,'Y SHUNT',11X,'LENGTH'/T40,'R',
             311X,'X',14X,'G',11X,'B'/)
0013      114 FORMAT(' ',T17,I5,2X,I5,5X,F10.5,2X,F10.5,5X,F10.5,2X,F10.5,5X,
             1F5.1)
0014      116 FORMAT('0',T20,'TOTAL TRANSMISSION LINES =',1X,I5)
0015      118 FORMAT('0'//T20,'TRANSFORMER LINE DATA (OLD BASE)'/T20,
             1'Y SHUNT IS TOTAL LINE CHARGING ADMITTANCE'/T20,'SB',5X,
             2'EB',14X,'Z SERIES',19X,'Y SHUNT',11X,'LENGTH'/T40,'R',11X,'X',
             314X,'G',11X,'B'/)
0016      119 FORMAT('0'//T20,'TRANSFORMER LINE DATA (OLD BASE)'/T20,
             1'Y SHUNT IS ONE-HALF OF THE TOTAL LINE CHARGING ADMITTANCE'/T20,
             2 'SB',5X,'EB',14X,'Z SERIES',19X,'Y SHUNT',12X,'TAP SETTING',
             311X,'LENGTH'/T40,'R',11X,'X',14X,'G',11X,'B'/)
0017      120 FORMAT(' ',T17,I5,2X,I5,5X,F10.5,2X,F10.5,5X,F10.5,2X,F10.5,9X,
             1F5.3,14X,F5.1)
0018      122 FORMAT('0',T20,'TOTAL TRANSFORMER LINES =',1X,I5)
0019      124 FORMAT('0'//T20,'VOLTAGE CONTROL BUS DATA'//T20,'BUS',10X,'VSPEC',
             110X,'QMIN',10X,'QMAX'/T35,'PU',11X,'MVAR',10X,'MVAR'/)
0020      126 FORMAT(' ',T17,I5,6X,F10.3,5X,F10.3,4X,F10.3)
0021      128 FORMAT('0'//T20,'SCHEDULED BUS POWERS'//T20,'BUS',13X,
             1'GENERATION',25X,'LOAD'/T33,'MW',12X,'MVAR',14X,'MW',12X,'MVAR'//)
0022      130 FORMAT(' ',T17,I5,5X,F10.3,5X,F10.3,7X,F10.3,5X,F10.3)
0023      132 FORMAT(' ',T17,I5,5X,F10.3,6X,'UNSPECIFIED',5X,F10.3,5X,F10.3)
0024      134 FORMAT(' ',T17,I5,6X,'UNSPECIFIED',4X,'UNSPECIFIED',5X,F10.3,
             15X,F10.3)
0025          WRITE(6,100)
0026          WRITE(6,102) NL,NB,NC,BM,OBASE,NBASE
0027          WRITE(6,104) TOLE,ITER1
0028          WRITE(6,106) MAGV,DELTAA
0029          IF(NC.EQ.0) GO TO 15
0030          WRITE(6,108)
```

```
      DO 5 I=1,NC
      CC(I)=CC(I)*NBASE/OBASE
      WRITE(6,110) BN1(I),CC(I)
    5 CONTINUE
      DO 10 I=1,NC
   10 CC(I)=CC(I)*OBASE/NBASE
   15 CONTINUE
      IF(ST.EQ.0) GO TO 17
      WRITE(6,112)
      GO TO 18
   17 WRITE(6,113)
   18 M=0
      DO 20 I=1,NL
      YSHT(I)=YSHT(I)*NBASE/OBASE
      ZSER(I)=ZSER(I)*OBASE/NBASE
      IF(TS(I).NE.0) GO TO 20
      WRITE(6,114) SB(I),EB(I),ZSER(I),YSHT(I),LENGTH(I)
      M=M+1
   20 CONTINUE
      WRITE(6,116) M
      DO 25 I=1,NL
      IF(TS(I).NE.0) GO TO 30
   25 CONTINUE
      GO TO 40
   30 IF(ST.EQ.0) GO TO 32
      WRITE(6,118)
      GO TO 33
   32 WRITE(6,119)
   33 M=0
      DO 35 I=1,NL
      IF(TS(I).EQ.0) GO TO 35
      TR(I)=1./TR(I)
      WRITE(6,120) SB(I),EB(I),ZSER(I),YSHT(I),TR(I),LENGTH(I)
      M=M+1
   35 CONTINUE
      WRITE(6,122)M
   40 CONTINUE
      DO 1 I=1,NL
      YSHT(I)=YSHT(I)*OBASE/NBASE
      ZSER(I)=ZSER(I)*NBASE/OBASE
    1 TR(I)=1./TR(I)
      IF(MB.LE.1) GO TO 50
      WRITE(6,124)
      DO 45 I=2,MB
   45 WRITE(6,126) I,VSPEC(I),QMIN(I),QMAX(I)
   50 CONTINUE
      WRITE(6,128)
      DO 65 I=1,NB
      IF(I.EQ.1) GO TO 60
      IF(I.LE.MB) GO TO 55
      WRITE(6,130) I,PG(I),QG(I),PL(I),QL(I)
      GO TO 65
   55 WRITE(6,132) I,PG(I),PL(I),QL(I)
      GO TO 65
   60 WRITE(6,134) I,PL(I),QL(I)
   65 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MISMAT(SB,EB,S,R,P,Q,CMVAR,NB,BN1,NL,NC,BM,MB)
      COMPLEX*8 CMPLX,S(100),R(100),AMM,BMM,TMM
      REAL P(60),Q(60),CMVAR(20),NBASE,QBASE
      INTEGER SB(100),NB,BN1(60),EB(100),BM
  100 FORMAT('1',T70,'MISMACHES'//)
  102 FORMAT(' ',60X,F9.3,6X,F9.3)
  104 FORMAT('0',T42,'TOTAL MISMACH',6X,F9.3,6X,F9.3)
  106 FORMAT('0',T42,'AVERAGE MISMACH',4X,F9.3,6X,F9.3//)
      WRITE(6,100)
      TMM=CMPLX(0.0,0.0)
      DO 425 J=1,NB
      BMM=CMPLX(0.0,0.0)
      DO 415 I=1,NL
      L=IABS(SB(I))
      M=IABS(EB(I))
      IF(L.EQ.J) GO TO 405
      IF(M.EQ.J) GO TO 410
      GO TO 415
  405 BMM=BMM+S(I)
      GO TO 415
  410 BMM=BMM+R(I)
  415 CONTINUE
      IF(J.EQ.1) GO TO 420
      IF(NC.EQ.0) GO TO 20
      DO 426 I=1,NC
      IF(BN1(I).EQ.J) GO TO 427
  426 CONTINUE
   20 CONTINUE
      BMM=BMM-CMPLX(P(J),Q(J))
      GO TO 420
  427 BMM=BMM-CMPLX(P(J),Q(J))-CMPLX(0.0,CMVAR(I))
