COMPUTER ANALYSIS OF ELECTROMAGNETIC TRANSIENTS IN A MULTIPHASE LOSSY POWER SYSTEM NETWORK

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A THESIS

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CERTIFICATE

This is to certify that this work was done by me and it has not been submitted elsewhere for the award of any Degree or Diploma or for the publication.

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A thesis on

Computer Analysis of Electromagnetic Transients in a Multiphase Lossy Power System Network

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Abstract

A digital computer program has been developed to find the time response of electromagnetic transients due to switching as well as lightning surges in a three phase power system network incorporating the line resistances. The formulation is based on Bergeron's method (method of characteristic) for distributed parameters and the trapezoidal rule of integration for lumped parameters. All the network elements are replaced by their equivalent impedance networks to form a nodal conductance matrix for the whole system. The performance equation of the system under transient conditions has been developed in the form of a nodal equation, which includes a past history term. This method gives simultaneous solution of all busbar voltages of a system under travelling wave conditions.

Clarke's transformation $(0,\alpha,\beta)$ matrix has been used to compute the transients of a three phase system in modal domain and then transform back to phase domain. A method has been developed for predetermination of overvoltages in the network as a result of simultaneous lightning stroke on all three phases.

A number of computer studies of switching and lightning transients have been made on some sample systems taken from different literatures and also on several important sections of both East and West grids as well as East-West interconnector of the transmission system of Bangladesh Power Development Board (BPDB). For each of the systems of studies the nodes which have the possibilities of appreciable voltage build up are identified and the computer plot of transient over-voltages at these nodes have been provided.

C O N T E N T S

CHAPTER 1

INTRODUCTION

1.1 Transients in Power Systems

Transients in power systems are the out-ward manifestations[1] of a sudden change in circuit conditions as when a switch opens or closes or a fault occurs in a system or any voltage is suddenly induced[2] (lightning stroke) from a source outside the system. By definition transients are non-sustained; the time elapsed between occurance of transient currents and voltages, and the adjustment to their steady state modes of variations is called the transient period. Although transient periods are generally of short duration[2], it is during these periods that some of the most serious and involved operating problems are encountered.

The origin, nature, and duration of a voltage transient normally determines the type[3] of the transient. Externally devloped over-voltages like lightning discharges on overhead transmission lines primarily determined the basic insulation level of a system operating at lower voltages in the past. But with the continued growth in demand for power, higher operating voltages (230 KV and above) are being adopted by the power systems these days. The insulation level of the extra high-voltage (EHV) and ultra high-voltage (UHV) transmission systems are considered to be entirely dependent on the magnitude of the dangerous transient over-voltages resulting from a switching operation specially energisation of transmission line.

Present day research in the field of power system transients aims at accurate determination of the peaks of a transient at the design stage so that means to minimise their effects or even to eliminate them completely can be incorporated in the design.

1.2 Methods of Solution

The transient over-voltages on the transmission systems have been determined for some time by means of an analogue computer such as a transient network analyser[4] (TNA). A TNA although facilitates setting up a physical model of a system and the measurement of transients, suffers from severe limitations in scope and accuracy which stems from the representation of distributed parameters such as line or line sections by π-sections or lumped elements.

Among the methods using digital computer simulation, those based on the partial differential equations known as wave equation of a distributed parameter line provide more accurate solutions. These methods have been widely used in the study of line energisation transients. In the method of reflection lattice technique due to Bewley[5,6] transient over-voltages at one or two points in a large system can be calculated efficiently with a prior knowledge of reflection and refraction coefficients. But their computation becomes more and more cumbersome process the more the complexity of the system under study. Another important method being used in a number of countries for digital computer studies of large systems is the Bergeron's method[8,20]. This is a special application of the method of characteristic for the solution of the wave equations. Bergeron's method, although originally devised as a graphical technique, can be described by the two port equations and equivalent network, which facilitates a matrix description of the whole system under travelling wave conditions for simultaneous solution of all busbar (node) voltages. Any number of sources can be accommodated, and non-linearities are easily dealt with.

Finite difference method offers an accurate solution of the line equations. However, the method appears to be an inefficient one - it requires a large storage, and to avoid numerical instability, inconveniently small increments in time and distance.

A Fourier transform[7] method has the advantage that transmission lines with frequency dependent parameters can be represented. However, the Fourier transform is applicable to linear systems. This is a limitation of this method. The use of truncated range of frequencies for time solution from the frequency response of a system leads to unwanted oscillations around the true function due to 'Gibbs phenomena'. The modified Fourier transform has been developed to minimise the problem. Also a modified Fourier transform method of dealing with some non-linearities which are piecewise linear has been recently developed. Compared to most of the other methods, the numerical calculations involved in this method are considerable. In spite of the accuracy provided by this method its application appears to be restricted to smaller systems.

Multiphase transmission problems are generally analysed by the method of modal analysis. The coefficient matrices of simultaneous pertial differential equations such as surge impedanc or brach admittance matrices containing off-diagonal elements which represent the mutual coupling between the phases, are transformed to diagonal form by the use of different modal transformations and the transient behaviour of the system is interpreted in terms of different modes of propagation. Modal analysis has been combined with most of the methods viz. the modified Fourier transform[7], Laplace transform[13], Bewley's method[11] and the Bergeron's method[8] to analyse the multiphase problem.

1.3 Purpose of the Present Investigation

In an investigation of transient on a transmission system when energised from an infinite bus, it is essential to consider losses and mutual coupling in a multiphase transmission line.

In this work for the computation of transients of a three phase system with a consideration of the losses in distributed line resistances, the nodal admittance matrix method has been used. This method is based on the characteristics method and therefore also on the graphical method for distributed parameters and the trapezoidal rule of integration for lumped parameters.

The choice of a modal reference frame for the solution of multiphase transmission problem is dependent on the electrical description of the line. The $0,\alpha,\beta$ reference has been considered as ideal for the purpose of the present investigation.

A new computer program has been developed on the basis of the analysis presented here. The results obtained for some of the systems of studies by this work have been compared with the results for the same systems studied by other works using different methods.

Some studies of important sections of both the East Grid and West Grid of BPDB power network together with those for the East-West Interconnector have been made to predetermine the overvoltages under transient conditions in the three phases system.

CHAPTER. 2

NODAL ADMITTANCE MATRIX METHOD AND MODAL ANALYSIS FOR MULTIPHASE SYSTEMS

2.1 Formulation of Nodal Admittance Matrix Method[8] for Transient Studies

A digital computer solution for transients is necessarily a step by step procedure that proceeds along the time axis with a variable or fixed step width Δt. Starting from the initial condition at $t = 0$ the state of the system is found at $t = \Delta t$, $2\ \Delta t$, $3\ \Delta t$, ... until the maximum time tmax for the particular case (fixed or variable Δt) has been reached. While solving for the state at time t, the previous states at $t - \Delta t$, known as the past history should be available. The solution of the wave equation for distributed parameter transmission line, has to be combined with solution of first order differential equations for such lumped elements as the transformers along the line.

In the case of distributed parameter transmission lines it is convenient to subdivide lines into section of equal travel time[7], $\tau = \Delta t$. This requires the introduction of fictitious nodes along the line.

2.1.1 Lossless line

The equivalent impedance network in Fig. 2.2 for a lossless transmission line[8] is constructed from d'Alemberts solution of the simplified wave equations and Bergeron's concept[20] of the constant relationship between voltage and current waves travelling along the line.

The Wave Equation

Fig.2.1 considers the single phase representation of a differential element dx of the transmission line[3] with inductance L' and capacitance C' per unit length.

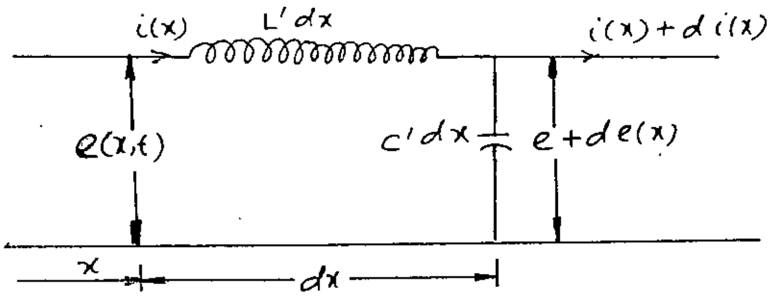


Fig. 2.1. Differential Line element.

The voltage e(x,t) measured at the coordinate x, changes with the amount $\frac{\delta e(x,t)}{\delta x}$ dx along the element dx. Whereas the voltage drop in the same will be $L' \frac{\delta i(x,t)}{\delta t}$ dx.

For voltage equilibrium we thus must require

$$\frac{\delta e(x,t)}{\delta x} = -L' \frac{\delta i(x,t)}{\delta t} \qquad 2.1$$

We similarly derive an expression for the current equation

$$\frac{\delta i(x,t)}{\delta x} = -C' \frac{\delta e(x,t)}{\delta t} \qquad 2.2$$

Upon differentiating equation (2.1) with respect to x and equation (2.2) with respect to t, and then combining the two, we get

$$\frac{\delta^2 e(x,t)}{\delta x^2} = \frac{1}{v^2} \frac{\delta^2 e(x,t)}{\delta t^2} \qquad 2.3$$

where for brevity we have introduced

$$v \triangleq \frac{1}{\sqrt{(L'C')}}$$

this parameter has the physical dimension of meters/second i.e. velocity. Equation (2.3) is known as wave equation. Its general solution as given by d'Alembert[8] is in terms of current:

$$i(x,t) = f_1(x-vt) + f_2(x+vt) \qquad 2.4$$

while in terms of voltage:

$$e(x,t) = Z f_1 (x-vt) - Z f_2 (x+vt) \qquad 2.5$$

with f_1 (x-vt) and f_2 (x+vt) being arbitrary functions of the variables (x-vt) and (x+vt). The physical interpretation is that f_1 (x-vt) is a wave travelling at velocity v in a forward direction and f_2(x+vt) a wave travelling at the same velocity in a backward direction.

Z in equation (2.5) is the surge impedance, v is the phase velocity.

$$Z = \sqrt{(L'/C')} \qquad 2.6a$$

$$v = 1/\sqrt{(L'C')} \qquad 2.6b$$

Multiplying equation (2.4) by Z and adding it to or subtracting it from equation (2.5) gives

$$e(x,t) + Zi(x,t) = -2Zf_1(x-vt) \qquad 2.7a$$

$$e(x,t) - Zi(x,t) = -2Zf_2(x+vt) \qquad 2.7b$$

In equation (2.7a) the expression (e+Zi) is constant when (x-vt) is constant and in equation (2.7b) (e-Zi) is constant when (x+vt) is constant. The expressions (x-vt) = constant and (x+vt) = constant are called the characteristics of the differential equation.

The significance of equation (2.7a) may be visualized in the following way; let a fictitious observer travel alog the line in a forward direction at velocity v. Then (x-vt) and conequently (e+Zi) along the line will be constant for him. If the travel time to get from one end of the line to the other end is

$$= \frac{d}{v} = d\sqrt{(L'C')} \qquad 2.8$$

where d is the length of the line; then the expression (e+Zi) encountered by the observer when he leaves node m at time t-τ must still be the same when he arrives at node K at time t, that is $e_m(t-\tau) + Zi_{m,k}(t-\tau) = e_k(t) + Z(-i_{k,m}(t))$

(currents as in Fig. 2.2). From this equation follows the simple two port equation for $i_{k,m}$:

$$i_{k,m}(t) = \frac{1}{Z} e_k(t) + I_k(t-\tau)$$

and anlogous 2.9a

$$i_{m,k}(t) = \frac{1}{Z} e_m(t) + I_m(t-\tau)$$

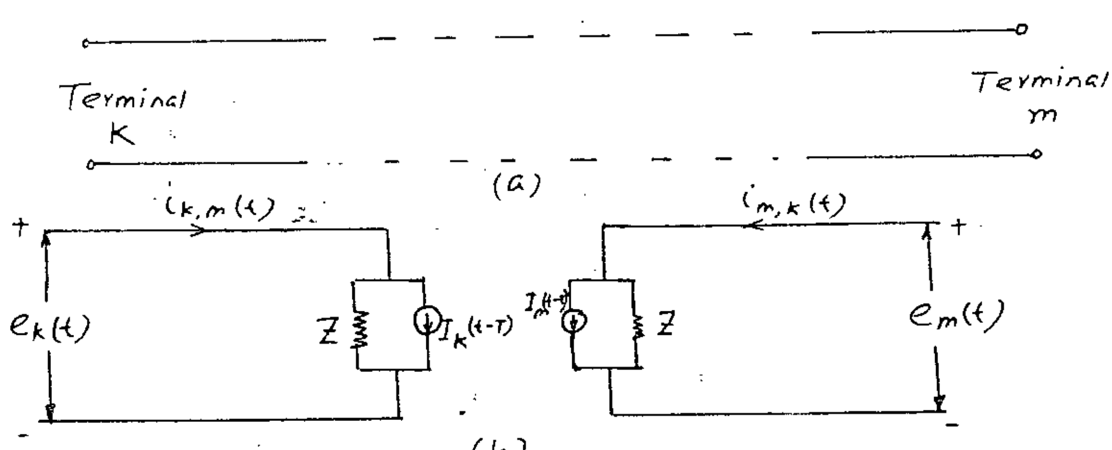


Fig. 2.2. (a) Lossless Line , (b) Equivalent Impedance Network

with equivalent current sources I_k and I_m, which are known at the instant t from the past history at time $t - \tau$;

$$I_k(t-\tau) = -\frac{1}{Z} e_m(t-\tau) - i_{m,k}(t-\tau)$$

$$I_m(t-\tau) = -\frac{1}{Z} e_k(t-\tau) - i_{k,m}(t-\tau) \qquad 2.9b$$

Figure 2.2 shows the corresponding equivalent inpedance network, which fully dascribes the lossless line at the terminals. Topologically the terminals are not connected; the conditions at the other end are only seen indirectly and with a time delay τ through the equivalent current sources I.

Updating past history

Replacing $t - \tau$ by t in equation (2.9b) it can be deduced that

$$I_k(t) = -\frac{1}{Z} e_m(t) - i_{m,k}(t)$$

when $\qquad 2.9c$

$$i_{m,k}(t) = \frac{1}{Z} e_m(t) + I_m(t - \Delta t); \quad \text{for } \tau = \Delta t$$

as seen from equation (2.9a)

And analogous $I_m(t) = -\frac{1}{Z} e_k(t) - i_{k,m}(t) \qquad 2.9d$

with $\qquad i_{k,m}(t) = \frac{1}{Z} e_k(t) + I_k(t - \Delta t)$

Thus at any time t the nodal currents are calculated using the value of I_k or I_m from the previous time step and then $I_k(I_m)$

is evaluated at time t in its turn using the latest value of $i_{m,k}$ ($i_{k,m}$) i.e. the value calculated just now. This value of I_k (I_m) is the past history for the next time step i.e. the time $t + \Delta t$.

For use in the very fist time step $t = \Delta t$ the initial value for I_k, I_m must be given as input data i.e. value at $t = 0$; or if $t = 0$ be the first time step than the values at $t = -\Delta t$.

2.1.2 Approximation of series resistance of lines

This work considers the total resistance R as if lumped by R/4 at both ends[8,21] and R/2 at the middle of the line section. Under this assumption the equivalent impedance network of Fig. 2.1. and the method of updating past hitory described in the preceding section 2.1.1. are still valid; only the values[8] change slightly (I_m analogous to I_k):

$$Z = \sqrt{(L'/C')} + R/4 \qquad 2.10a$$

$$I_k(t-\tau) = ((1+h)/2) \left\{ I_k \text{ from equation (2.9b)} \right\} + ((1-h)/2) \left\{ I_m \text{ from equation (2.9b)} \right\} \qquad 2.10b$$

$$\text{with} \quad h = (Z - R/4)/(Z + R/4) \qquad 2.10c$$

2.1.3 Inductance

For the inductance L of a branch k,m (Fig. 2.3) we have,

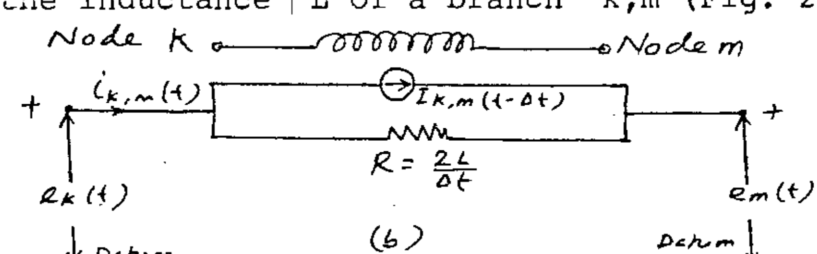


Fig. 2.3 (a) Inductance (b) Equivalent impedance network

$$e_k - e_m = L \frac{di_{k,m}}{dt} \qquad 2.11a$$

which must be integrated from the known state at $t - \Delta t$ to the unknown state at t :

$$i_{k,m}(t) = i_{k,m}(t-\Delta t) + \frac{1}{L} \int_{t-\Delta t}^{t} (e_k - e_m)\,dt \qquad 2.11b$$

Using the trapzoidal rule[22] of integration

$$i_{k,m}(t) = i_{k,m}(t-\Delta t) + \frac{1}{L}\Delta t \left(\frac{e_k(t) + e_k(t-\Delta t)}{2} - \frac{e_m(t) + e_m(t-\Delta t)}{2} \right)$$

$$= \frac{\Delta t}{2L}\left(e_k(t) - e_m(t)\right) + I_{k,m}(t-\Delta t) \qquad 2.12a$$

with the equivalent current source $I_{k,m}$ known from the past history:

$$I_{k,m}(t-\Delta t) = i_{k,m}(t-\Delta t) + \frac{\Delta t}{2L}(e_k(t-\Delta t) - e_m(t-\Delta t)) \qquad 2.12b$$

<u>Updating past history</u>

Substitating $t = t - \Delta t$ in equation (2.12a) gives

$$i_{k,m}(t-\Delta t) = \frac{\Delta t}{2L}(e_k(t-\Delta t) - e_m(t-\Delta t)) + I_{k,m}(t-2\Delta t) \qquad 2.12c$$

Substituting $i_{k,m}(t-\Delta t)$ from equation (2.12c) into equation (2.12b) gives,

$$I_{k,m}(t-\Delta t) = 2\left(\frac{\Delta t}{2L}\right)\left(e_k(t-\Delta t) - e_m(t-\Delta t)\right) + I_{k,m}(t-2\Delta t) \qquad 2.12d$$

Equation (2.12d) is a recursive formula to be used in updating $I_{k,m}$ is each time step. Thus $I_{k,m}$ evaluated using this equation at time $(t-\Delta t)$ becomes a past history for the next time step i.e. at time t or in other words at t what is current value of $I_{k,m}$ becomes a past history at next time step or time $(t+\Delta t)$.

To assure correct initial values, in the very first time step $I_{k,m}$ must be preset before entering the time step loop i.e. $t=\Delta t$

$$I_{k,m}(\text{initial}) = i_{k,m}(0) - \frac{\Delta t}{2L}\left(e_k(0) - e_m(0)\right)$$

The initial conditions e(0) for voltage and i(0) for currents are part of the imput.

The Fig. 2.3. corresponds to equation (2.12a)

2.1.4 Capacitance

For the capacitance C of a branch k,m (Fig.2.4), we have

$$i_{k,m}(t) = C\frac{d}{dt}\left(e_k(t) - e_m(t)\right) \qquad 2.13a$$

which on integration from known state at $(t-\Delta t)$ to the unknown state at t gives;

$$\int_{t-\Delta t}^{t} i_{k,m}(t)\,dt = C\left[\left(e_k(t) - e_m(t)\right) - \left(e_k(t-\Delta t) - e_m(t-\Delta t)\right)\right]$$

$$\text{or,}\quad e_k(t) - e_m(t) = \frac{1}{C}\left[\int_{t-\Delta t}^{t} i_{k,m}(t)\,dt\right] + e_k(t-\Delta t) - e_m(t-\Delta t)$$

which can be integrated on R.H.S. with the trapezoidal rule, which yields after a simple manipulation and rearrangement,

$$i_{k,m}(t) = \frac{2C}{\Delta t}\left(e_k(t) - e_m(t)\right) + I_{k,m}(t-\Delta t) \qquad 2.13b$$

with the equivalent current source $I_{k,m}$ known from the past history:

$$I_{k,m}(t-\Delta t) = -i_{k,m}(t-\Delta t) - \left(\frac{2C}{\Delta t}\right)\left(e_k(t-\Delta t) - e_m(t-\Delta t)\right) \qquad 2.13C$$

The equivalent impedance network corresponding to equation(2.13b) is shown in Fig.2.4

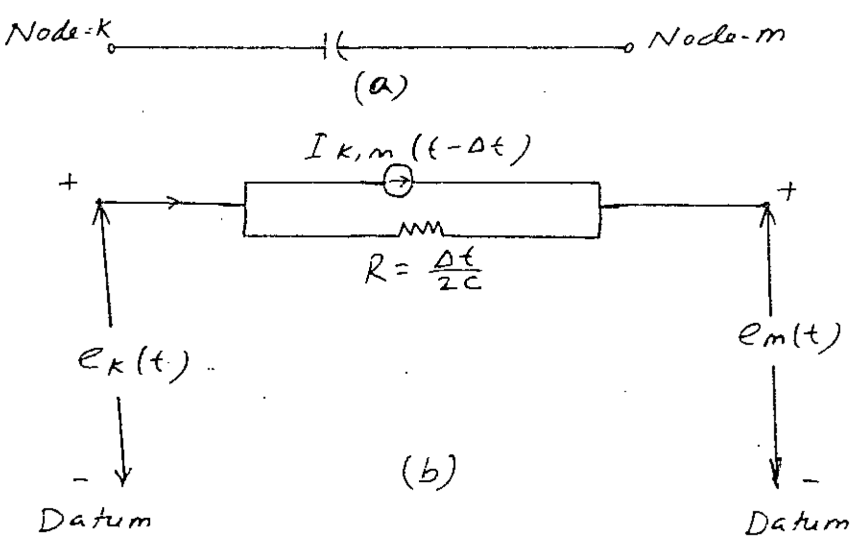


Fig. 2.4. (a) Capacitance (b) Equivalent impedance network

Updating past history:

Exactly following the same procedure as applied for inductance a recursive formula for updating the past history record

$I_{k,m}$ can be deduced:

$$I_{k,m}(t-\Delta t) = -2\left(\frac{2C}{\Delta t}\right)\left(e_k(t-\Delta t) - e_m(t-\Delta t)\right) - I_{k,m}(t-2\Delta t) \qquad 2.13d$$

2.1.5 Resistance

For completeness we add the branch equation for the resistance (Fig.2.5):

$$i_{k,m}(t) = (1/R)\left(e_k(t) - e_m(t)\right) \qquad 2.14$$

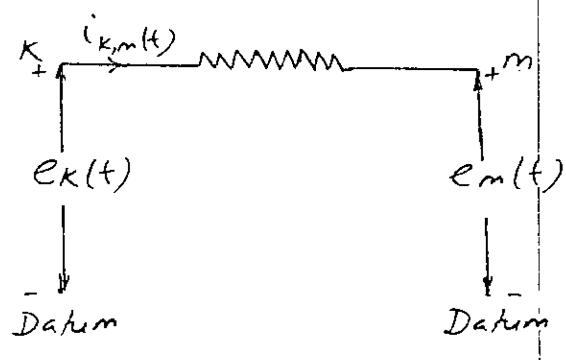


Fig. 2.5. Resistance

2.2 Nodal Equ:tions

With all natwrok elements replaced by equivalent impedance networks[8] as in Figs. 2.2 - 2.5, it is very simple to establish the nodal equations for any arbitrary system comprising transmission line and lumped parameters R.L.C. The result is a system of linear algebraic equations that describe the state of the system at time t:

$$[Y][e(t)] = [i(t)] - [I] \qquad 2.15$$

With $[Y]$: nodal conductance matrix

$[e(t)]$: Column vector of node voltages at time t.

$[i(t)]$: Column cector of injected node currents at time t (specified current source from datum to node)

$[I]$: Known column vector, which is made up of known equivalent current sources I.

The real symmetric conductance matrix $[Y]$ remains unchanged as long as Δt remains unchanged. It is therefore preferable though not mandatory, to work with fixed time step width Δt.

Example: Let us consider the following sample system to illustrate the formation of the nodal equations and hence nodal conductance matrix $[Y]$ under transient conditions as in equation (2.15).

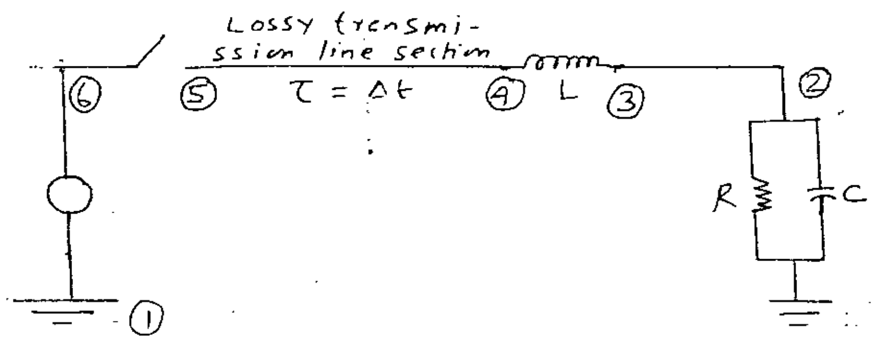


Fig. 2.6. Sample System. The number in circle indicates a node number.

The different elements or branches between nodes of the above system may be replaced by the corresponding equivalent impedance networks to obtain the configuration of Fig. 2.7.

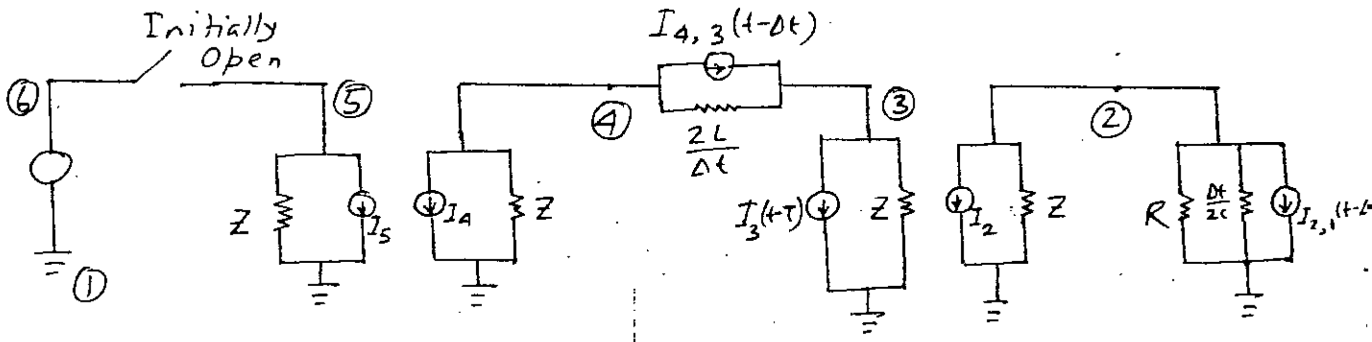


Fig 2.7. The sample system of Fig. 2.6. when its different branches are replaced by the equivalent impedance networks under transient conditions.

Then,

$[Y] =$

	②	③	④	⑤	⑥
②	$Z+R+\frac{\Delta t}{2C}$	0	0	0	0
③	0	$Z+\frac{2L}{\Delta t}$	$-\frac{2L}{\Delta t}$	0	0
④	0	$-\frac{2L}{\Delta t}$	$Z+\frac{2L}{\Delta t}$	0	0
⑤	0	0	0	Z	0
⑥	0	0	0	0	0

In [Y] the row corresponding to the node (6) of known voltage is excluded. If the switch between nodes (6) and (5) be closed then Y_{56} and Y_{65} would be -1000.00 p.u. (an arbitrary large value to represent infinite conductance), Y_{55} = Z +1000.00, and Y_{66} = 1000.00.

In the matrix [Y] all the elements must be in per unit. Z and the equivalent current sources associated with the lossy transmission line section should be according to equations (2.10a) through (2.10c).

$$[e(t)] = \begin{bmatrix} e_2 \\ e_3 \\ e_4 \\ e_5 \\ e_6 \end{bmatrix} \quad \text{where } e_6 \text{ is known;}$$

$$[I] = [i(t)] - [I_{past}]$$

$$\text{where } [i(t)] = [0];$$

since no specified current sources exists between any node and datum of the sample system.

$$\text{and,} \quad \left[I_{past}\right] = \begin{bmatrix} (I_{past})_2 \\ (I_{past})_3 \\ (I_{past})_4 \\ (I_{past})_5 \\ (I_{past})_6 \end{bmatrix} = \begin{bmatrix} I_{2,1}(t-\Delta t) + I_2(t-\tau) \\ I_{4,3}(t-\Delta t) + I_3(t-\tau) \\ I_4(t-\tau) \\ I_5(t-\tau) \\ 0 \end{bmatrix}$$

2.2.1 Practical computation

In the equation (2.15) part of the voltages will be known (specified excitations) and the other will be unknown. Let the nodes be subdivided into a subset A of nodes with unknown voltages and a subsect B of nodes with known voltages. Subdividing the matrices and colum vectors accordingly, we get from equation (2.15),

$$\begin{bmatrix} [Y_{AA}] & [Y_{AB}] \\ [Y_{BA}] & [Y_{BB}] \end{bmatrix} \begin{bmatrix} e_A(t) \\ e_B(t) \end{bmatrix} = \begin{bmatrix} i_A(t) \\ i_B(t) \end{bmatrix} - \begin{bmatrix} [I_A] \\ [I_B] \end{bmatrix}$$

for which the unknown vector $[e_A(t)]$ is found by solving

$$[Y_{AA}][e_A(t)] = [I_{total}] - [Y_{AB}][e_B(t)] \qquad 2.16$$

with $[I_{total}] = [i_A(t)] - [I_A]$

Both the matrices $[Y_{AA}]$ and $[Y_{AB}]$ involving step length Δt remain constant so long as Δt remains unchanged. This amounts to the solution of a system of linear equations in each time step. Equation (2.16) is solved by the diagonalization of the augmented matix $[Y_{AA}][Y_{AB}]$ by Gauss-Jorden elimination method[22] once and for all before entering the time step loop. The same procedure is then extended to the vector $[I_{total}]$ in each time step.

2.2.2 Incorporation of switching criteria

The network may include any number of switches or circuit breakers which may change their positions in accordance with a predefined criteria. They are represented as ideal ($Y = \infty$ when closed and $Y = 0$ when open)[8]. But as computer can not handle '∞' the value of Y in closed condition will be approximated by 1000.00 p.u. which is large relative to the values of other elements in the matrix $[Y]$. With more than one switches in the network it is preferable to build $[Y_{AA}][Y_{AB}]$ anew each time a change occurs. However it is not necessary to repeat the entire diagonalization process with each change. Nodes with switches connected are arranged at the bottom (Fig. 2.8a)

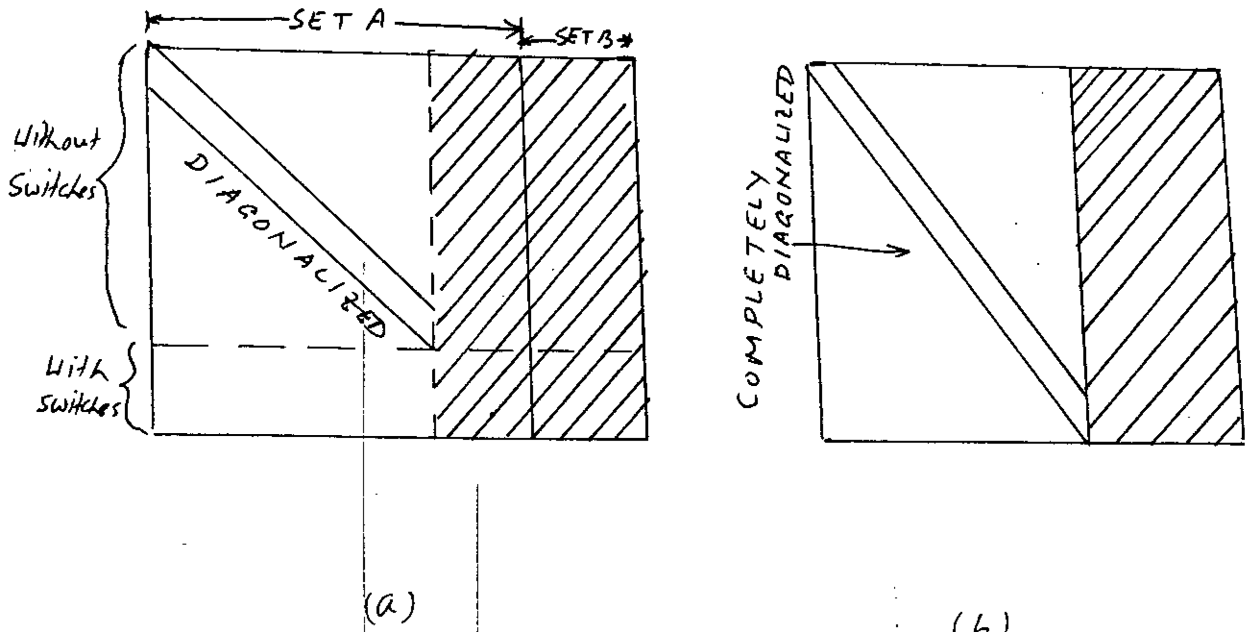


Fig. 2.8. Shaded areas show computation. (a) Initially (b) After each change.

Then the diagonalization is carried out only for nodes without switches. This also yields a reduced matrix for the node with switches (assumed to be open before entering the time step loop). Whenever the switch position changes the value of the elements in the reduced matrix is modified to reflect switch positions (if switch between nodes i and j be closed Y_{ij} = 1000.00 otherwise Y_{ij} = 0). Then the diagonalization is completed for the rest of the matrix $[Y_{AA}][Y_{AB}]$.

2.3 Modal Analysis of Multiphase Systems

The power transmission lines are constructed as three phase line either single circuit involing three power conductors with or without an earth wire or double circuit in which there are six power conductors[7] again with the possibility of an earth wire.

Although the basic travelling wave equations remain unaltered when a multiphase or multiconductor system is considered. Mutual coupling exists between the phase conductors of the system which modifies the transmission line overvoltages[7] due to line surges or line energisation and must be taken into consideration. This may be effected by replacement of scalar surge impedance or branch admittances in a single phase system by impedance and admitance matrices. But then the solution of remaining system equations become complicated by the presence of off-diagonal elements in the matrices representing the mutual cupling[8] between the phases.

2.3.1 Transformation matrix

Matrix theory provides a solution to the above problem by introducing[7] a trnsformation matrix of a suitable form to diagonalize the matric equations. Finding such a transformation matrix is the well-known eigen value[8] problem. Briefly the procedure for a three phase system consists of finding three eign values or characteristic roots λ of the matrix[13,14] to be diagonalized and then from these corresponding three column matrices $\overline{X}$ (the eign vectors) to satisfy: $(\bar{Z} - \lambda \bar{U})\bar{X} = 0$ 2.17

when the bar (-) carrys same meaning as '[ ]' for matrix notation.

In our problem $\bar{Z}$ is the surge impedance matrix or the impedance of a three phase (a,b,c) symmetrical element[24] given by

$$\bar{Z}_{abc} = [Z_{abc}] = \begin{bmatrix} Z_s & Z_m & Z_m \\ Z_m & Z_s & Z_m \\ Z_m & Z_m & Z_s \end{bmatrix} \qquad 2.18$$

where self impedance : $Z_s = Z_{aa} = Z_{bb} = Z_{ca} = a$

and mutual impedance : $Z_m = Z_{ab} = Z_{bc} = Z_{ca} = Z_{ba} = Z_{ab} = Z_{ac} = b$

We are required to find a transformation matrix L such that $[L]^{-1}[Z_{abc}][L]$ is diagonal.