  420 WRITE(6,102) BMM
      IF(J.EQ.1) GO TO 425
      TMM=TMM+BMM
  425 CONTINUE
      WRITE(6,104) TMM
      AMM=TMM/(NB-1)
      WRITE(6,106) AMM
      RETURN
      END
```

APPENDIX B

(Program Listing for TSRK)

```
FORTRAN IV G LEVEL  21                 MAIN                DATE = 75305          17/40/42                PAGE 0001

               C ************************************************************************
               C *THIS PROGRAM IS A SIMULATION OF POWER SYSTEM IN TRANSIENT STATE*
               C ************************************************************************
               C
               C
 0001                COMPLEX*8 CMPLX,CONJG,YBUS(150),BIT,V(50),SUM,
                    1WKJP(1,10),JAC(150),BC,DD2,ETEMP(60),YS(50),SERY(100),SHTY(100)
 0002                REAL PL(20),QL(20),P(20),Q(20),XDP(10),EQ(20),PRMT(5),
                    1H(10),ES(10),DERY(100),DG(10),Y(100),PP(20),MAGV,TR1(100),
                    2E3(20),KE,KA,AUX(8,100),KF,X,T,TT,DELTT,NBASE,OBASE,TSW
 0003                INTEGER IYBUS(150),JYBUS(150),KTABI(20,3),NTABI(20,3),
                    1MAB(10),FB(10),INDEX(10),IINDEX(20),KWKJ(2,10),
                    2NCCL(2,20),JJAC(150),IJAC(20,2),IABS,SB(100),EB(100),
                    3SB1(10),EB1(10)
 0004                WRITE(6,150)
 0005            150 FORMAT('1',//T57,'I N P U T   D A T A'/)
 0006                READ(5,334) NL
 0007            334 FORMAT(I3)
 0008                READ(5,331) (SERY(I),SHTY(I),I=1,NL)
 0009            331 FORMAT(4F10.5)
 0010                READ(5,332) (SB(I),EB(I),I=1,NL)
 0011            332 FORMAT(2I3)
 0012                READ(5,333) (TR1(I),I=1,NL)
 0013            333 FORMAT(2F10.5)
 0014                READ(5,511) NBASE,OBASE
 0015            511 FORMAT(2F10.5)
 0016                READ(5,205) NB,NOET
 0017            205 FORMAT(2I3)
 0018                READ(5,213) (V(I),I=1,NB)
 0019            213 FORMAT(2F10.5)
 0020                READ(5,206) (PL(I),QL(I),I=1,NB)
 0021            206 FORMAT(2F10.5)
 0022                READ(5,211) (P(I),Q(I),I=1,NB)
 0023            211 FORMAT(2F10.5)
 0024                READ(5,207) ((KTABI(I,J),J=1,3),I=1,NB)
 0025            207 FORMAT(3I3)
 0026                READ(5,208) ((NTABI(I,J),J=1,3),I=1,NB)
 0027            208 FORMAT(3I3)
 0028                READ(5,209) (YBUS(I),I=1,NOET)
 0029            209 FORMAT(6F10.5)
 0030                READ(5,210) (IYBUS(I),JYBUS(I),I=1,NOET)
 0031            210 FORMAT(2I3)
 0032                DO 1 I=1,NB
 0033                IF(PL(I).NE.0.0) GO TO 101
 0034                IF(QL(I).EQ.0.0) GO TO 999
 0035            101 YS(I)=CMPLX(PL(I),-QL(I))/(CABS(V(I))**2)
 0036                NOET1=1
 0037                IF(I.EQ.1) GO TO 102
 0038                II=I-1
 0039                DO 2 I1=1,II
 0040              2 NOET1=NOET1+NTABI(I1,2)
 0041            102 YBUS(NOET1)=YBUS(NOET1)+YS(I)
 0042                GO TO 1
 0043            999 YS(I)=CMPLX(0.0,0.0)
 0044              1 CONTINUE
 0045                READ(5,201) M,TOOP
 0046            201 FORMAT(I3,F10.5)
 0047                DO 3 I=1,M
```

```
      READ(5,202) MAB(I),XDP(I),H(I)
  202 FORMAT(I3,2F10.5)
      NOET2=NOET+I
      XDPR=-1.0/XDP(I)
      YBUS(NOET2)=-CMPLX(0.0,XDPR)
      MABI=MAB(I)
      IYBUS(NOET2)=KTABI(MABI,3)
      JYBUS(NOET2)=IABS(KTABI(MABI,3))+NB
      NOET1=1
      IAKT=IABS(KTABI(MABI,3))
      IF(IAKT.EQ.1) GO TO 103
      II=IAKT-1
      DO 4 I1=1,II
    4 NOET1=NOET1+NTABI(I1,2)
  103 YBUS(NOET1)=YBUS(NOET1)+CMPLX(0.0,XDPR)
    3 CONTINUE
      READ(5,216) NFB,NFBL,TMAX,TSW
  216 FORMAT(2I3,2F10.5)
      DO 500 I=1,M
      II=IABS(KTABI(MAB(I),3))
  500 ES(I)=CABS(V(II))
      DO 5 I=1,M
      MABI=MAB(I)
      J=IABS(KTABI(MABI,3))
      PP(J)=P(J)+PL(J)
      QQ=Q(J)+QL(J)
      BIT=CMPLX(PP(J),-QQ)/CONJG(V(J))
    5 V(J+NB)=V(J)+BIT*(CMPLX(0.0,XDP(I)))
      WRITE(6,151) M,NFB,NFBL
  151 FORMAT('0',T20,'NO. OF MACHINES(M)= ',I5,5X,