With Z of equation (2.18) the values of λ are given as the roots[7] of the following determinantal equation

$$\begin{vmatrix} Z_s - \lambda & Z_m & Z_m \\ Z_m & Z_s - \lambda & Z_m \\ Z_m & Z_m & Z_s - \lambda \end{vmatrix} = 0$$

i.e. $\lambda = a-b,\ a-b,\ a+2b$

The corresponding eigen vectors are found by using each of these three eigen values inturn in equation (2.17). Then with $\bar{X}$ in the form

$$\bar{X} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = (x_1, \ x_2, \ x_3)$$

the repeated value of $\lambda = a - b$ yields,

$$x_1 + x_2 + x_3 = 0$$

and it is possible to choose two independent solution to this equation. Possible choices of X are,

$$\left\{ 1, \ (-1 + j\sqrt{3})/2, \ (-1 - j\sqrt{3})/2 \right\}$$

$$\left\{ 1, \ (-1 - j\sqrt{3})/2, \ (-1 + j\sqrt{3})/2 \right\}$$

This choice introduces the complex quantities of the well-known symmetrical components which are generally used for sinusoidal steady state[11] conditions. The use of complex quantities in transient analysis will almost double the computation time. Therefore it is preferable to work with real quantities.

Consequently it is convenient in studying transient phenomena to choose a real eign vector such as

$$\left\{ \sqrt{2}, \ -\frac{1}{\sqrt{2}}, \ -\frac{1}{\sqrt{2}} \right\} = X_\alpha$$

being associated with $\lambda_\alpha = a - b$

and $\left\{ 0, \ \sqrt{\frac{3}{2}}, \ -\sqrt{\frac{3}{2}} \right\} = X_\beta$, associated with $\lambda_\beta = a - b$

The eigen vector associatrd with the eign value $\lambda_o = a+2b$ can be chosen to be $\{1, 1, 1\} = X_o$ say. If the 3 X 3 matrix L is constructed from the eigen vectors as

$$[L] = [X_o, X_\alpha, X_\beta] = \begin{bmatrix} 1 & \sqrt{2} & 0 \\ 1 & -\frac{1}{\sqrt{2}} & \sqrt{3/2} \\ 1 & -\frac{1}{\sqrt{2}} & -\sqrt{3/2} \end{bmatrix}$$

then it is generally known as the modal transformation matrix. This is also the well-known $0\alpha\beta$ transformation matrix.

The matrix L has the following properties:

i) $[L]^{-1} = [L]^t$;
where t denotes transposition

ii) $[L][L]^t = 3[U]$
or, $[T_c][T_c]^t = [U]$

where $[T_c] = \frac{1}{\sqrt{3}}[L]$ being known as

Clarke's transformation matrix[24] and $[U]$ is the unit matrix. Properties (i) and (ii) show respectively that the matrix $[L]$ and hence $[T_c]$ are orthogonal and unitary matrices. These two properties enable the same matrix $[T_c]$ to hold equally for current and voltage transformations.

$$\text{i.e.}\quad [e_{phase}] = [e_{abc}] = [T_c][e_{mode}] = [T_c][e_{o\alpha\beta}]$$

$$[i_{phase}] = [i_{abc}] = [T_c][i_{mode}] = [T_c][e_{o\alpha\beta}]$$

Also the matrix T_c is power invariant i.e.

$$[e_{abc}][i_{abc}] = [e_{o\alpha\beta}][i_{o\alpha\beta}]$$

In the above expression the term 'mode' refers to three modes of propagation designated by o, α, β of which any solution to voltage and currents in a three phase system can be comprised.

$$\text{Thus,}\quad \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} i_o + \begin{bmatrix} \sqrt{2} \\ -\frac{1}{\sqrt{2}} \\ -\frac{1}{\sqrt{2}} \end{bmatrix} i_\alpha + \begin{bmatrix} 0 \\ \sqrt{3/2} \\ -\sqrt{3/2} \end{bmatrix} i_\beta$$

And it is evident that $i_a+i_b+i_c = 3i_o$ which shows that sum of three phase currents is independent of i_α, i_β rather equal to three times the ground current. Accordingly the α, β modes of propagation are described as aerial mode or line mode and 0 mode as ground mode. Their physical significance[21] is that the ground mode with all elements equal to 1 describes the loop with all conductors of the multiphase system in parallel and return through the ground conductor or ground itself (identical to zero sequence component) while α and β mode describes two loops each consisting of the first conductor but having return via the second conductor and the third conductor respectively.

With the help of a transformation matrix it is possible to represent a three phase line by three modes of propagation, the voltages (current) of which travel independently of each other and are free of mutual effects[7]. Each of the independent equation in the modal domain[8] can then be solved with the algorithm to the single phase line by using its own modal travel time and modal surge impedance. Finally we transform our results back into abc phse quantities by power invariant form of transformation matrix 'T_c'.

2.3.2 Modal Analysis of Multiphase Switching Transients

Let us consider a three phase equilateral line[11] section of Fig.2.9 (transposed and hence symmetric impedance matrix) energised by balanced three phase sinusoidal excitations from an infinite bus.

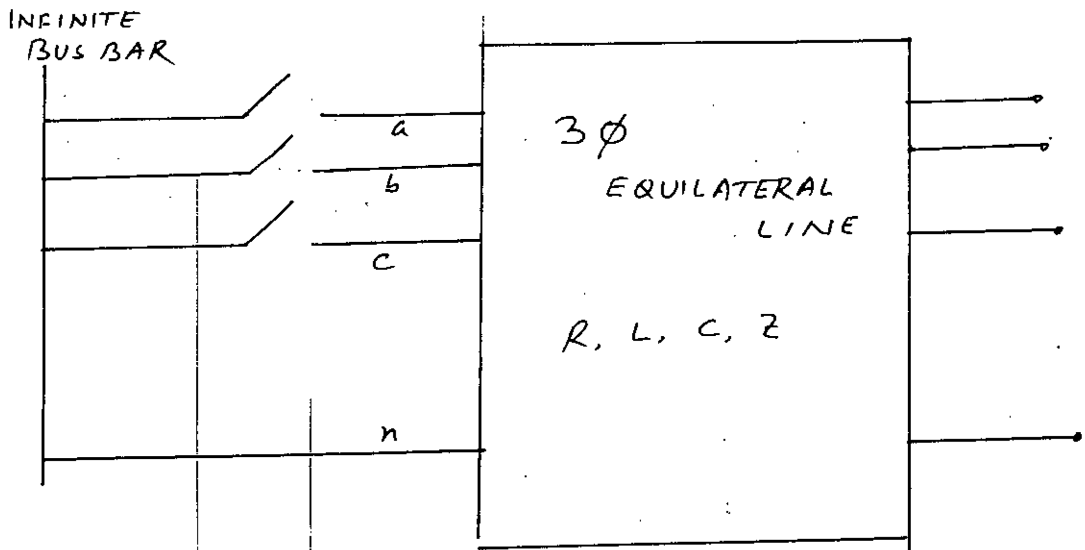


Fig. 2.9. 3ϕ Equilateral Circuit

Then transforming the terminal conditions into $0, \alpha, \beta$ components gives the source voltage

$$[e_{0\alpha\beta}] = [T_c]^{-1}[e_{abc}] = [T_c]^t [e_{abc}]$$

$$= \begin{bmatrix} 1/\sqrt{3} & 1/\sqrt{3} & 1/\sqrt{3} \\ \sqrt{2/3} & -\sqrt{1/6} & -\sqrt{1/6} \\ 0 & \sqrt{1/2} & -\sqrt{1/2} \end{bmatrix} \begin{bmatrix} V_m \cos\omega t \\ V_m \cos(\omega t - 120^\circ) \\ V_m \cos(\omega t - 240^\circ) \end{bmatrix}$$

which can be shown[11] to be equal to

$$\begin{bmatrix} e_o \\ e_\alpha \\ e_\beta \end{bmatrix} = \begin{bmatrix} 0 \\ \sqrt{\frac{3}{2}}\, V_m \cos \omega t \\ \sqrt{\frac{3}{2}}\, V_m \sin \omega t \end{bmatrix} = \begin{bmatrix} 0 \\ \sqrt{3}\, \cos \omega t \\ \sqrt{3}\, \sin \omega t \end{bmatrix}$$

when expressed as p.u. of the r.m.s. voltage from line to neutral.

Obviously this trnsformation has effered us a great advantage in that we have not to deal with zero mode response since zero mode excitation is absent i.e. $e_o(t) = 0$. Thus out of the three decoupled mode transform equivalent circuits depicted in Fig. 2.10, we need to consider only α and β mode.

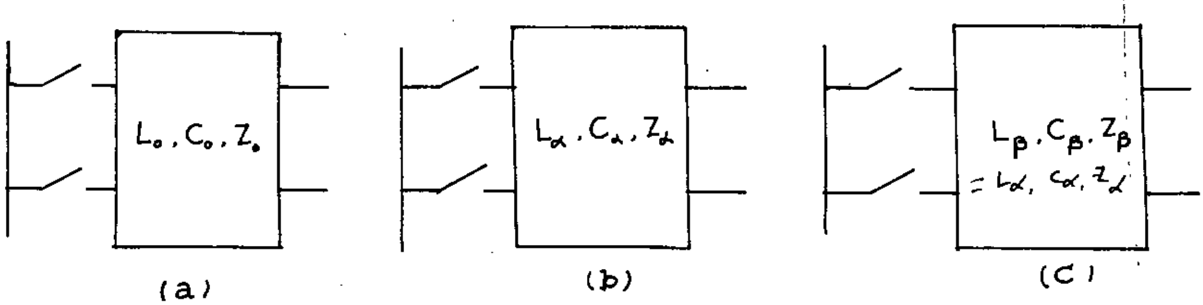


Fig.2.10 (a) Zero mode transform equivalent circuit

(b) Alpha mode transform equivalent circuit

(c) Beta mode transform equivalent circuit.

Interestingly enough another advantage results; alpha and beta mode parameters are equal for a symmetrical network such as transmission lines so that we do not have to account the difference in surge impedance and surge velocity due to mode variation and hence have not to follow a different scheme of subdivision of the line length and interpolate[8] the past history records between different modal time steps to correlate all the modes at any instant of time. Moreover we need to compute the system admittance matrix [Y] only once corresponding to either alpha or beta mode equivalent circuits, which differ only in excitation functions.

The final step requires transformation back to the phase values. If v_α, v_β be the alpha and beta mode response voltages at any node in the network of Fig. 2.9 then the phase values of the response are obtained by the equation:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} T_c \end{bmatrix} \begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} 1/\sqrt{3} & \sqrt{2/3} & 0 \\ 1/\sqrt{3} & -1/\sqrt{6} & 1/\sqrt{2} \\ 1/\sqrt{3} & -1/\sqrt{6} & -1/\sqrt{2} \end{bmatrix} \begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix}$$

Since zero mode cxcitation is zero so is its response. Then the phase voltages become

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} 1/\sqrt{3} & \sqrt{2/3} & 0 \\ 1/\sqrt{3} & -1/\sqrt{6} & 1/\sqrt{2} \\ 1/\sqrt{3} & -1/\sqrt{6} & -1/\sqrt{2} \end{bmatrix} \begin{bmatrix} 0 \\ v_\alpha \\ v_\beta \end{bmatrix}$$

$$= \begin{bmatrix} \sqrt{2/3}\ v_\alpha \\ -\frac{1}{\sqrt{6}}\ v_\alpha + \frac{1}{\sqrt{2}}\ v_\beta \\ -\frac{1}{\sqrt{6}}\ v_\alpha - \frac{1}{\sqrt{2}}\ v_\beta \end{bmatrix}$$

$$= \begin{bmatrix} 0.8164965\ v_\alpha \\ -0.4082482\ v_\alpha + 0.7071067\ v_\beta \\ -0.4082482\ v_\alpha - 0.7071067\ v_\beta \end{bmatrix}$$

2.3.3 Modal Analysis of Lightning Transients in a Multiphase System:

It is assumed that all the three phases are simultaneously hit by lightning stroke. The lightning stroke is considered as if three identical 1/50 μs impulse voltages each applied to a phase conductor at the point of incidence of a lightning stroke. Thus the problem of analysing lightning transient becomes modified to that of switching. Applying transformation from phase to modal domain as in the section 2.3.2. provides,

$$[e_{o\alpha\beta}] = [T_c]^{-1} [e_{abc}]$$

$$\text{or, } \begin{bmatrix} e_o \\ e_\alpha \\ e_\beta \end{bmatrix} = \begin{bmatrix} 1/\sqrt{3} & 1/\sqrt{3} & 1/\sqrt{3} \\ \sqrt{2/3} & -1/\sqrt{6} & -1/\sqrt{6} \\ 0 & 1/\sqrt{2} & -1/\sqrt{2} \end{bmatrix} \begin{bmatrix} e(t) \\ e(t) \\ e(t) \end{bmatrix}$$

$$= \begin{bmatrix} \sqrt{3}\, e(t) \\ 0 \\ 0 \end{bmatrix}$$

when e(t) represents lightning impulse[5] and is identical for stroke on each phase. The expression for e(t) is

$$e(t) = 1.0166702\left(e^{-.014936t} - e^{-6.0730104t}\right)$$

p.u. of the normal or power frequency peak voltage[12] from line to neutral. The symbol 'e' on R.H.S. means exponential.

This when needs to be referred to the normal r.m.s voltage from line to neutral should be multiplied by $\sqrt{2} = 1.4142135$

The transformation carried out suggests that while analysing lightning transient only one mode of excitation be considered, the other two modes being zero.

The next step is the transformation back from modal to phase domain using the equation

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} 1/\sqrt{3} & \sqrt{2/3} & 0 \\ 1/\sqrt{3} & -1/\sqrt{6} & 1/\sqrt{2} \\ 1/\sqrt{3} & -1/\sqrt{6} & -1/\sqrt{2} \end{bmatrix} \begin{bmatrix} v_o \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} v_o/\sqrt{3} \\ v_o/\sqrt{3} \\ v_o/\sqrt{3} \end{bmatrix}$$

where α and β mode responses are zero since the corresponding excitations were zero.

It is evident that if all the phases are affected equally due to lightning stroke then computation in only one modal domain simplifies the work.

CHAPTER 3

COMPUTER ANALYSIS

3.1 Computer Program

Developing an efficient program requires optimum saving both in memory and computer time requirements. Electromagnetic transient programs become more and more complex and time consuming as the size of the system increases. Significant and useful studies as regards the predetermination of the development of over-voltages under transient conditions on selected and important sections of the whole system can therefore be undertaken.

This work has developed a computer program based on some simplifying assumptions and has run the same on IBM 370/115 computer at BUET.

3.1.1 Assumptions

i) Zero and positive sequence data in actual unit as well as the corresponding base value are input data for respectively lightning and switching transient study.

ii) The initial conditions are also part of input if the system under study is not initially relaxed. Otherwise zero initial conditions are assumed.

iii) The system comprises only transmission line, R, L,C lumped parameter and circuit breakers between nodes (buses) or between node and datum in such a way that lumped parameters L and C do not occur together while a lumped resistance R occurs not alone but with either an inductance or a capacitance between same two nodes (other than datum node). In case of parallel R-L or R-C branch between two nodes, the branch card furnishing data on L or C branch follows that for R in the sequence of data card.

iv) The datum node is designated as 1.

v) The remaining nodes or buses are numbered in such a way that the nodes with unknown voltage and without switchs occupy the lowest ones, those with switches higher and the nodes with specified voltage sources the highest.

vi) There is a switch between each node with specified voltage source and that with unknown voltage. This switch would remain closed throughout the analysis of lightning transient but not in case of switching transient.

3.2 Algorithm and Flow-Chart

A brief description of the computer program developed is presented in the form of algorithm and flow chart combined. Figures 3.1 through 3.3 respectively show the flow charts for the main-program, the subroutines for lightning and switching transients.

C MAIN PROGRAM

↓

START

t=0

READ DATA CORRESPONDING TO PARTICULAR TYPE OF TRANSIENT STUDY VIZ. LIGHTNING, SWITCHING WITH OR WITHOUT ANY INITIAL VALUES OF NODE VOLTAGES AND NODE TO NODE CURRENTS.

↓

CALL SUBROUTINE 'LTNMOD' OR 'SWITCH' IF 'ITYPTR' = 2 OR 1 AND 0 RESPECTIVELY.
'ITYPTR' = TYPE OF TRANSIENT.

↓

SET ZERO INITIAL CONDITIONS FOR LIGHTNING AND SWITCHING WITHOUT NON-ZERO INITIAL VALUES WHILE READ INITIAL CURRENTS FROM NODE TO NODE (MODAL VALUES) FOR SWITCHING TRANSIENT STUDY WITH REFERENCE TO NON-ZERO INITIAL VALUES ('ITYPTR' = 0).

↓

(A)

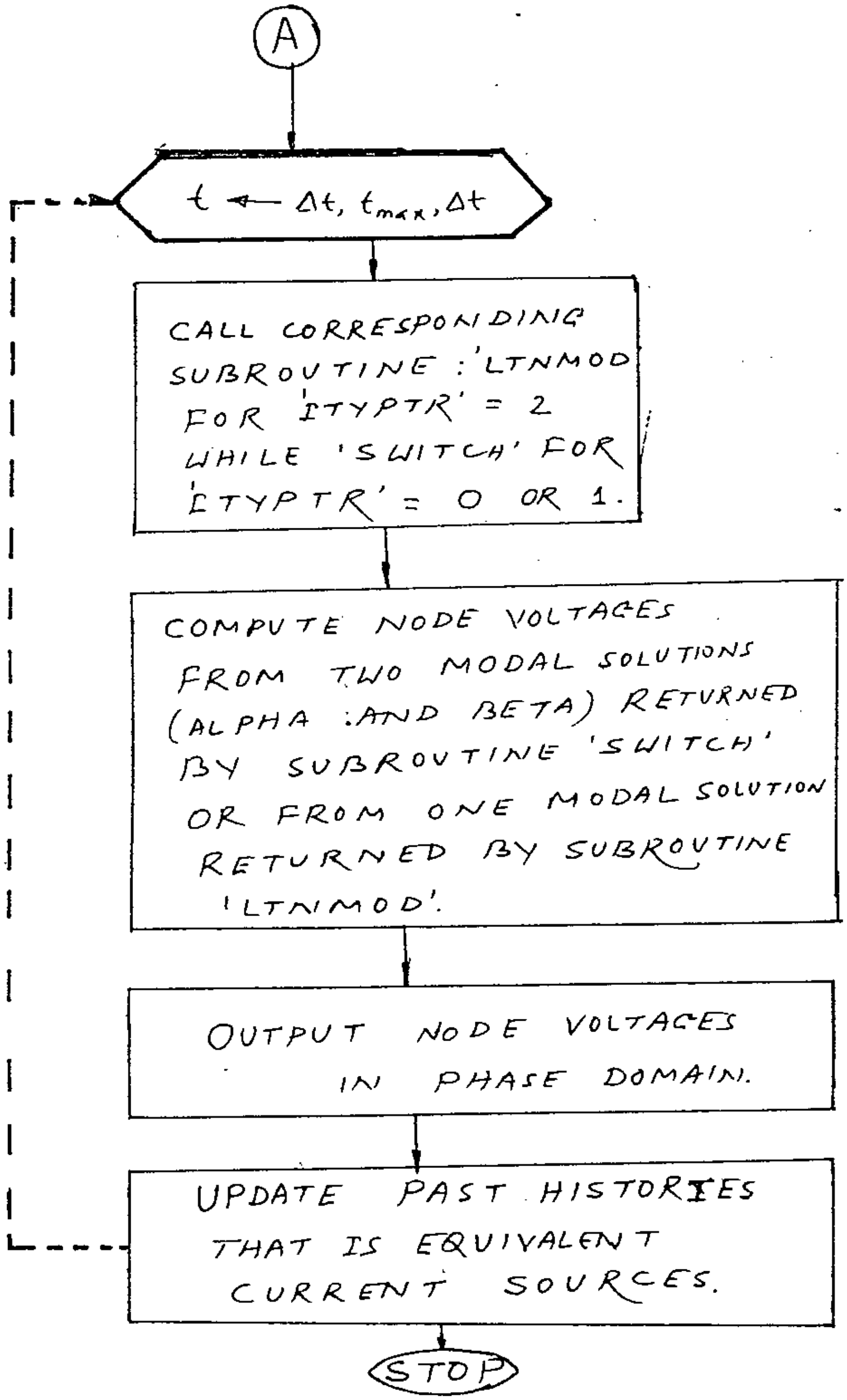
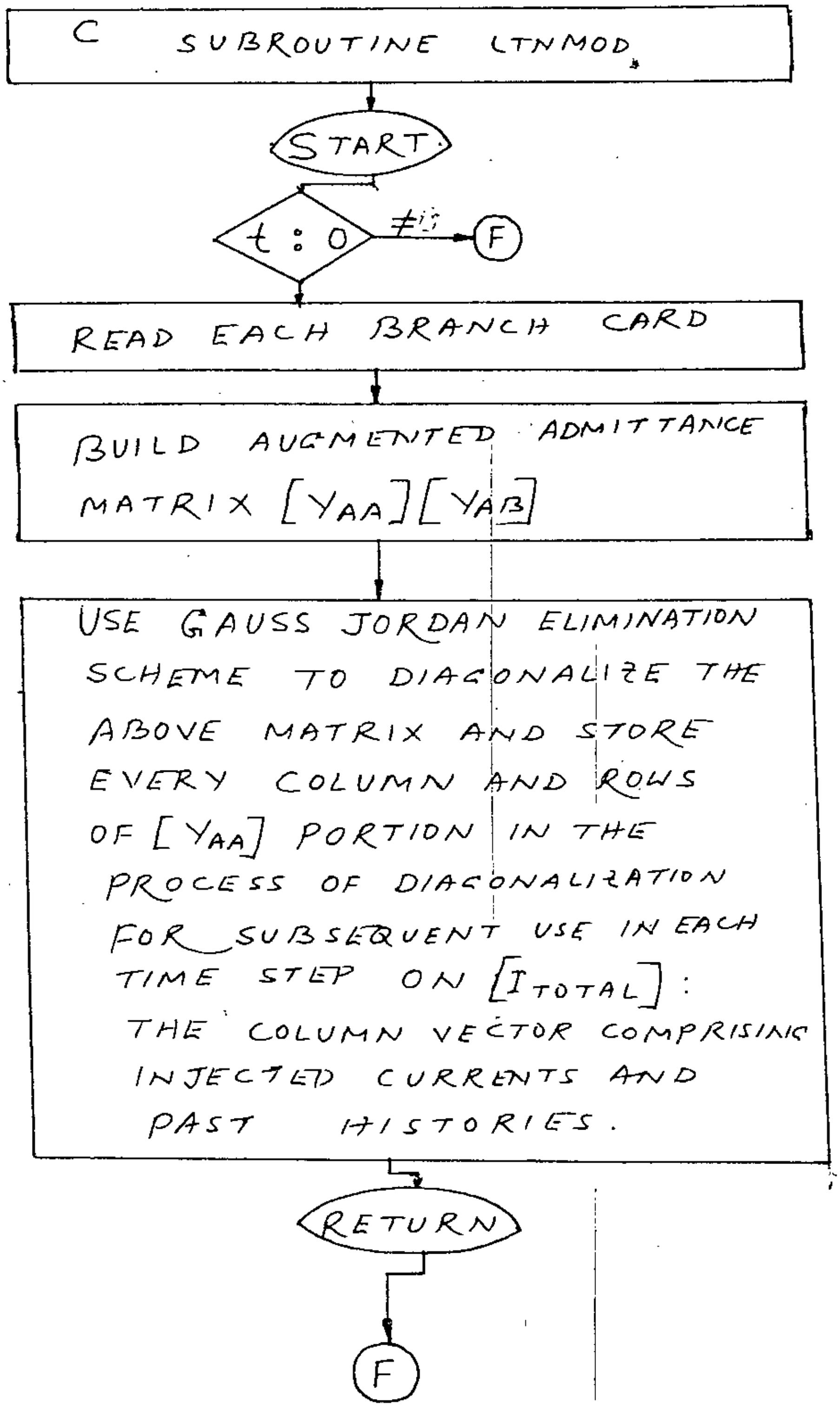


Fig. 3.1. FLOW CHART OF THE MAIN PROGRAM FOR STUDY OF LIGHTNING AND SWITCHING TRANSIENTS.


C SUBROUTINE LTNMOD
START
t : 0
≠
F
READ EACH BRANCH CARD
BUILD AUGMENTED ADMITTANCE MATRIX [YAA][YAB]
USE GAUSS JORDAN ELIMINATION SCHEME TO DIAGONALIZE THE ABOVE MATRIX AND STORE EVERY COLUMN AND ROWS OF [YAA] PORTION IN THE PROCESS OF DIAGONALIZATION FOR SUBSEQUENT USE IN EACH TIME STEP ON [ITOTAL] : THE COLUMN VECTOR COMPRISING INJECTED CURRENTS AND PAST HISTORIES.
RETURN
F

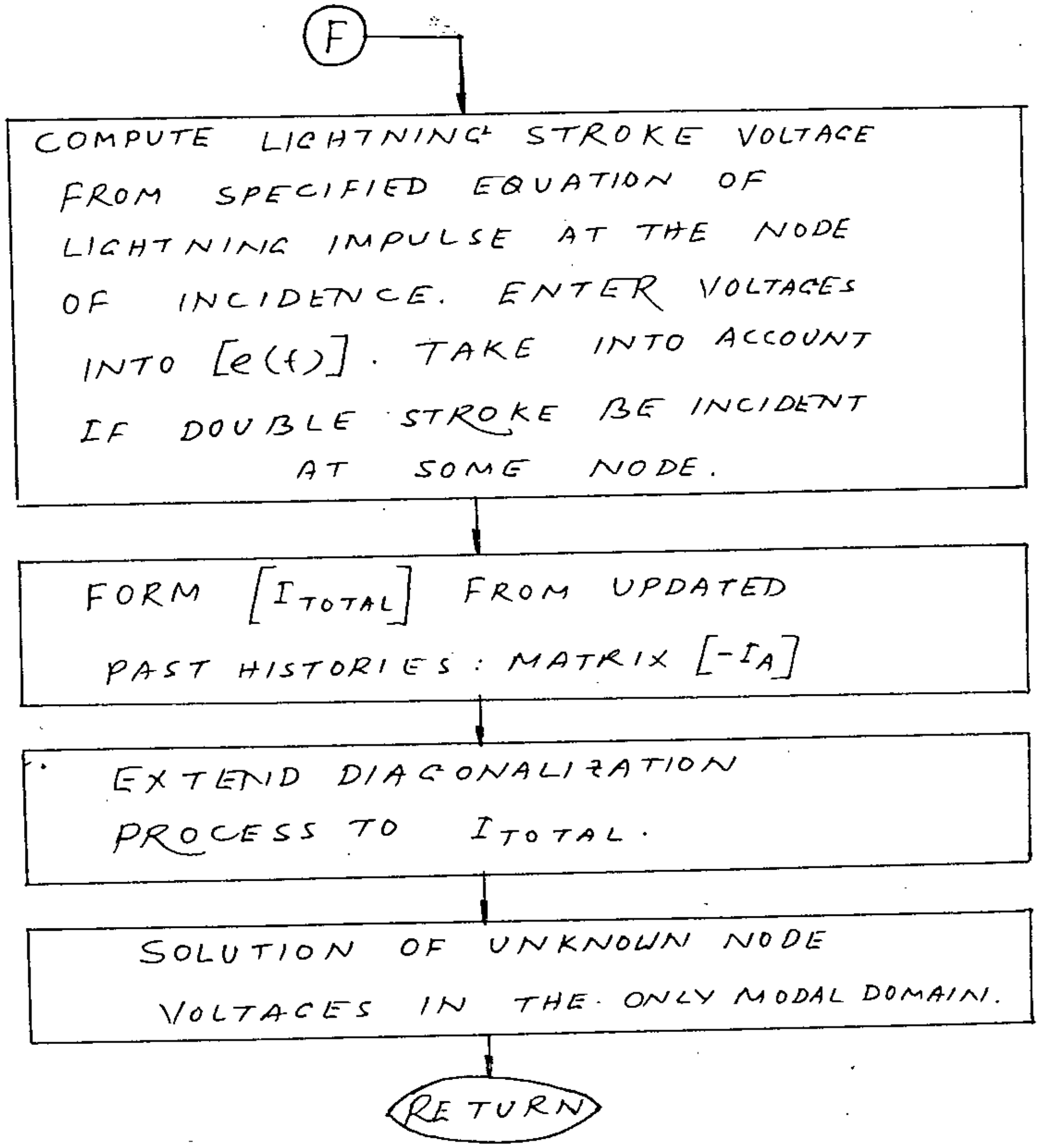
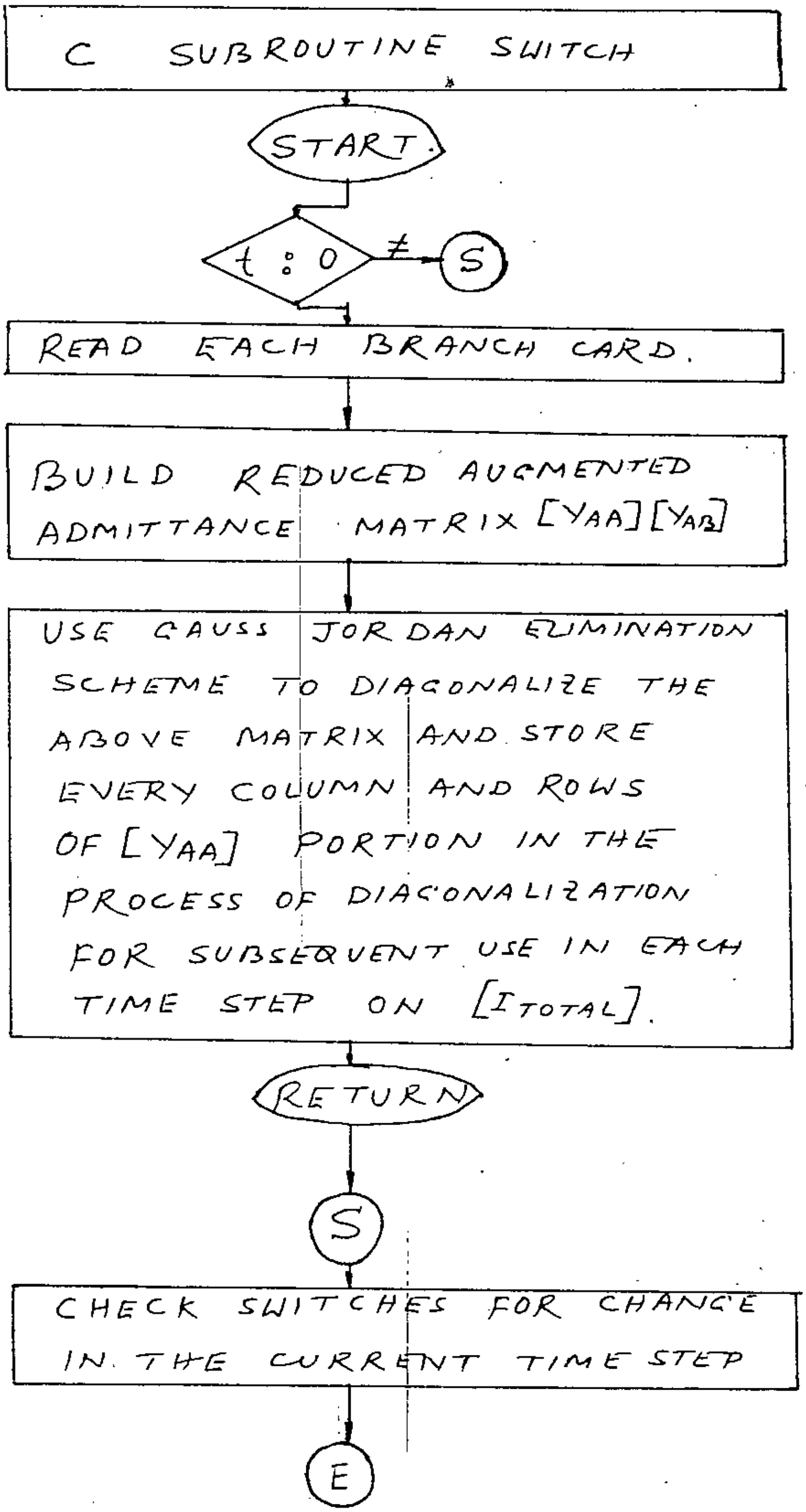
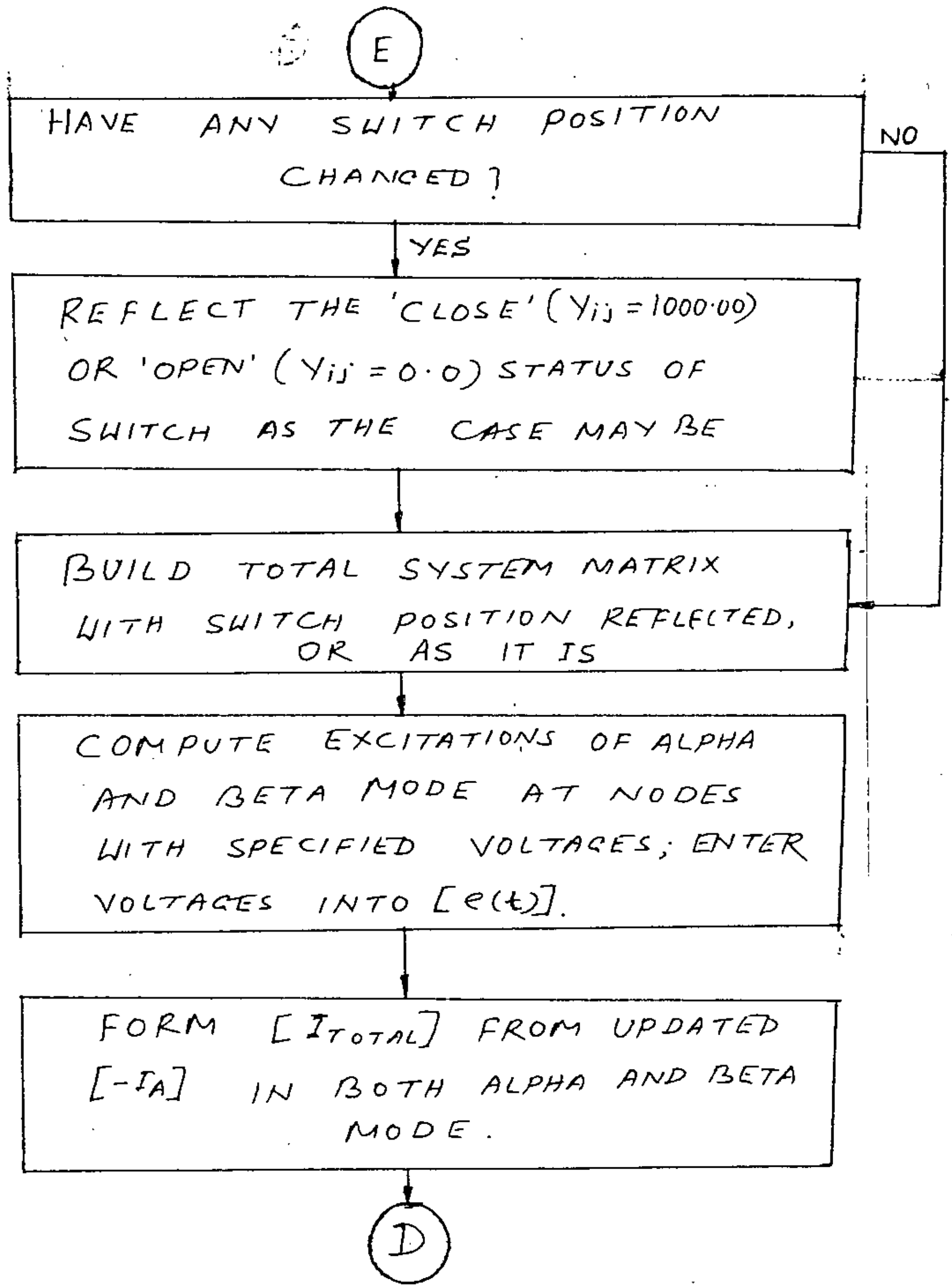


Fig. 3.2. FLOW CHART OF THE SUBROUTINE 'LTNMOD' FOR LIGHTNING TRANSIENTS.