     1'NO. OF FAULTED BUSES(NFB)= ',I5,5X,
     2'NO. OF FAULTED LINES(NFBL)= ',I5)
      WRITE(6,152) MAB(1)
  152 FORMAT(' ',T20,'MACHINE BUSES ARE:',T40,'BUS',1X,I3)
      WRITE(6,153) (MAB(I),I=2,M)
  153 FORMAT(' ',T40,'BUS',1X,I3)
      DO 6 I=1,NFB
      READ(5,204) FB(I)
  204 FORMAT(I3)
      IF(I.NE.1) GO TO 155
      WRITE(6,154) FB(1)
  154 FORMAT(' ',T20,'FAULTED BUSES ARE:',T40,'BUS',1X,I3)
      GO TO 509
  155 WRITE(6,156) FB(I)
  156 FORMAT(' ',T40,'BUS',1X,I3)
  509 II=FB(I)
    6 FB(I)=KTABI(II,3)
      CALL FORM(NB,NTABI,KTABI,NFB,FB,YBUS,V,K,KK,M,MAB,NOET,
     1IINDEX,INDEX,JYBUS,WKJR,KWKJ,NOCL,IJAC,JJAC,JAC,IYBUS)
      DO 112 I=1,M
      MABI=MAB(I)
      K1=IABS(KTABI(MABI,3))
      KN=K1+NB
  112 EQ(K1)=CABS(V(KN))
      READ(5,349) (SBL(I),EBL(I),I=1,NFBL)
  349 FORMAT(2I3)
      READ(5,215) TS,TC,R,DBT,PMAX,TR,TA,KA,TE,KE,TF,KF,A1,B1
  215 FORMAT(5F10.5)
```

```
0103          READ(5,203) DELTT,PRMT(4)
0104      203 FORMAT(2F10.5)
0105          WRITE(6,197) SB1(1),EB1(1)
0106      197 FORMAT(' ',T20,'FAULTED LINES ARE:',T40,'STARTING BUS',1X,
             1I3,5X,'ENDING BUS',1X,I3)
0107          IF(NFBL.EQ.1) GO TO 196
0108          DO 198 I=2,NFBL
0109      198 WRITE(6,195) SB1(I),EB1(I)
0110      195 FORMAT(' ',T40,'STARTING BUS',1X,I3,5X,'ENDING BUS',1X,I3)
0111      196 CONTINUE
0112          WRITE(6,157)
0113      157 FORMAT(' ',T20,'THE THREE PHASE TO GROUND FAULTS HAPPEN AT TIME(T)
             1=',1X,'0.0',1X,'SECONDS')
0114          WRITE(6,158) TMAX,TSW
0115      158 FORMAT(' ',T20,'THE FAULT WILL BE CLEARED AT TIME(T)=',1X,F7.3,1X,
             1'SECONDS'/' ',T20,'THE FAULT WILL BE SWITCHED OFF AT TIME(T)=',
             21X,F7.3,1X,'SECONDS')
0116          WRITE(6,159)
0117      159 FORMAT('0',T20,'** DATA FOR MACHINES**')
0118          WRITE(6,160) (MAB(I),XDP(I),I=1,M)
0119      160 FORMAT(' ',T20,'THE MACHINE AT BUS',1X,I3,1X,'; TRANSIENT REACTANC
             1E=',1X,F10.5,1X,'PU')
0120          WRITE(6,161) (MAB(I),H(I),I=1,M)
0121      161 FORMAT(' ',T20,'THE MACHINE AT BUS',1X,I3,1X,'; THE INERTIA CONSTA
             1NT(H)=',1X,F10.5,1X,'PU')
0122          WRITE(6,162)
0123      162 FORMAT('0',T20,'** DATA FOR EXCITATION SYSTEMS **')
0124          WRITE(6,163) TR,TA
0125      163 FORMAT(' ',T20,'REGULATOR TIME CONSTANT(TR)=',F10.5,5X,
             1'AMPLIFIER TIME CONSTANT(TA)=',F10.5)
0126          WRITE(6,164) TE,TF
0127      164 FORMAT(' ',T20,'EXCITER TIME CONSTANT(TE)=',F10.5,5X,
             1'STABILIZING LOOP TIME CONSTANT(TF)=',F10.5)
0128          WRITE(6,165) KA,KE
0129      165 FORMAT(' ',T20,'AMPLIFIER GAIN(KA)=',F10.5,5X,
             1'EXCITER GAIN(KE)=',F10.5)
0130          WRITE(6,166) KF
0131      166 FORMAT(' ',T20,'STABILIZING LOOP GAIN=',F10.5)
0132          WRITE(6,167)
0133      167 FORMAT('0',T20,'** DATA FOR SPEED GOVERNOR CONTROL SYSTEM **')
0134          WRITE(6,168) TS,TC
0135      168 FORMAT(' ',T20,'STEAM SYSTEM TIME CONSTANT(TS)=',F10.5,5X,
             1'CONTROL SYSTEM TIME CONSTANT(TC)=',F10.5)
0136          WRITE(6,169) DELTT
0137      169 FORMAT('0',T20,'** TIME INCREMENT USED(DELTT)= ',F10.5)
0138          WRITE(6,194) PRMT(4)
0139      194 FORMAT(' ',T20,'ERROR TOLERENCE USED(PRMT(4))= ',F10.5)
0140          WRITE(6,170)
0141      170 FORMAT('1',T57,'I N I T I A L   C O N D I T I O N S')
0142          WRITE(6,171)
0143      171 FORMAT('0',T20,'TERMINAL VOLTAGE OF EVERY BUS')
0144          DO 173 I=1,NB
0145          II=IABS(NTABI(I,3))
0146          WRITE(6,172) II,V(I)
0147      172 FORMAT(' ',T20,'TERMINAL VOLTAGE AT BUS',1X,I3,1X,'=',2F10.5)
0148      173 CONTINUE
0149          DO 174 I=1,M
0150          MABI=MAB(I)
```

```
      KN=IABS(KTABI(MABI,3))+NB
  174 WRITE(6,175) MABI,V(KN)
  175 FORMAT('0',T20,'INTERNAL VOLTAGE FOR MACHINE AT BUS',1X,I3,1X,
     1'=',2F10.5)
      WRITE(6,199)
  199 FORMAT('1',T57,'THE RESULT FOR EVERY 0.02 SEC IS AS FOLLOWS')
      T=0.0
      TT=0.0
      LBR1=0
      FLEF1=0.0
      TGG=TMAX+DELTT
      TSW1=TSW-DELTT/2.