C SUBROUTINE SWITCH
START
t : 0
≠
S
READ EACH BRANCH CARD.
BUILD REDUCED AUGMENTED ADMITTANCE MATRIX [YAA] [YAB]
USE GAUSS JORDAN ELIMINATION SCHEME TO DIAGONALIZE THE ABOVE MATRIX AND STORE EVERY COLUMN AND ROWS OF [YAA] PORTION IN THE PROCESS OF DIAGONALIZATION FOR SUBSEQUENT USE IN EACH TIME STEP ON [ITOTAL].
RETURN
S
CHECK SWITCHES FOR CHANGE IN THE CURRENT TIME STEP
E


E
HAVE ANY SWITCH POSITION CHANGED ?
NO
YES
REFLECT THE 'CLOSE' (Y_{ij} = 1000·00) OR 'OPEN' (Y_{ij} = 0·0) STATUS OF SWITCH AS THE CASE MAY BE
BUILD TOTAL SYSTEM MATRIX WITH SWITCH POSITION REFLECTED, OR AS IT IS
COMPUTE EXCITATIONS OF ALPHA AND BETA MODE AT NODES WITH SPECIFIED VOLTAGES; ENTER VOLTAGES INTO [e(t)].
FORM [I_{TOTAL}] FROM UPDATED [$-I_A$] IN BOTH ALPHA AND BETA MODE.
D

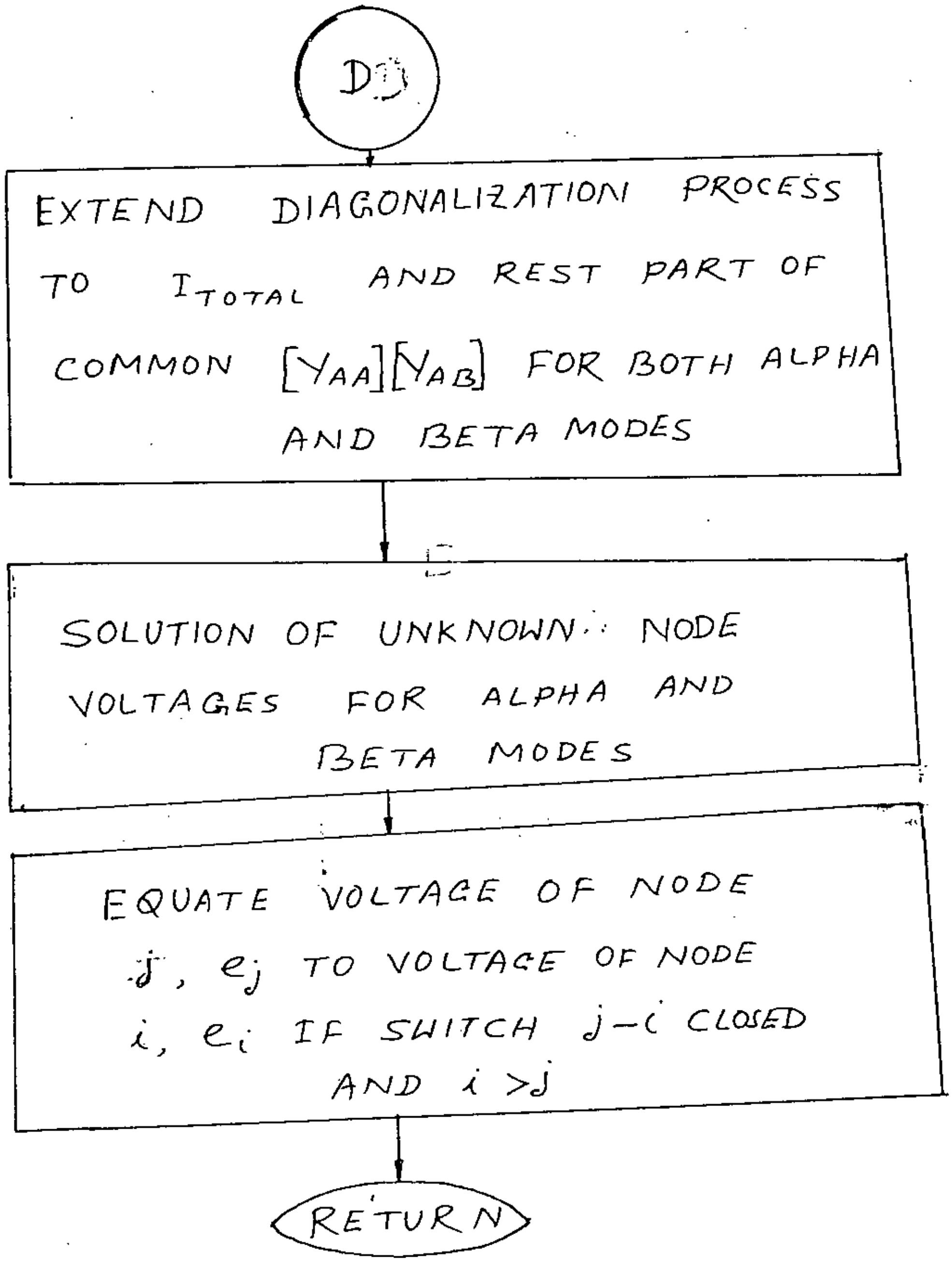


Fig. 3.3. FLOW CHART OF THE SUBROUTINE 'SWITCH' FOR SWITCHING TRANSIENTS.

In addition to the [illegible] program for transient computation two supporting programs have been developed to find initial voltages and currents of a system initially in steady state by a load flow study and to plot the output data on overvoltages respectively prior and subsequent to the use of the transient program.

Listing of all these programs are enclosed in Appendix-A.

CHAPTER 4

SYSTEMS OF STUDIES AND RESULTS

4.1 Introduction

In this chapter a number of studies are incorporated of which first three are made on system configuration taken from available literatures[10,13] to verify the results obtained by the method adopted by this work.

Study-II reveals that most severe transient over-voltage occurs for the energisation of a transmission line with open circuit condition and it takes a time longer than 5 cycles to settle to a steady state value. Instead of a computer analysis for such a long time an idea of miximum over-voltage can be had from an analysis for first few cycles or a fraction thereof depending upon the length and travel time of the whole line section. The remaining studies are mostly on energisation of different important scetions with one or more open receiving end condition taken from both East and West grid of Bangladesh Power Development Board (BPDB); the analyses were made just for a time about twice the respective travel time of each line section.

Unlike studies II & III in subsequent studies three phase cosine voltages of 1.0 p.u. rms value were applied to the line with first phase having a zero initial angle and the other two phase angles being -120 degrees and -240 degres.

With each study computer plots of over-voltages at one or more selected nodes is provided. The plots are approximate since a digital computer can not locate a point exactly; e.g. if 0.2 p.u. per small division is a choice of scale for plot then 1.0 or 1.10 p.u. over-voltage will be marked at the same point on the plot-plane.

4.2 Systems of Studies

4.2.1 Study-I

System under Study-I is identical to a small single phase system (Fig.4.1) analysed by Weedy[10] using digital lattice technique. In the Fig.4.1. each line is labelled with surge impedance and surge travel time in micro-second (multiple of basic unit) e.g. 400 Ω, 1 s. At node 3 the stimulant is a rectangular wave of infinite duration.

The configuration in a form acceptable for the computer program of this work is shown in Fig.4.2.

The plot in Fig.4.3. for over-voltages at node 4 and node 5 (identical) obtained by this work using a quite different method is in agreement with that found by Weedy[10].

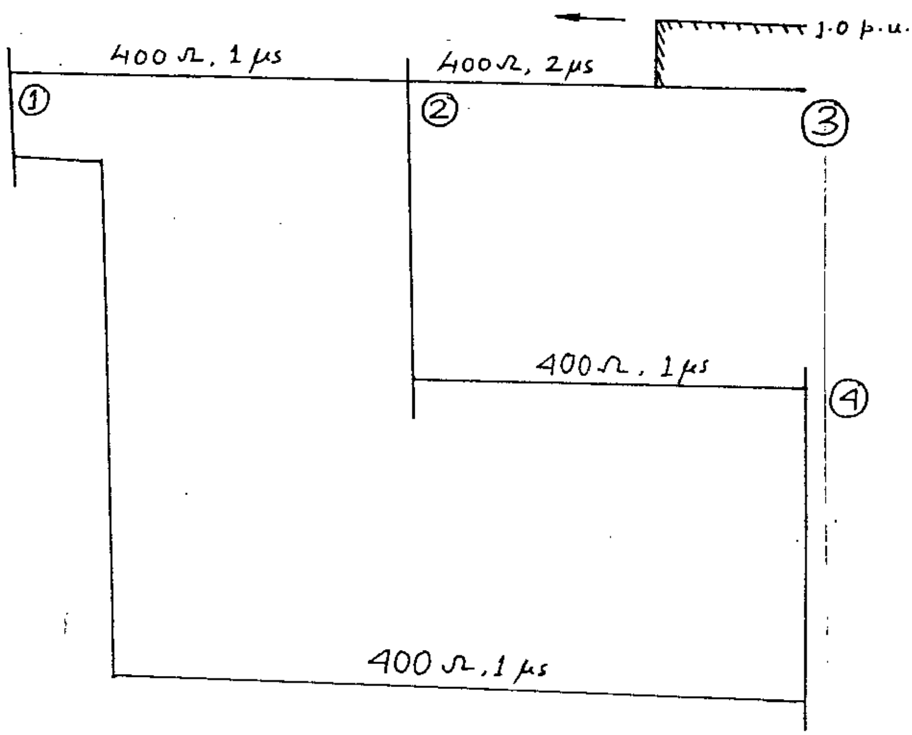


Fig. 4.1. System configuration of Study-I.
Number inside a circle indicates node no.

DATA:

Base voltage = 132 kV, Base MVA = 100 MVA.

Line parameters:

Resistance per unit length = 0.0
Inductance per unit length = 2000.0 μH
Capacitance per unit length = 0.0125 μF
Travel time = 1 μs.
Length of each segment = 0.189 miles.

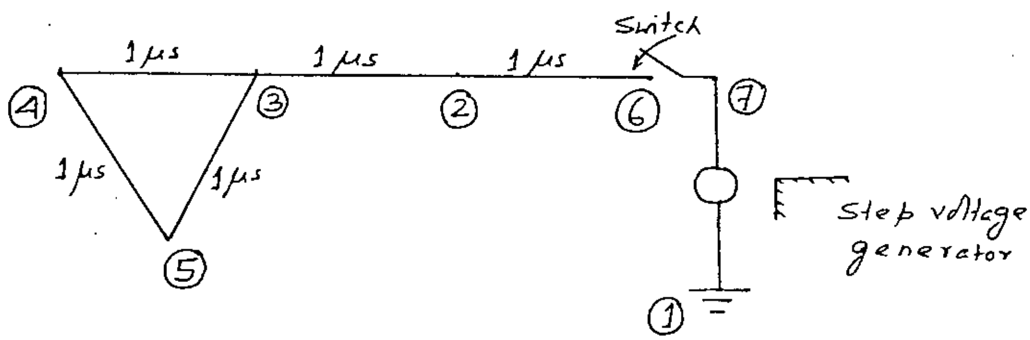


Fig. 4.2. Modified configuration of system shown in Fig. 4.1.

PLOT OF SWITCHING OVER-VOLTAGE AT NODE NO. 4
DUE TO STEP INPUT IN A 1.PHASE SYSTEM

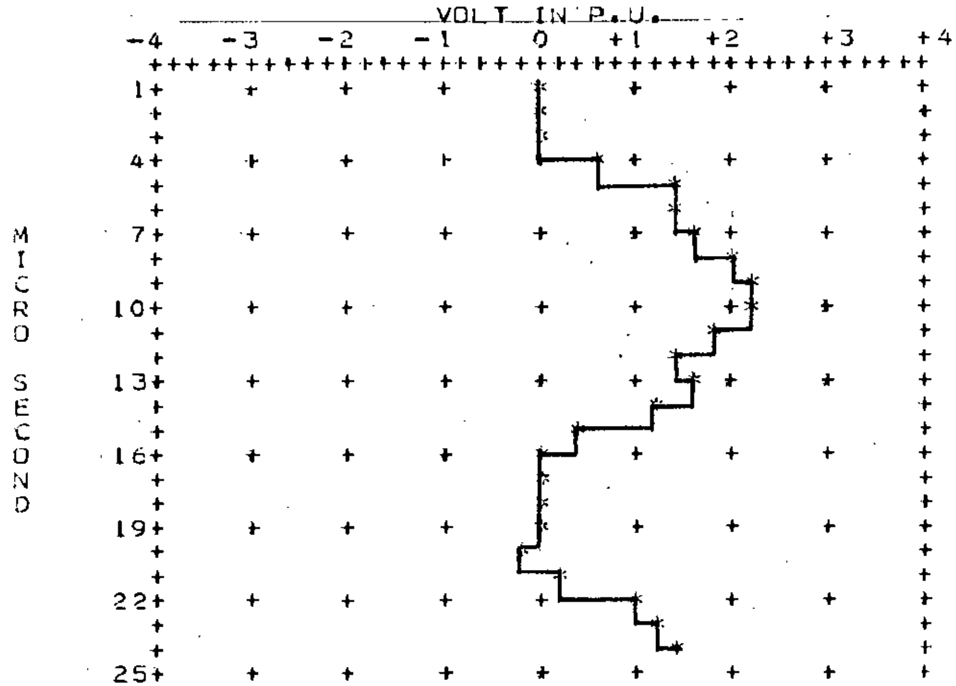


Fig.4.3. Response at node no.4 of system shown in Fig.4.2. of Study-1

4.2.2 Study-II

System under Study-II is a 156.23 miles long three phase line with receiving end open and sending end connected to an infinite bus or impedanceless generator as in Fig. 4.4. The simple was analysed by Uram and Miller[13] using matrix method of Laplace transform. To make the system compatible with the method of this work as well as to achieve more accuracy the line is divided into 17 segments of 50 μs travel time (9.15 miles) each as in Fig. 4.5

It was assumed that three phase sine voltages of unit amplitude were applied to the line, with the first phase having a zero initial angle and the other two phse angles being -120 degrees and -240 degrees.

Three phase voltages at the receiving end of the line are plotted individually as in Fig.4.6 with the help of digital computer. A good agreement is obtained between this and that provided by Uram and Miller[23].

The voltage wave shapes are quite erratic before settling down to a recognizable sinusoidal pattern after about five to six cycles with respect to system frequency (60 H_z in the said work[13]). This extreme transient response is a result of two factors : first, the open circuit at the receiving end of the line leads to severe reflection of the travelling waves,

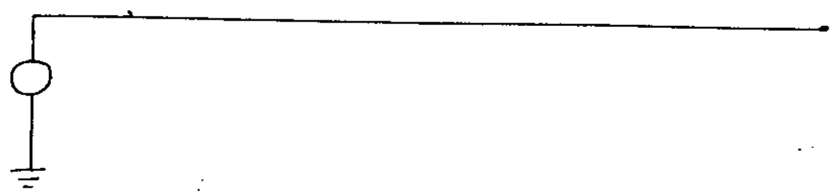


Fig. 4.4. System configuration of Study - II.

Transmission line Data[13].

Total Resistance = ·00918 p.u.
Total Inductive Reactance = ·099 p.u.
Total Capacitive Reactance = 0·96 p.u.
Line length = 156·23 miles
Velocity of Propagation = 183,000 miles per second.

System frequency : 60 Hz.
System base data : 345 KV, 100MVA, 1190 Ohms.

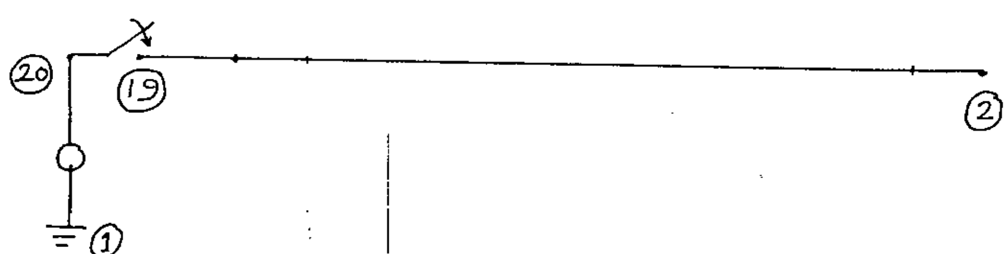


Fig. 4.5. Modified Configuration of system in Fig. 4.4.

PLOT OF SWITCHING OVER-VOLTAGE AT NODE NO. 2
VOLT IN P.U.

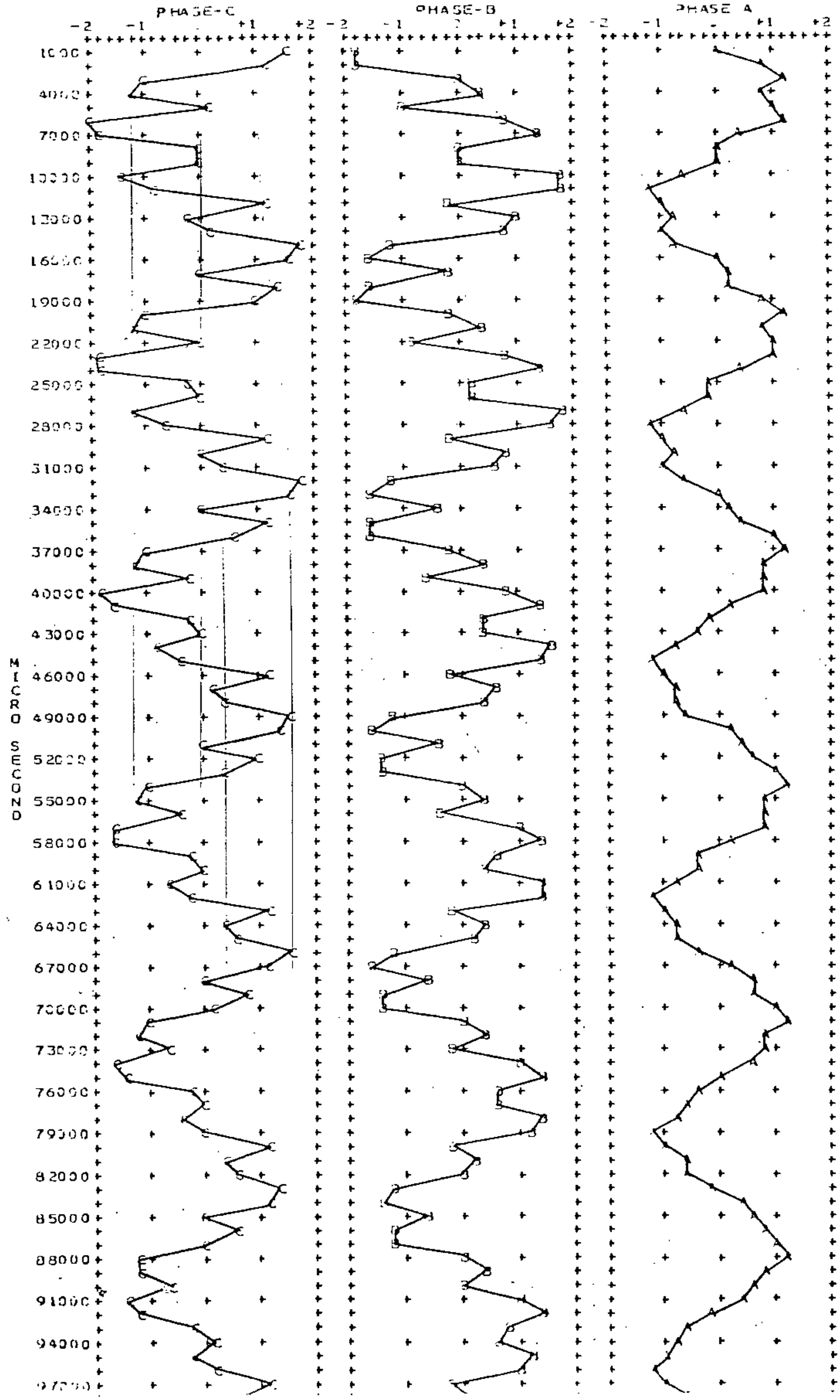


Fig. 4.6. Response at receiving end (node no. 2) of an unloaded line shown in Fig. 4.5. of Study-II

and second the lack of impedance at excitation end, which normally would attenuate the reflection and thus smooth the transient response.