      TSW2=TSW+DELTT/2.
   17 CONTINUE
      PRMT(1)=T
      PRMT(2)=T+DELTT
      PRMT(3)=DELTT
      NDIM=M*9
      DO 18 I=1,M
      DO 19 II=1,9
      ID=(I-1)*9+II
   19 DERY(ID)=1./9.
   18 CONTINUE
      IF(T.EQ.0.0) GO TO 104
      GO TO 22
  104 CONTINUE
      DO 21 I=1,M
      MABI=MAB(I)
      K1=IABS(KTABI(MABI,3))
      ID=(I-1)*9+1
      KN=K1+NB
      Y(ID)=ATAN2(AIMAG(V(KN)),REAL(V(KN)))
      ID=ID+1
      Y(ID)=2.*3.141592654*60.
      ID=ID+1
      Y(ID)=PP(K1)
      ID1=ID+1
      Y(ID1)=Y(ID)
      ID=ID1+1
      Y(ID)=CABS(V(KN))
      ID1=ID+1
      Y(ID1)=Y(ID)
      ID=ID1+1
      BIN=B1*Y(ID1)
      Y(ID)=(KE*Y(ID1))+A1*EXP(BIN)
      F3(K1)=Y(ID)
      ID=ID+1
      Y(ID)=0.0
      ID=ID+1
      Y(ID)=0.0
   21 CONTINUE
   22 CONTINUE
      IF(T.LE.TSW1) GO TO 300
      IF(T.GE.TSW2) GO TO 300
      DO 301 I=1,NFBL
      DO 302 J=1,NL
      IF(SB(J).NE.SB1(I)) GO TO 302
      IF(EB(J).EQ.EB1(I)) GO TO 303
```

```
0208        302 CONTINUE
0209        303 J1=0
0210            DO 304 I1=1,NOET
0211            IS=IABS(SB1(I))
0212            IE=IABS(EB1(I))
0213            IS=KTABI(IS,3)
0214            IF=KTABI(IE,3)
0215            IF(IYBUS(I1).NE.IS) GO TO 305
0216            IF(JYBUS(I1).EQ.IE) GO TO 306
0217            GO TO 304
0218        305 IF(IYBUS(I1).NE.IE) GO TO 304
0219            IF(JYBUS(I1).NE.IS) GO TO 304
0220            J1=J1+1
0221            IEIS=I1
0222            GO TO 304
0223        306 J1=J1+1
0224            ISIE=I1
0225        304 CONTINUE
0226            IS=IABS(SB1(I))
0227            IE=IABS(EB1(I))
0228            IS=IABS(KTABI(IS,3))
0229            IE=IABS(KTABI(IE,3))
0230            MAS=1
0231            IS=IS-1
0232            IF(IS.EQ.0) GO TO 307
0233            DO 308 I2=1,IS
0234        308 MAS=MAS+NTABI(I2,2)
0235        307 MAE=1
0236            IE=IE-1
0237            IF(IE.EQ.0) GO TO 309
0238            DO 310 I2=1,IE
0239        310 MAE=MAE+NTABI(I2,2)
0240        309 YBUS(MAE)=YBUS(MAE)-SERY(J)-SHTY(J)
0241            YBUS(MAS)=YBUS(MAS)-(SERY(J)+SHTY(J))*TR1(J)*TR1(J)
0242            YBUS(ISIE)=YBUS(ISIE)+SERY(J)*TR1(J)
0243            YBUS(IEIS)=YBUS(IEIS)+SERY(J)*TR1(J)
0244        301 CONTINUE
0245            NFB=0
0246        300 CONTINUE
0247            CALL RKGS(NB,NTABI,YBUS,IYBUS,JYBUS,V,NOET,T,PRMT,Y,DERY,X,
               1NDIM,IHLF,AUX,CG,M,MAR,KTABI,XDP,H,TS,R,DBI,PP,PMAX,TC,TOOP,
               2A1,B1,TE,KE,KA,TA,ES,TR,KF,TF,E3,NFB,FB,EQ,YS,TT,P,O,PL,QL,NBASE)
0248            LBR1=LBR1+1
0249            FLEE1=FLEE1+1.0
0250            LBR2=LBR1/2
0251            FLEE2=FLEE1/2.
0252            FLEE3=FLEE2-LBR2
0253            T=T+DELTT
0254            IF(X.GE.TGG) GO TO 99
0255            IF(FLEE3.NE.0.0) GO TO 299
0256            TT=TT+2.*DELTT
0257        299 CONTINUE
0258            GO TO 17
0259         99 CONTINUE
0260            STOP
0261            END
```

```
      SUBROUTINE FORM(NB,NTABI,KTABI,NFB,FB,YBUS,V,K,KK,M,MAB,NOET,
     1IINDEX,INDEX,JYBUS,WKJR,KWKJ,NOCL,IJAC,JJAC,JAC,IYBUS)
      COMPLEX*8 CMPLX,CONJG,YBUS(150),V(50),WKJR(1,10),JAC(150)
      INTEGER IYBUS(150),JYBUS(150),KTABI(20,3),NTABI(20,3),MAB(10),
     1FB(10),INDEX(10),IINDEX(20),KWKJ(2,10),NOCL(2,20),JJAC(150),
     2IJAC(20,2)
      K=0
      DO 7 I=1,NB
      NOET5=1
      IF(I.EQ.1) GO TO 104
      IL=I-1
      DO 100 I1=1,IL
  100 NOET5=NOET5+NTABI(I1,2)
  104 NOET6=NOET5-1+NTABI(I,2)
      IF(NFB.EQ.0) GO TO 320
      DO 8 J=1,NFB
      IF(IABS(FB(J)).EQ.I) GO TO 108
    8 CONTINUE
  320 CONTINUE
      K=K+1
      KK=NTABI(I,1)
      INDEX(K)=I
      IINDEX(I)=K
      NCOUNT=1
      DO 9 N=1,NB
      IF(NFB.EQ.0) GO TO 321
      DO 10 J=1,NFB
      IF(IABS(FB(J)).EQ.N) GO TO 9
   10 CONTINUE
  321 CONTINUE
      DO 11 KJ1=NOET5,NOET6
      IF(IABS(JYBUS(KJ1)).EQ.N) GO TO 12