4.2.3 Study-III

System under Study-III is exactly the same as that of Study-II but with a balanced load of 1.0 per unit resistance connected at the receiving end (Fig. 4.7).

The computer plot in Fig. 4.8. of voltages at receiving end is in close agreement with that of Uram and Ferro[13]. The voltages go through a transient period of about 1 cycle before reaching steady state values of approximately 1.0 per unit in all phases.

The response of the first phase (A) is quite smooth and drops out quickly while the second (B) and third (C) phases have rough edges and require about 1 cycle before the transient disappears. The reason for this is that the first phase is excited at zero voltage, which then continued sinusoidally. On the other hand, the second and third phases were excited with sudden steps of voltages because their phase angles were -120 degrees and -240 degrees lagging relative to the first phase. The transient responses[13] circuit excited with unit steps will be erratic and of relatively long duration.

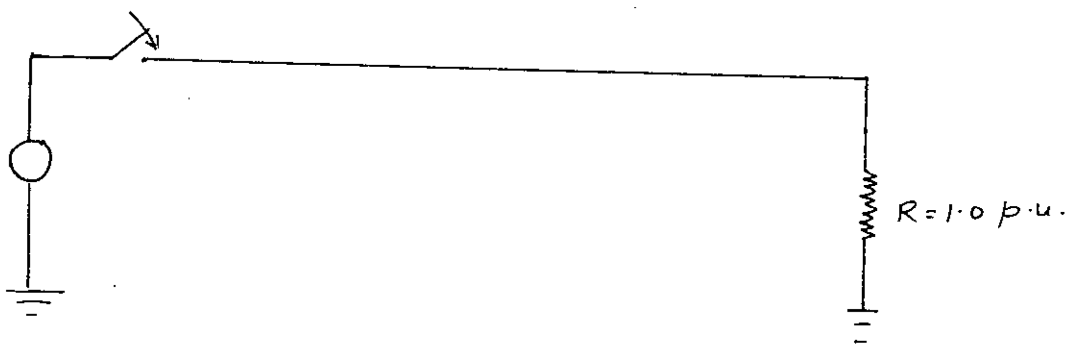


Fig · 4.7. System configuration of Study - III .

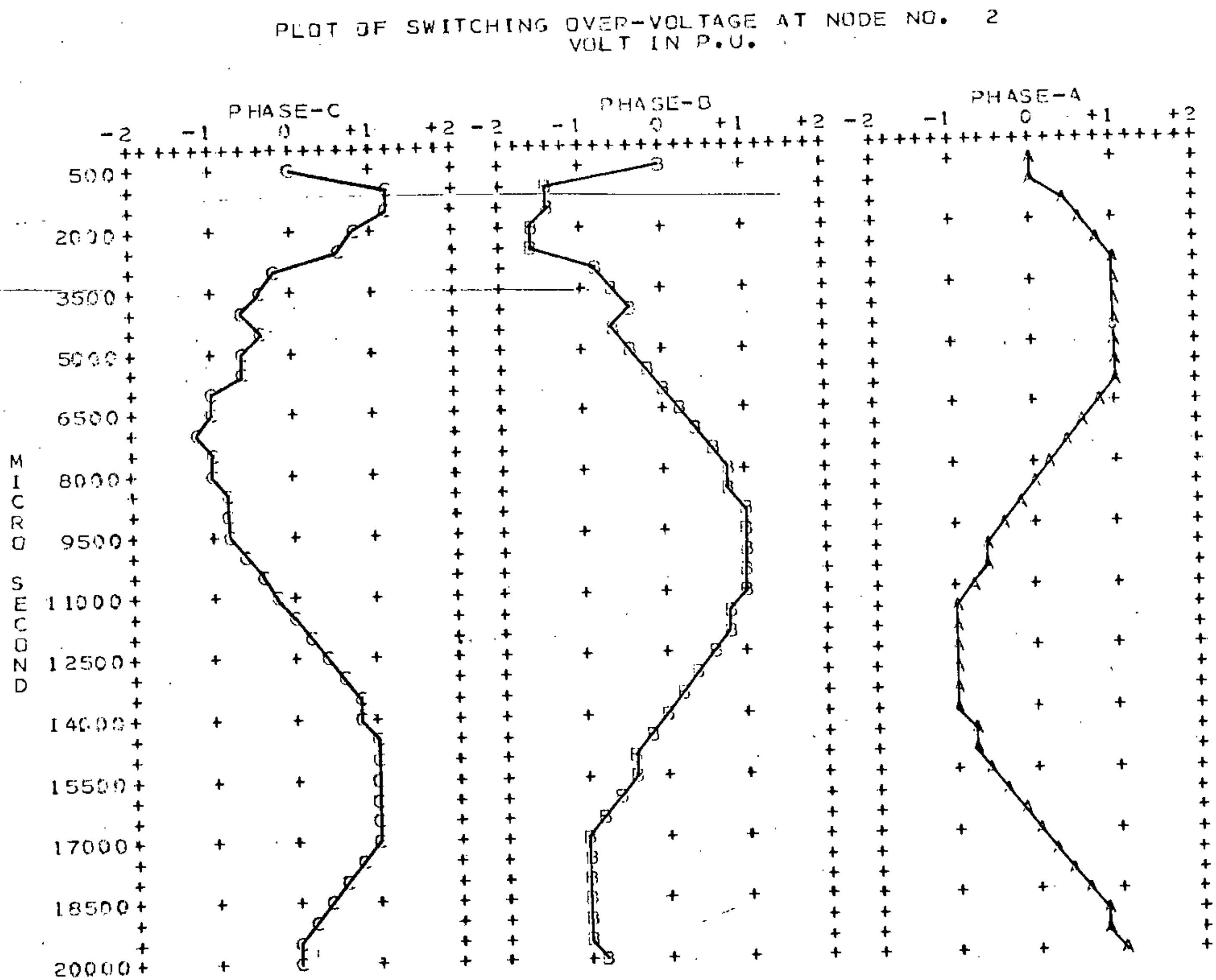


Fig. 4.8 Response at receiving end (node no.2) of balance resistive load terminated system shown in Fig.4.7 of Study-III .

4.2.4 Study-IV

This study considers a section of the BBDB grid, namely the East-West interconnector of an approximate length 110 miles (586 μs travel time) being excited from an infinate bus at Ghorasal and transformer terminated at Ishurdi bus as in Fig.4.9. The energisation rms voltage is assumed to be 230 KV so that the base impedance for this system is 529 ohms on the bases of 230 KV and 100 MVA.

The transformer is represented by the leakage inductance referred to primary side. Then both the nodes 3 and 2 respectively representing the primary and the secondary side of the transformer or two ends of the inductance are apparently at same voltages due to the open end condition at node 2(capacitance effect of the transformer has been neglected).

The plot of over-voltages in Fig. 4.10 shows distorted and oscillatry nature of the voltage transient due to the presence of transformer (inductance) terminated end (node no.2).

The over-voltage in first phase (A) surpasses those of the second (B) and the third (C) phases because of initial values (at t =0 or just immediately before the first time setp) of corresponding excitation as mentioned in the section 4.2.3. In the first phase it was 1.41 p.u. ($e_A = \sqrt{2} \cos\omega t$ p.u.)

while in each of 2nd and 3rd phases were -.707 p.u. corresponding to ($e_B = \sqrt{2}\cos(\omega t - 120°)$) and ($e_c = \sqrt{2}\cos(\omega t - 240°)$) respectively.

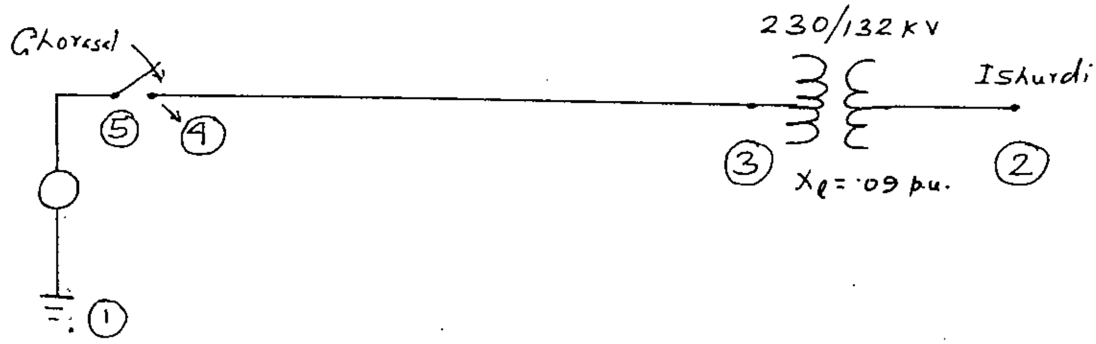


Fig. 4.9. System configuration of Study - IV

Transmission line Data.

Resistance per unit length = 0.219 Ohms
Inductance per unit length = 2038.2 μH
Capacitance per unit length = 6.0146 μF
Line length = 110.0 miles
Travel time = 586 μs
Velocity of propagation = 186,000 miles per second.

System frequency : 50 Hz.
System base data : 230 KV, 100 MVA, 529 Ohms.

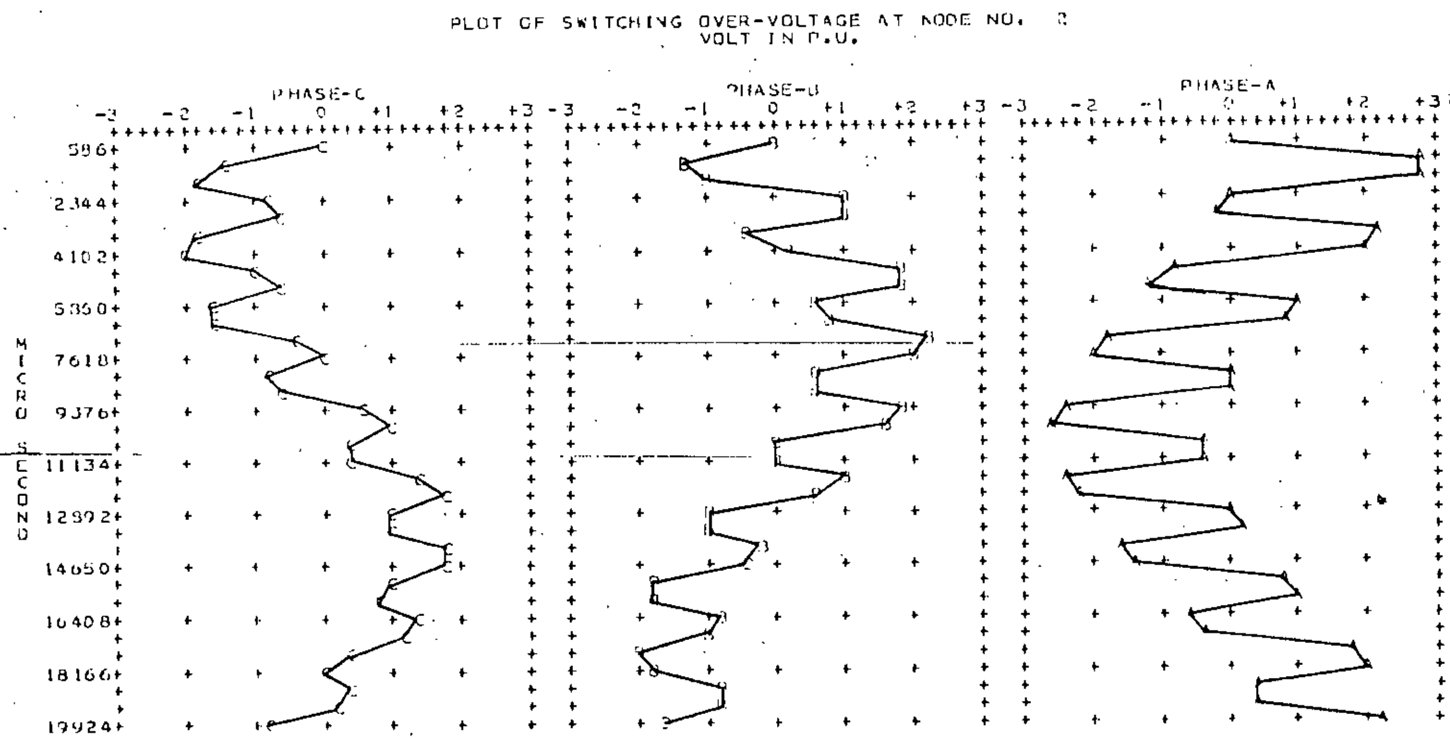


Fig. 4.10. Response at the terminal point (node no.2) of a transformer terminated system shown in Fig. 4.9 of Study-IV.

4.2.5 Study-V

The system under this study consists of the Ghorasal-Siddhirganj-Kaptai 132 KV line section of BPDB grid being energised from Ghorasal as in Fig.4.11. The line was divided into 9 segments of travel time 126 μs (24.0 miles) each.

A small cable section of 0.9 mile length between node no.2 (Siddhirganj) and overhead transmission line section coming from node no. 10 (Kaptai) has been represented as a lumped parameter (π- section). However, the branch comprising inductance (L) and resistance (R) is series in the π section has been converted into a parallel R-L branch resulting in the elemination of an excess node.

The plots in Figs.4.12-4.14 are obtained for transient over-voltages at a nearby open terminal (node no.11), an intermediate node (node no.5) and the open far end (node no. 10) respectively.

The large difference between the surge impedance (30 ohma) of cable section and that of the overhead transmission line (300 ohms) causes a major percentage of the incident voltage to be reflected from both the junction (node no.2 and node no.3) of the system showm in Fig.4.11. Consequently appreciable over-voltages results at nearby open terminal (node no. 11) and the far open end (node no.10). The maximum over-voltage (Phase-A and phase-C) at the node no.10 exceeds that at the node no.11 because of added reflections from the 'open-end' condition.

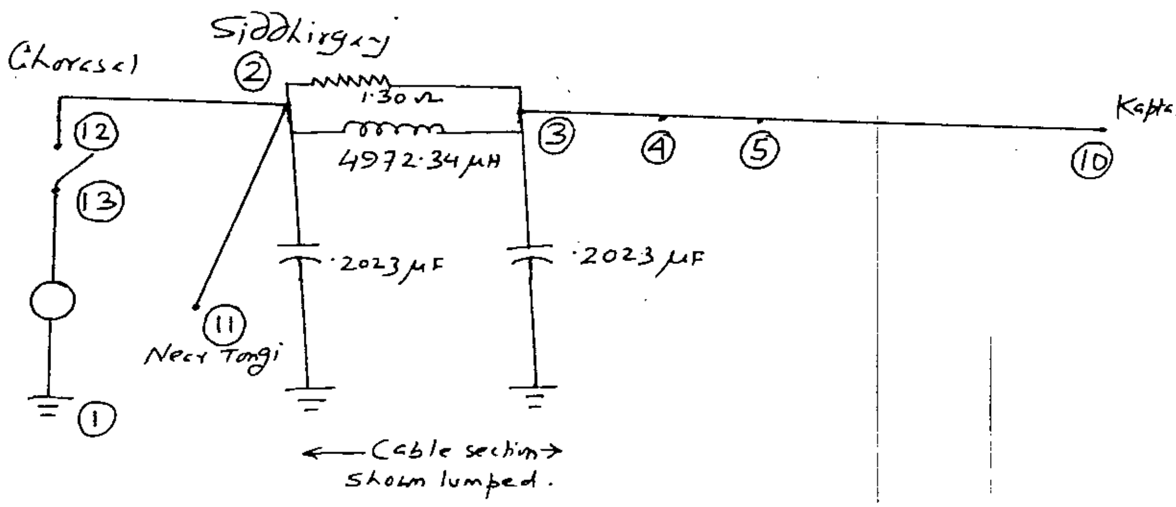


Fig. 4.11. System configuration of Study - V

Transmission line Data:

Resistance per unit length = 0·162 Ohms/mile
Inductance per unit length = 1968·2 μH/mile
Capacitance per unit length = ·0152 μF/mile
Line length (each segment) = 24·0 miles
Velocity of propagation = 186000 miles per second

Cable section data:

Length = 0·9 miles
Resistance per unit length = 0·162 ohms/mile
Inductive reactance per unit length = 0·135 ohms/mile
Capacitance per unit length = 450·0 nF/mile

System base data: 132 KV, 100 MVA, 174·24 ohms.

PLOT OF SWITCHING OVER-VOLTAGE AT NODE NO. 11
VOLT IN P.U.

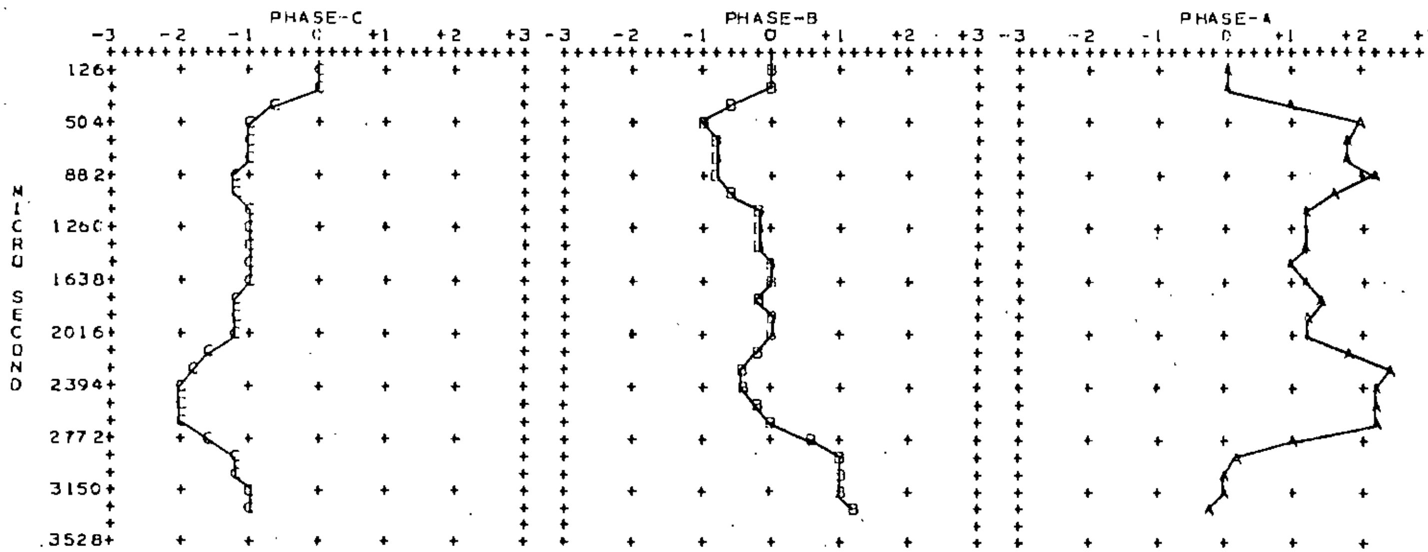


Fig. 4.12. Response at an open terminals (node no.11) of system shown in Fig. 4.11 of Study-V.

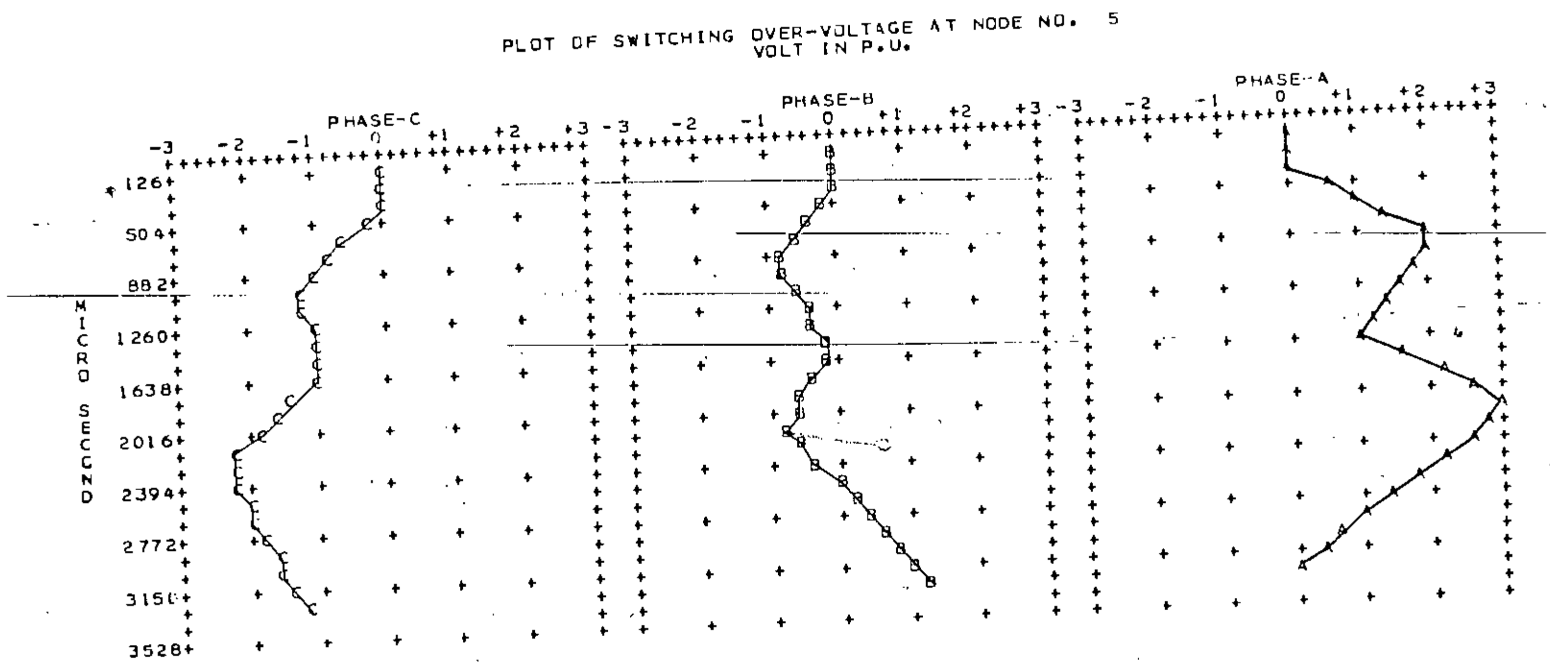


Fig. 4.13. Response at an intermediate node (node no.5) between source end and open receiving end of system shown in Fig.4.11 of Study-V.

PLOT OF SWITCHING OVER-VOLTAGE AT NODE NO. 10
VOLT IN P.U.

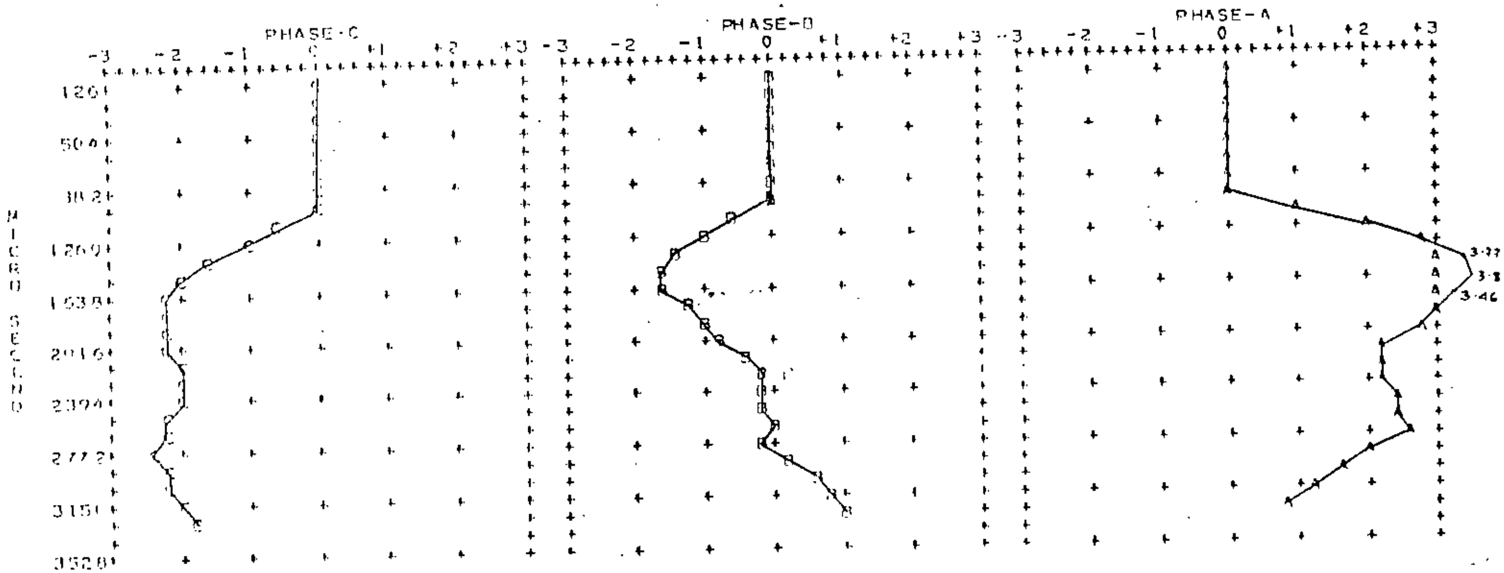


Fig.4.14. Response at open receiving end (node no.10) of system shown in Fig.4.11 of Study-V.

4.2.6 Study-VI

The system of this study is the same as that of Study-V excepting that the excitation [redacted] from Ghorasal may be looked upon as that from a large external system represented by a Thevenin's voltage source together with a series reactance X_{th} computed from (Base MVA)/(Short circuit MVA).

The presence of the impedance in generator circuit at Ghorasal end makes the magnitude of over-voltages of same phases less compared with those at the same nodes of the system of Study-V as shown in the plots of Fig. 4.16 - 4.18.

Also the wave shapes are more smooth than those obtained in Study-V.

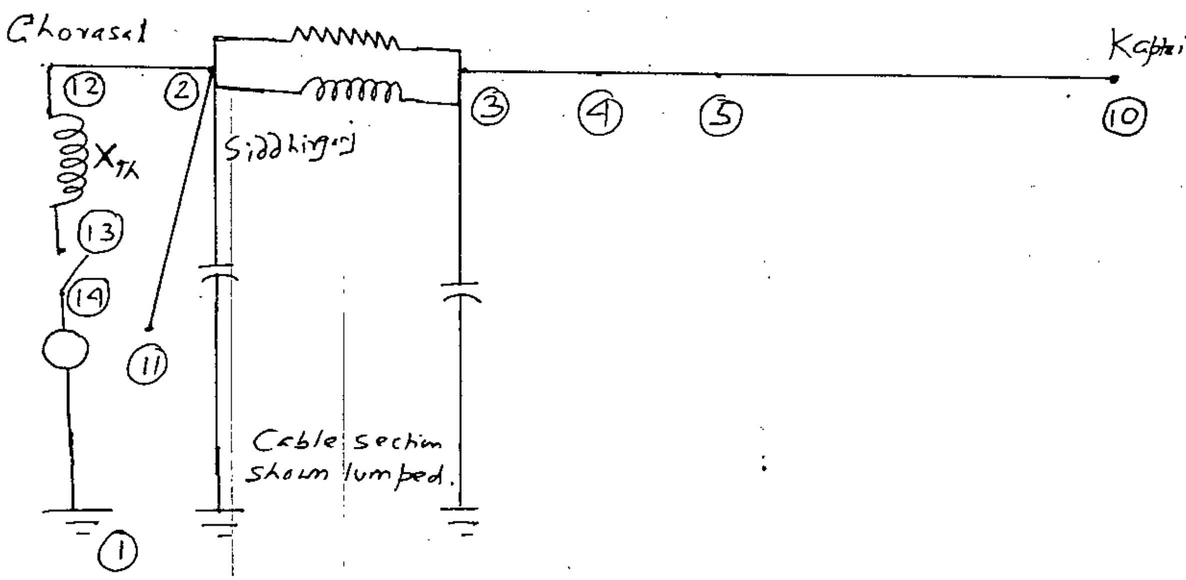


Fig. 4.15. System configuration of Study-VI

System Data : Same as that for System Configuration in Fig. 4.11. (Page. 4-16) of Study-V

Assumption:

$$X_{th} = \frac{\text{Base MVA}}{\text{Short Circuit MVA}}$$

$$= \frac{100}{2 \times 68.7} = 0.727 \text{ p.u.}$$

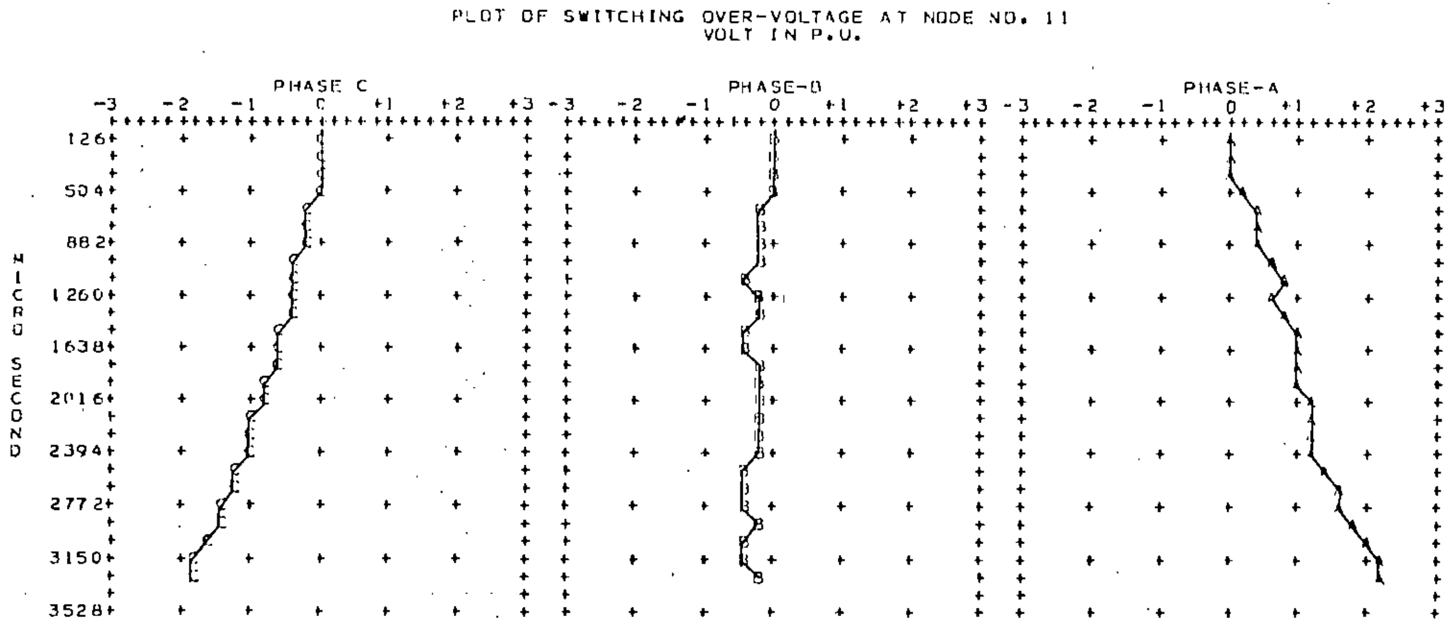


Fig. 4.16. Response at an open terminal (node no.11) of system shown in Fig.4.15 of Study-VI.

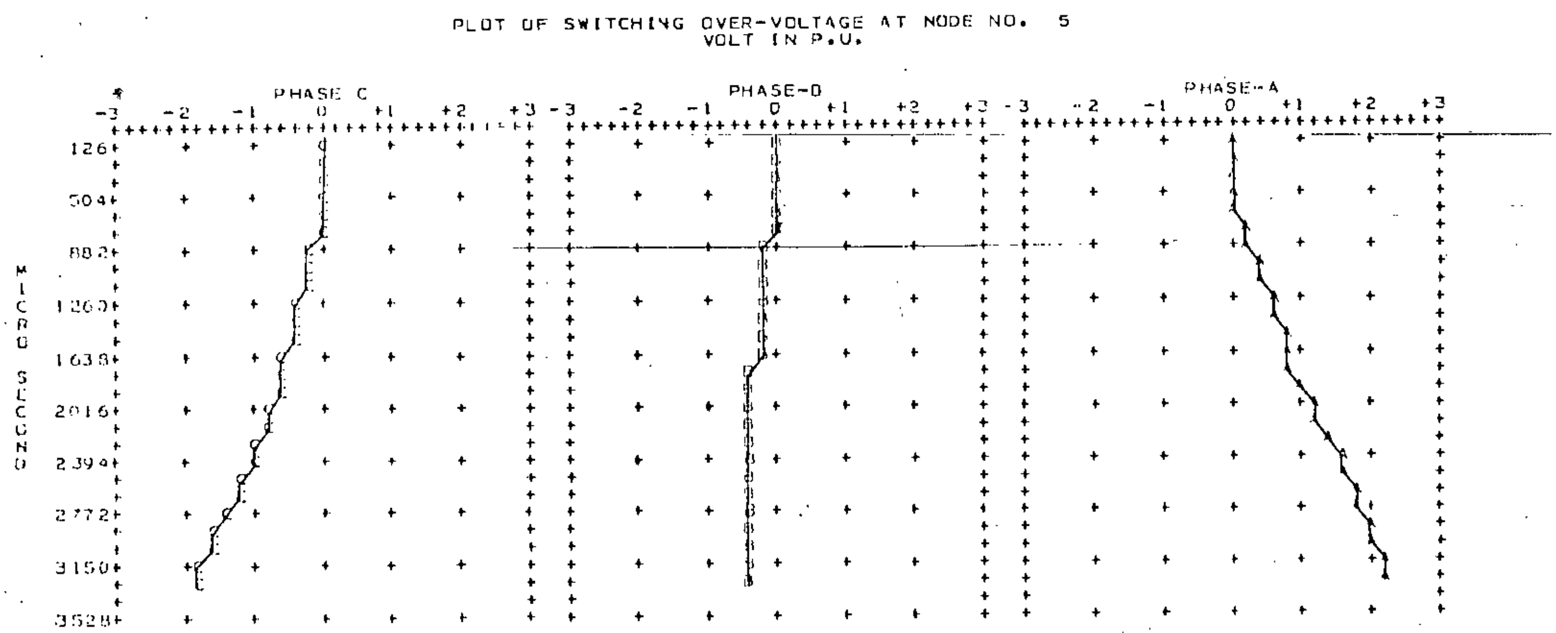


Fig. 4.17. Response at an intermediate node (node no.5) between source end and open receiving end of system shown in Fig. 4.15 of Study-VI.