      IF(KJ1.EQ.NOET6) GO TO 9
   11 CONTINUE
   12 NCOUNT=NCOUNT+1
      WKJR(1,NCOUNT)=YBUS(KJ1)
      KWKJ(1,NCOUNT)=NTABI(N,1)
      KWKJ(2,NCOUNT)=NCOUNT+1
    9 CONTINUE
      KWKJ(2,NCOUNT)=0
      NOCL(1,K)=KK
      NOCL(2,K)=NCOUNT
      DO 13 J=1,M
      MABI=MAB(J)
      IF(IABS(KTABI(MABI,3)).EQ.I) GO TO 105
   13 CONTINUE
      WKJR(1,1)=CMPLX(0.0,0.0)
      GO TO 106
  105 WKJR(1,1)=-(V(I+NB))*YBUS(NOET+J)
  106 KWKJ(1,1)=NTABI(I,1)
      KWKJ(2,1)=2
      CALL GGSEL(K,KK,WKJR,KWKJ,V,INDEX,IINDEX,NOCL,JAC,IJAC,JJAC,JNG)
      GO TO 7
  108 V(I)=CMPLX(0.0,0.0)
    7 CONTINUE
      NBNF=NB-NFB
      DO 14 K=1,NBNF
      J=NBNF+1-K
```

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          KSL=IJAC(J,2)
          I=INDEX(J)
          V(I)=JAC(KSL)
          IF(K.EQ.1) GO TO 14
          J1=J+1
          KEL=IJAC(J1,2)-1
          ML1=K-1
          DO 15 KD=1,ML1
          IX=NB-NFB-ML1+KD
          IA=INDEX(IX)
          KSL1=KSL+1
          DO 16 L1=KSL1,KEL
          IF(JJAC(L1).EQ.NTABI(IA,1)) GO TO 107
          IF(IABS(JJAC(L1)).GT.IABS(NTABI(IA,1))) GO TO 15
       16 CONTINUE
          GO TO 15
      107 V(I)=V(I)-V(IA)*JAC(L1)
       15 CONTINUE
       14 CONTINUE
          RETURN
          END
```

```
0001          SUBROUTINE GGSEL(K,KK,WKJR,KWKJ,V,INDEX,IINDEX,NOCL,JAC,IJAC,JJAC,
             1JNG)
0002          COMPLEX*8 CMPLX,CONJG,V(50),WKJR(1,10),JAC(150)
0003          INTEGER INDEX(10),IINDEX(20),KWKJ(2,10),NOCL(2,20),JJAC(150),
             1IJAC(20,2)
0004          EQUIVALENCE(KA,KB)
0005          EQUIVALENCE(NG,NNG)
0006          IF(K.NE.1) GO TO 1114
0007          KA=1
0008          JAC(1)=WKJR(1,1)/WKJR(1,2)
0009          JJAC(1)=KK
0010          IJAC(1,1)=KK
0011          IJAC(1,2)=1
0012          NN=NOCL(2,1)
0013          DO 9 I=3,NN
0014          KA=KA+1
0015          JAC(KA)=WKJR(1,I)/WKJR(1,2)
0016          JJAC(KA)=KWKJ(1,I)
0017        9 CONTINUE
0018          JNG=KA
0019          GO TO 1)00
0020     1114 CONTINUE
0021          LOCT=1
0022          NG=NOCL(2,K)
0023          DO 20 I=2,NG
0024          II=KWKJ(2,LOCT)
0025          KWA=IABS(KWKJ(1,II))
0026          KWB=KWA-INDEX(K)
0027          IF(KWB.EQ.0) GO TO 777
0028          L=IINDEX(KWA)
0029          L1=L+1
0030          IGA=IABS(L-K)
0031          IS=IJAC(L,2)+1
0032          IF(IGA.EQ.1) GO TO 553
0033          IE=IJAC(L1,2)-1
0034          GO TO 556
0035      553 IE=JNG
0036      556 IS1=IS-1
0037          WKJR(1,1)=WKJR(1,1)-JAC(IS1)*WKJR(1,II)
0038          LA=II
0039          DO 30 KA=IS,IE
0040          NEXT=KWKJ(2,LA)
0041          IF(NEXT.EQ.0) GO TO 34
0042          N=IABS(KWKJ(1,NEXT))
0043          JJ=IABS(JJAC(KA))
0044          JJN=JJ-N
0045          IF(JJN-0) 34,35,36
0046       35 WKJR(1,NEXT)=WKJR(1,NEXT)-JAC(KA)*WKJR(1,II)
0047          LA=NEXT
0048          GO TO 30
0049       36 LA=NEXT
0050          KB=KB-1
0051          GO TO 30
0052       34 NOCL(2,K)=NOCL(2,K)+1
0053          NN=NOCL(2,K)
0054          WKJR(1,NN)=-JAC(KA)*WKJR(1,II)
0055          KWKJ(1,NN)=JJAC(KA)
0056          NN=NOCL(2,K)-1
```

```
      DO 42 N=2,NM
      KWA=KWKJ(2,N)
      IF(KWA.EQ.0) GO TO 122
   42 CONTINUE
  122 KW1=IABS(KWKJ(1,N))
      JJ1=IABS(JJAC(KA))
      KJ1=KW1-JJ1
      IF(KJ1.GT.0) GO TO 422
      KWKJ(2,N)=NN
      KWKJ(2,NN)=0
      GO TO 4222
  422 CONTINUE
      NN1=NN-1
      DO 43 M=2,NN1
      MA=KWKJ(2,M)
      IF(MA.NE.0) GO TO 1962
      GO TO 43
 1962 KW1=IABS(KWKJ(1,M))
      KW2=IABS(KWKJ(1,MA))
      JK1=JJ1-KW1
      JK2=JJ1-KW2
      IF(JK1.LT.0) GO TO 43
      IF(JK2.GT.0) GO TO 43
      KWKJ(2,NN)=MA
      KWKJ(2,M)=NN
      GO TO 4222
   43 CONTINUE
 4222 CONTINUE
      NNG=NNG+1
   30 CONTINUE
  201 LOCT=II
   20 CONTINUE
  777 KA=JNG+1
      IJAC(K,1)=KK
      IJAC(K,2)=KA
      JAC(KA)=WKJR(1,1)/WKJR(1,II)
      JJAC(KA)=KK
      IB=II
      NN=NOCL(2,K)
      DO 100 IT=1,NN
      IB=KWKJ(2,IB)
      JNG=KA
      IF(IB.EQ.0) GO TO 1000
      KA=KA+1
      JAC(KA)=WKJR(1,IB)/WKJR(1,II)
      JJAC(KA)=KWKJ(1,IB)
  100 CONTINUE
 1000 CONTINUE
      RETURN
      END
```

```
0001            SUBROUTINE RKGS(NB,NTABI,YBUS,IYBUS,JYBUS,V,NOET,T,PRMT,Y,DERY,X,
               1NDIM,IHLF,AUX,DG,M,MAB,KTABI,XDP,H,TS,R,DBT,PP,PMAX,TC,TDOP,
               2A1,B1,TE,KF,KA,TA,ES,TR,KE,TF,E3,NFB,FB,FO,YS,TT,P,Q,PL,QL,NBASE)
0002            COMPLEX*8 CMPLX,CONJG,YBUS(150),V(50),WKJP(1,10),JAC(150),BC,DD2,
               1ETEMP(60),YS(50)
0003            REAL XDP(10),FO(20),H(10),ES(10),E3(10),Y(100),DERY(100),
               1PP(20),DG(10),PRMT(5),AUX(8,100),KF,KE,KA,A(4),B(4),C(4),
               2MAGV,TT,P(20),Q(20),PL(20),QL(20),NBASE
0004            INTEGER IYBUS(150),JYBUS(150),KTABI(20,3),NTABI(20,3),IABS,
               1MAB(10),FB(10),INDEX(10),IINDEX(20),KWKJ(2,10),NOCL(2,20),
               2JJAC(150),IJAC(20,2)
0005            DO 1 I=1,NDIM
0006          1 AUX(8,I)=0.06666667*DERY(I)
0007            X=PRMT(1)
0008            XEND=PRMT(2)
0009            H1=PRMT(3)
0010            PRMT(5)=0.
0011            J=0
0012            CALL FCT(J,X,Y,DERY,M,MAB,NFB,FB,KTABI,NTABI,NB,YBUS,
               1IYBUS,JYBUS,V,NOET,XDP,H,TS,R,DBT,PP,PMAX,TC,TDOP,A1,B1,TE,KE,KA,
               2TA,ES,TR,KF,TF,E3,DG,EQ,T)
0013            IF(H1*(XEND-X)) 38,37,2
0014          2 A(1)=.5
0015            A(2)=.2928932
0016            A(3)=1.707107
0017            A(4)=0.1666667
0018            B(1)=2.
0019            B(2)=1.
0020            B(3)=1.
0021            B(4)=2.
0022            C(1)=.5
0023            C(2)=.2928932
0024            C(3)=1.707107
0025            C(4)=.5
0026            DO 3 I=1,NDIM
0027            AUX(1,I)=Y(I)
0028            AUX(2,I)=DERY(I)
0029            AUX(3,I)=0.
0030          3 AUX(6,I)=0.
0031            IREC=0
0032            H1=H1+H1
0033            IHLF=-1
0034            ISTEP=0
0035            IEND=0
0036          4 IF((X+H1-XEND)*H1) 7,6,5
0037          5 H1=XEND-X
0038          6 IEND=1
0039            IF(X.EQ.TT) GO TO 7
0040            GO TO 500
0041          7 CALL OUTP(X,Y,DERY,IHLF,NDIM,PRMT,V,NB,KTABI,
               1M,MAB,PL,QL,P,Q,NTABI,YBUS,JYBUS,NBASE,YS,XDP)
0042        500 IF(PRMT(5)) 40,8,40
0043          8 ITEST=0
0044          9 ISTEP=ISTEP+1
0045            J=1
0046         10 AJ=A(J)
0047            BJ=B(J)
0048            CJ=C(J)
```

```
0049          DO 11 I=1,NDIM
0050          R1=H1*DERY(I)
0051          R2=AJ*(R1-BJ*AUX(6,I))
0052          Y(I)=Y(I)+R2
0053          R2=R2+R2+R2
0054       11 AUX(6,I)=AUX(6,I)+R2-CJ*R1
0055          IF(J-4) 12,15,15
0056       12 J=J+1
0057          IF(J-3) 13,14,13
0058       13 X=X+.5*H1
0059       14 CALL FCT(J,X,Y,DERY,M,MAB,NFB,FB,KTABI,NTABI,NB,YBUS,
             1IYBUS,JYBUS,V,NOET,XDP,H,TS,R,DBT,PP,PMAX,TC,TDOP,A1,B1,TE,KE,KA,
             2TA,ES,T9,KF,TF,E3,DG,EQ,T)
0060          GO TO 10
0061       15 IF(ITEST) 16,16,20
0062       16 DO 17 I=1,NDIM
0063       17 AUX(4,I)=Y(I)
0064          ITEST=1
0065          ISTEP=ISTEP*2-2
0066       18 IHLF=IHLF+1
0067          X=X-H1
0068          H1=.5*H1
0069          DO 19 I=1,NDIM
0070          Y(I)=AUX(1,I)
0071          DERY(I)=AUX(2,I)
0072       19 AUX(6,I)=AUX(3,I)
0073          GO TO 9
0074       20 IMOD=ISTEP/2
0075          IF(ISTEP-IMOD-IMOD) 21,23,21
0076       21 CALL FCT(J,X,Y,DERY,M,MAB,NFB,FB,KTABI,NTABI,NB,YBUS,
             1IYBUS,JYBUS,V,NOET,XDP,H,TS,R,DBT,PP,PMAX,TC,TDOP,A1,B1,TE,KE,KA,
             2TA,ES,TR,KF,TF,E3,DG,EQ,T)
0077          DO 22 I=1,NDIM
0078          AUX(5,I)=Y(I)
0079       22 AUX(7,I)=DERY(I)
0080          GO TO 9
0081       23 DELT=0.
0082          DO 24 I=1,NDIM
0083       24 DELT=DELT+AUX(8,I)*ABS(AUX(4,I)-Y(I))
0084          IF(DELT-PRMT(4)) 28,28,25
0085       25 IF(IHLF-10) 26,36,36
0086       26 DO 27 I=1,NDIM
0087       27 AUX(4,I)=AUX(5,I)
0088          ISTEP=ISTEP*2-4
0089          X=X-H1
0090          IEND=0
0091          GO TO 18
0092       28 CALL FCT(J,X,Y,DERY,M,MAB,NFB,FB,KTABI,NTABI,NB,YBUS,
             1IYBUS,JYBUS,V,NOEF,XDP,H,TS,R,DBT,PP,PMAX,TC,TDOP,A1,B1,TE,KE,KA,
             2TA,ES,TR,KF,TF,E3,DG,EQ,T)
0093          DO 29 I=1,NDIM
0094          AUX(1,I)=Y(I)
0095          AUX(2,I)=DERY(I)
0096          AUX(3,I)=AUX(6,I)
0097          Y(I)=AUX(5,I)
0098       29 DERY(I)=AUX(7,I)
0099          IF(PRMT(5)) 40,30,40
0100       30 DO 31 I=1,NDIM
```

```
0101          Y(I)=AUX(1,I)
0102       31 DERY(I)=AUX(2,I)
0103          IREC=IHLF
0104          IF(IEND) 32,32,39
0105       32 IHLF=IHLF-1
0106          ISTEP=ISTEP/2
0107          H1=H1+H1
0108          IF(IHLF) 4,33,33
0109       33 IMOD=ISTEP/2
0110          IF(ISTEP-IMOD-IMOD) 4,34,4
0111       34 IF(DELT-0.2*PRMT(4)) 35,35,4
0112       35 IHLF=IHLF-1
0113          ISTEP=ISTEP/2
0114          H1=H1+H1
0115          GO TO 4
0116       36 IHLF=11
0117          CALL FCT(J,X,Y,DERY,M,MAB,NFB,FB,KTABI,NTABI,NB,YBUS,
             1IYBUS,JYBUS,V,NDET,XDP,H,TS,R,DBT,PP,PMAX,TC,TDOP,A1,B1,TE,KE,KA,
             2TA,ES,TR,KF,TF,E3,DG,EQ,T)
0118          GO TO 39
0119       37 IHLF=12
0120          GO TO 39
0121       38 IHLF=13
0122       39 CONTINUE
0123       40 RETURN
0124          END
```

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0001           SUBROUTINE FCT(J,X,Y,DERY,M,MAB,NFB,FB,KTABI,NTABI,NB,YBUS,
              1IYBUS,JYBUS,V,NOET,XDP,H,TS,R,DBT,PP,PMAX,TC,TDOP,A1,B1,TE,KE,KA,
              2TA,ES,TR,KF,TF,E3,DG,EQ,T)
0002           COMPLEX*8 CMPLX,CONJG,YBUS(150),V(50),WKJR(1,10),JAC(150),BC,DD2
0003           REAL XDP(10),EQ(20),H(10),ES(10),E3(10),Y(100),DERY(100),
              1PP(20),DG(10),KF,KE,KA
0004           INTEGER IYBUS(150),JYBUS(150),KTABI(20,3),NTABI(20,3),IABS,
              1MAB(10),FB(10),INDEX(10),IINDEX(20),KWKJ(2,10),NOCL(2,20),
              2JJAC(150),IJAC(20,2)
0005           IF(T.NE.0.0) GO TO 100
0006           IF(J.NE.0) GO TO 100
0007           GO TO 101
0008       100 CONTINUE
0009           DO 2 I=1,M
0010           MABI=MAB(I)
0011           K1=IABS(KTABI(MABI,3))
0012           ID=(I-1)*9+1
0013           KN=K1+NB
0014         2 V(K1+NB)=Y(ID+4)*CMPLX(COS(Y(ID)),SIN(Y(ID)))
0015           CALL FORM(NB,NTABI,KTABI,NFB,FB,YBUS,V,K,KK,M,MAB,NOET,
              1IINDEX,INDEX,JYBUS,WKJR,KWKJ,NOCL,IJAC,JJAC,JAC,IYBUS)
0016       101 DO 1 I=1,M
0017           MABI=MAB(I)
0018           K1=IABS(KTABI(MABI,3))
0019           KN=K1+NB
0020           ID=(I-1)*9+1
0021           ID1=ID+1
0022         9 DERY(ID)=Y(ID1)-2.*3.141592654*60.
0023        10 ID4=ID+4
0024           V(KN)=Y(ID4)*CMPLX(COS(Y(ID)),SIN(Y(ID)))
0025           BC=(V(KN)-V(K1))/CMPLX(0.0,XDP(I))
0026           BC=BC*CONJG(V(K1))
0027           PG=REAL(BC)
0028           IF(NFB.EQ.0) GO TO 322
0029           DO 6 KL =1,NFB
0030           IF(IABS(FB(KL)).EQ.K1) GO TO 7
0031         6 CONTINUE
0032       322 CONTINUE
0033           GO TO 8
0034         7 PG=0.0
0035         8 ID=ID1+1
0036           DERY(ID1)=(Y(ID)-PG)*3.141592654*60./H(I)
0037           ID1=ID+1
0038           DERY(ID)=(Y(ID1)-Y(ID))/TS
0039           IDN=ID-1
0040           GG=2.*3.141592654*60.
0041           GGA=ABS(GG-Y(IDN))
0042           GGA=GGA/GG
0043           IF(GGA.LE.DBT) GO TO 555
0044           IF(Y(IDN).LE.GG) GO TO 888
0045           GO TO 999
0046       888 PM4=(GG-Y(IDN))/(R*GG)-DBT/R
0047           GO TO 666
0048       999 PM4=(GG-Y(IDN))/(R*GG)+DBT/R
0049           GO TO 666
0050       555 PM4=0.0
0051       666 CONTINUE
0052           PM3=PP(K1)-PM4
```

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```
      IF(PM3.LE.0.0) GO TO 3
      IF(PM3.LT.PMAX) GO TO 4
      PM2=PMAX
      GO TO 5
    4 PM2=PM3
      GO TO 5
    3 PM2=0.0
    5 CONTINUE
      DERY(ID1)=(PM2-Y(ID1))/TC
      ID=ID1+1
      ID1=ID+1
      DD1=(1.0-XDP(I))
      DD2=BC*CMPLX(0.0,DD1)+V(KN)
      EQ(K1)=CABS(DD2)
      DERY(ID)=(Y(ID1)-EQ(K1))/TDOP
      BIN=B1*Y(ID1)
      E6=AI*EXP(BIN)
      ID=ID1+1
      E2=Y(ID)-E6
      DERY(ID1)=(E2-KE*Y(ID1))/TE
      DG(I)=DERY(ID1)
      ID1=ID+1
      ID2=ID+2
      DERY(ID)=(KA*(Y(ID1)-Y(ID2)+E3(K1)/KA)-Y(ID))/TA
      DERY(ID1)=(ES(I)-CABS(V(K1))-Y(ID1))/TR
      DERY(ID2)=(KF*DG(I)-Y(ID2))/TF
    1 CONTINUE
      RETURN
      END
```

```
FORTRAN IV G LEVEL  21                OUTP              DATE = 75305          17/40/42              PAGE 0001

0001            SUBROUTINE OUTP(X,Y,DERY,IHLF,NDIM,PRMT,V,NB,KTABI,
               1M,MAB,PL,QL,P,Q,NTABI,YBUS,JYBUS,NBASE,YS,XDP)
0002            COMPLEX*8 V(50),ETEMP(60),SUM,YBUS(150),CMPLX,CONJG,YS(50)
0003            REAL Y(100),DERY(100),PRMT(5),MAGV,NBASE,PL(20),QL(20),P(20),
               1Q(20),XDP(10)
0004            INTEGER KTABI(20,3),MAB(10),NTABI(20,3),JYBUS(150)
0005            DO 6 I=1,NB
0006            II=IABS(KTABI(I,3))
0007          6 ETEMP(I)=V(II)
0008            WRITE(6,1) X
0009          1 FORMAT('0',T20,'THE RESULT AT TIME(T)=',1X,F10.5,1X,'SECONDS')
0010            DO 7 I=1,M
0011            MABI=MAB(I)
0012            II=IABS(KTABI(MABI,3))
0013            KN=II+NB
0014            MAGV=CABS(V(KN))
0015            ID=(I-1)*9+1
0016            DELTA=Y(ID)*90.0/ARSIN(1.0)
0017            WRITE(6,2) MAB(I)
0018          2 FORMAT(' ',T20,'THE MACHINE AT BUS',1X,I3)
0019            WRITE(6,3) MAGV,DELTA
0020          3 FORMAT(' ',T20,'ITS INTERNAL VOLTAGE MAGNITUDE=',1X,F10.5,
               15X,'ANGULAR POSITION OF THE ROTOR=',1X,F10.5,1X,'DEGREES')
0021            ID=ID+1
0022            WRITE(6,4) Y(ID)
0023          4 FORMAT(' ',T20,'ITS MACHINE SPEED=',1X,F10.5,1X,'RADIANS PER SECON
               1D')
0024          7 CONTINUE
0025            WRITE(6,1116)
0026       1116 FORMAT('0',T31,'VOLTAGE'/T30,'MAGNITUDE',T42,'DELTA(DEGREES)',
               1T62,'INJECTED POWER',T86,'LOCAL LOAD SUPPLIED'/T33,'PU',T60,'MW',
               2T74,'MVAR',T88,'MW',T102,'MVAR')
0027            DO 9 I=1,NB
0028            SUM=CMPLX(0.0,0.0)
0029            MAGV=CABS(ETEMP(I))
0030            IF(REAL(ETEMP(I)).EQ.0.0) GO TO 11
0031            DELTA=ATAN2(AIMAG(ETEMP(I)),REAL(ETEMP(I)))*90.0/ARSIN(1.0)
0032            GO TO 12
0033         11 DELTA=0.0
0034         12 CONTINUE
0035            I1=IABS(KTABI(I,3))
0036            ISY=1
0037            IF(I1.EQ.1) GO TO 55
0038            I1=I1-1
0039            DO 54 M1=1,I1
0040         54 ISY=ISY+NTABI(M1,2)
0041         55 IEY=ISY-1+NTABI(I1,2)
0042            DO 56 M2=1,NB
0043            DO 57 IY=ISY,IEY
0044            IAJ=IABS(JYBUS(IY))
0045            IAJJ=IABS(NTABI(IAJ,3))
0046            IF(IAJJ.EQ.M2) GO TO 58
0047            IF(IY.EQ.IEY) GO TO 56
0048         57 CONTINUE
0049         58 IF(IY.NE.ISY) GO TO 59
0050            DO 60 M3=1,M
0051            IF(MAB(M3).EQ.I) GO TO 61
0052         60 CONTINUE
```

```
0053          SUM=SUM+(YBUS(IY)-YS(I1))*ETEMP(M2)
0054          GO TO 56
0055       61 XDPR=-1.0/XDP(M3)
0056          SUM=SUM+(YBUS(IY)-CMPLX(0.0,XDPR)-YS(I1))*ETEMP(M2)
0057          GO TO 56
0058       59 SUM=SUM+YBUS(IY)*ETEMP(M2)
0059       56 CONTINUE
0060          P(I)=REAL(SUM*CONJG(ETEMP(I))*NBASE)
0061          Q(I)=-AIMAG(SUM*CONJG(ETEMP(I))*NBASE)
0062          QL(I)=-AIMAG((MAGV**2)*YS(I1)*NBASE)
0063          PL(I)=REAL((MAGV**2)*YS(I1)*NBASE)
0064          WRITE(6,1118) I,MAGV,DELTA,P(I),Q(I),PL(I),QL(I)
0065     1118 FORMAT('0',T20,'BUS',I5,2X,F7.3,5X,F9.4,5X,F9.3,5X,F9.3,5X,F9.3,
             15X,F9.3)
0066        9 CONTINUE
0067          RETURN
0068          END
```

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ABSTRACT

The objective of the projected described in this report was to develop a set of digital computer programs that will enable the students and faculty of the Department of Electrical Engineering at KSU to make meaningful studies of the dynamic behavior of electrical power systems in the first 2 or 3 seconds after the occurence of a major disturbance such as a three-phase fault at a bus and subsequent clearing of that fault. The resulting set of programs are dimensioned to handle electric power systems containing up to 60 significant buses, 100 transmission lines and transformers, and 20 synchronouse machines. All component and system modeling is designed to be consistent with the observation interval of 2 or 3 seconds and to give the user as much flexibility as is judged to be practical. The models used account for the action of the excitation and speed governor control loops. Although it is recognized that these control loops are relatively slow and may not affect the response significantly in this time interval, these control loops were included in anticipation of the further extension of the programs to longer observation intervals.