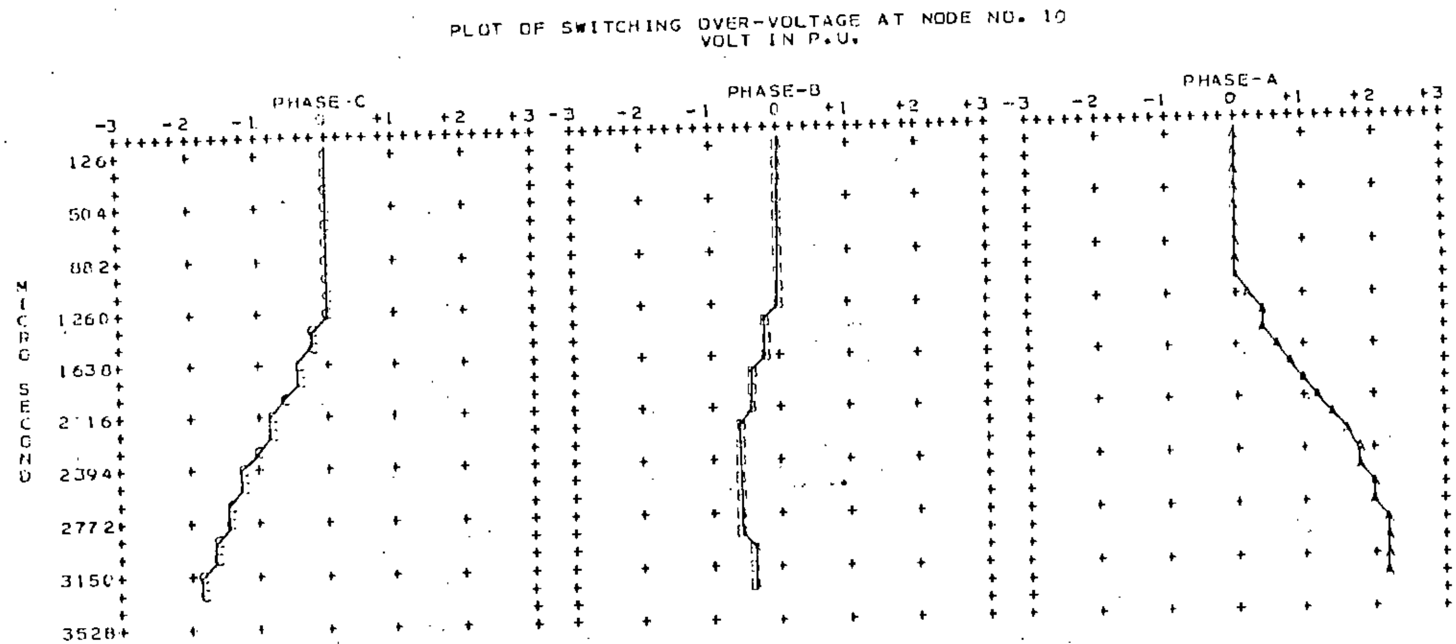


Fig. 4.18 Response at open receiving end (node no.10) of system shown in Fig. 4.15 of Study-VI.

4.2.7 Study-VII

This study undertakes the system configration of the Study-V in section 4.2.5. but considers excitation of the line section from Kaptai end (node no.12) as shown in Fig.4.19.

The plots of over-voltages at two open terminals (node no.11 and node no.2) and at an intermediate point (node no.6) on the right of the cable section are shown in Fig.4.20, Fig. 4.22 and Fig.4.21 respectively.

The identical over-voltages at node no. 2 and node no. 11 are more than those for same phases at corresponding nodes 10 and 11 of the system configuration of Study-V.. This is because of the presence of two open terminals (node no.2 and node no. 11) in the form of a bifurcation (fork) at the receiving end of the line section of this study, leading to an increased reflection of the voltage incident at the cable overhead line junction at node no.3 (Fig.4.19).

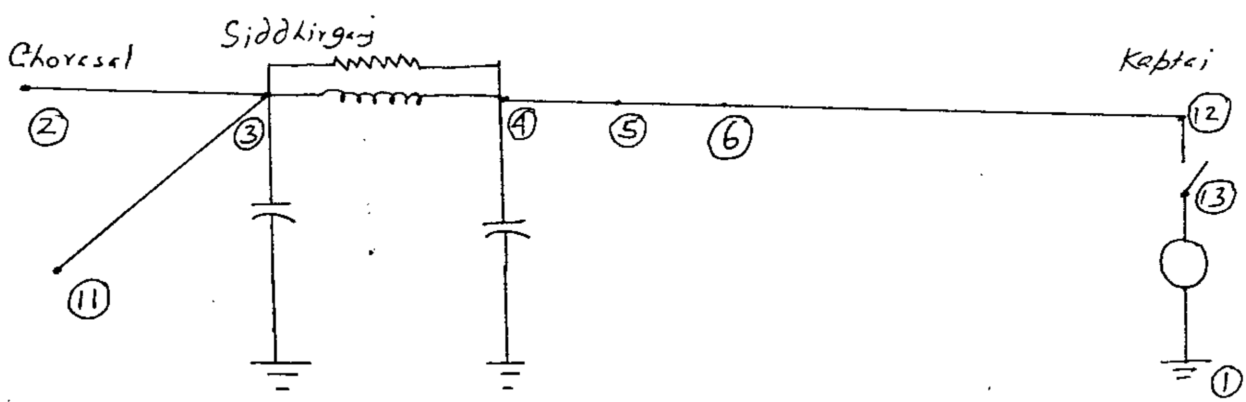


Fig. 4.19. System configuration of Study - VII

System Data: Same as that for system Configuration in Fig. 4.11. (Page. 4-16) of Study - V.

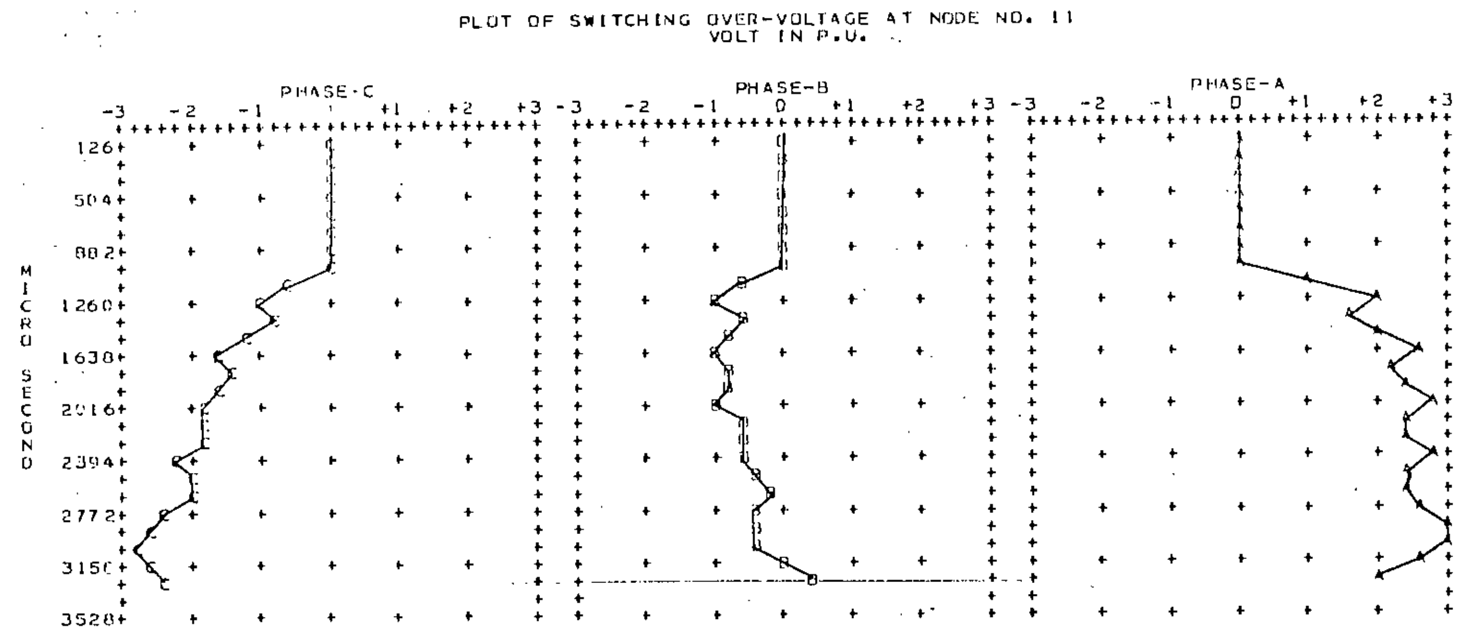


Fig. 4.20. Response at an open terminal (node no.11) of system shown in Fig. 4.19. of Study-VII.

P_OT OF SWITCHING OVER-VOLTAGE AT NODE NO. 6
VOLT IN P.U.

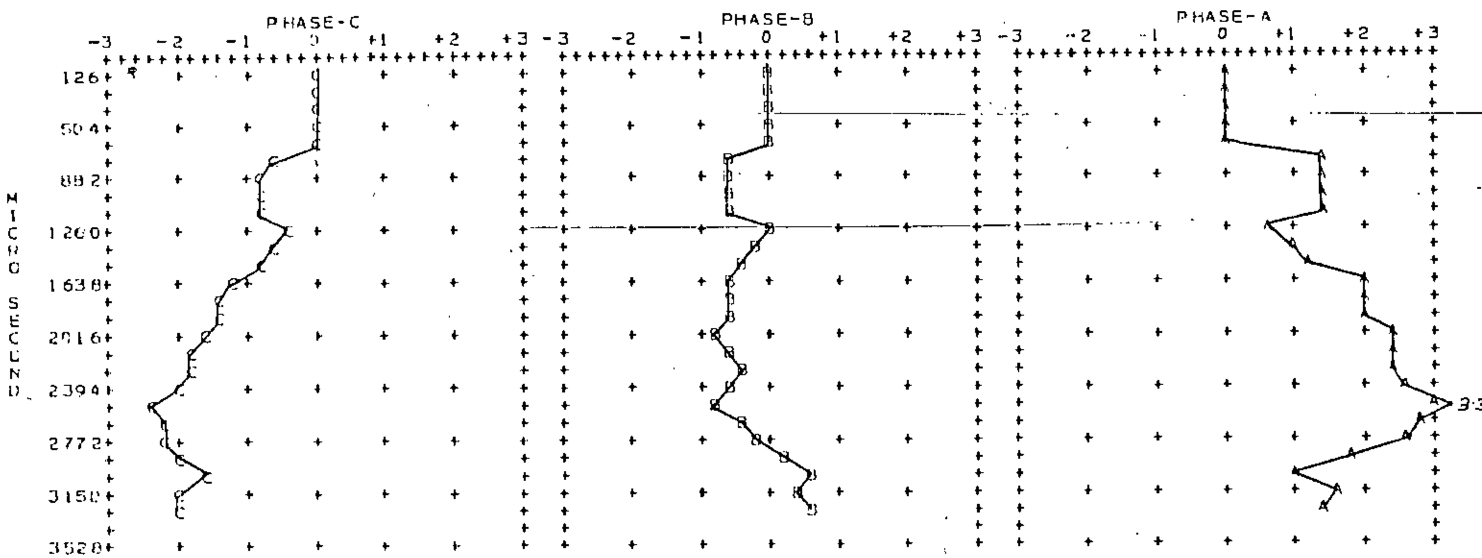


Fig. 4.21. Response at an intermediate node (node no.6) between source end and open receiving end of system shown in Fig.4.19. of Study-VII

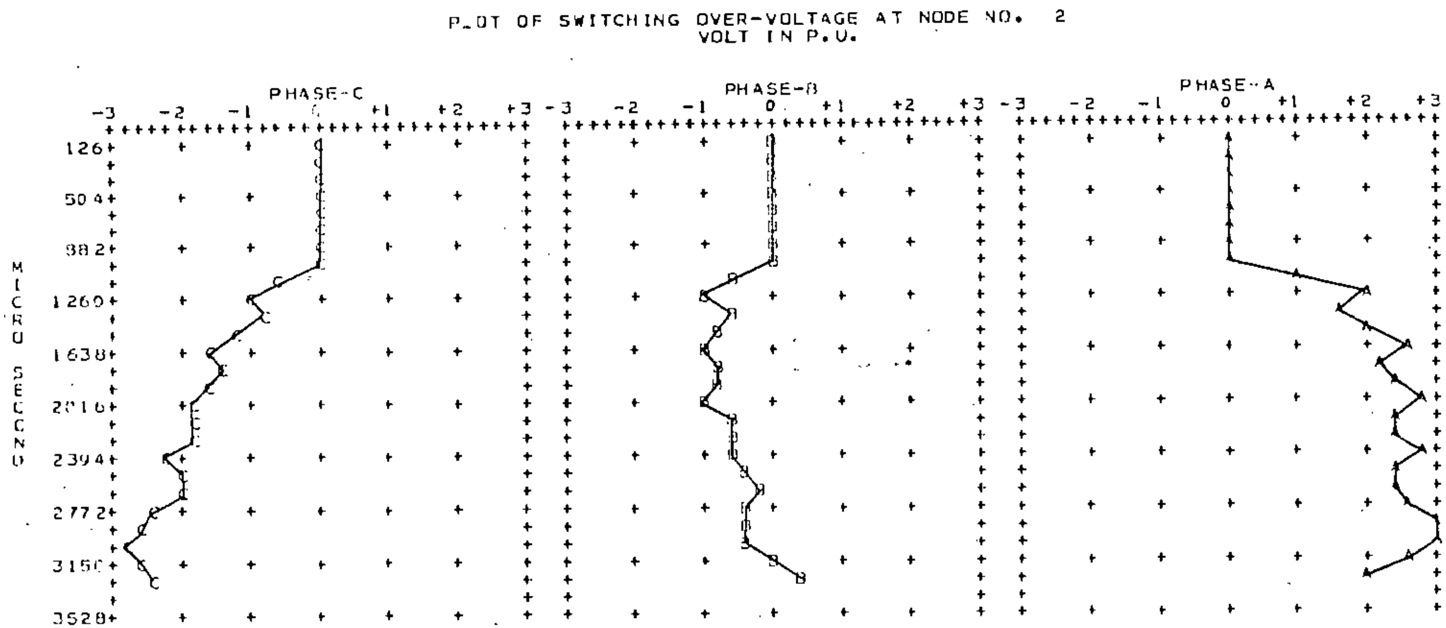


Fig. 4.21 Response at open receiving end (node no.2) of system shown in Fig. 4.19 of Study-VII.

4.2.8 Study-VIII

The system shown in Fig. 4.23 and considered by this study is Goalpara-Ishurdi-Thakurgaon transmission line of West grid BPDB which was in relaxed condition before its energisation from Ghorasal through East-West interconnector. The total length of line was divided into 11 segments of travel time 195 micro seconds (37.0 miles) each.

Over-voltages were plotted at both the open ends (node nos. 2 and 10) as shown in Fig. 4.24 and Fig. 4.25 respectivly. The wave shapes can be explained in the same way as in section 4.2.7 because of the presence of a bifurcated line at Ishurdi (node no.7).

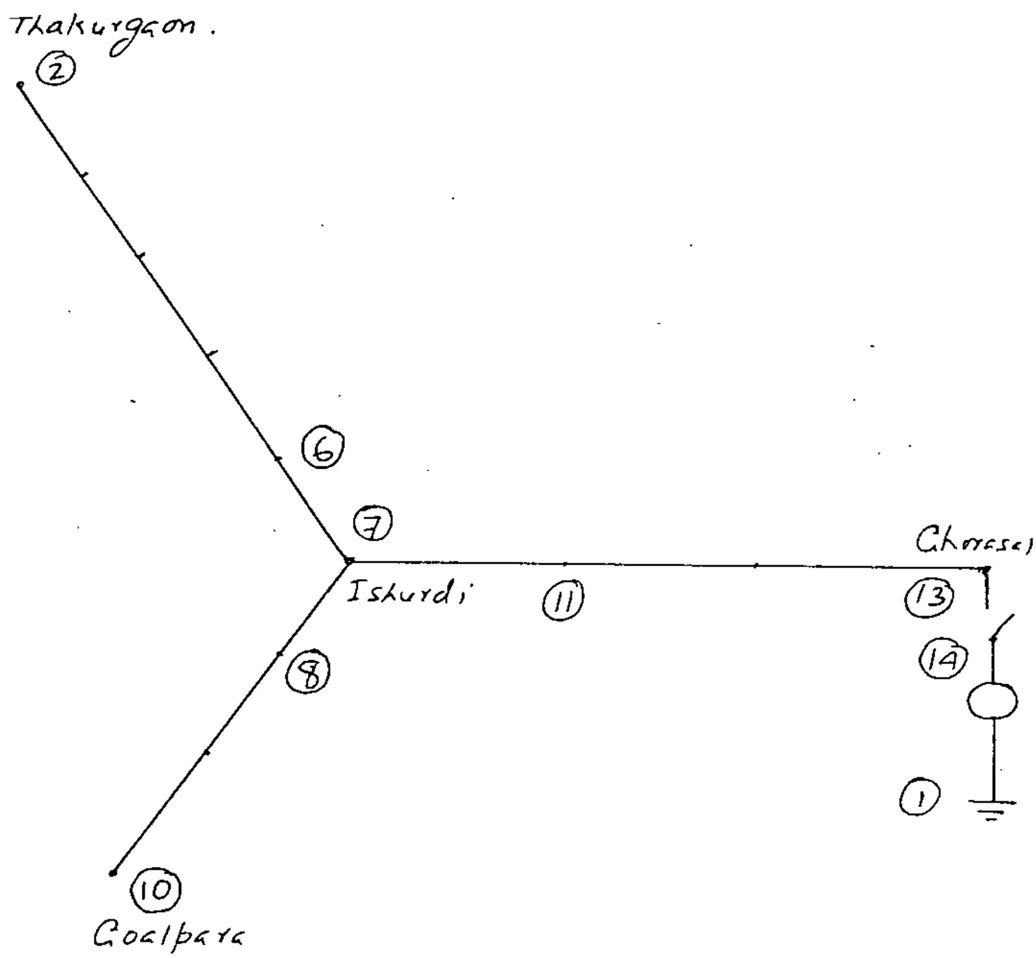


Fig. 4.23. System configuration of Study-VIII

System base data: 132 kV, 100 MVA, 174.24 ohms.

Transmission Line Data:

Resistance per unit length = 0.216 ohms
Inductance per unit length = 2031.8 μH/mile
Capacitance per unit length = .0147 μF/mile
Length of each segment = 37.0 miles
Travel time = 195 μs.

System frequency: 50 Hz.

PLOT OF SWITCHING OVER-VOLTAGE AT NODE NO. 2
VOLT IN P.U.

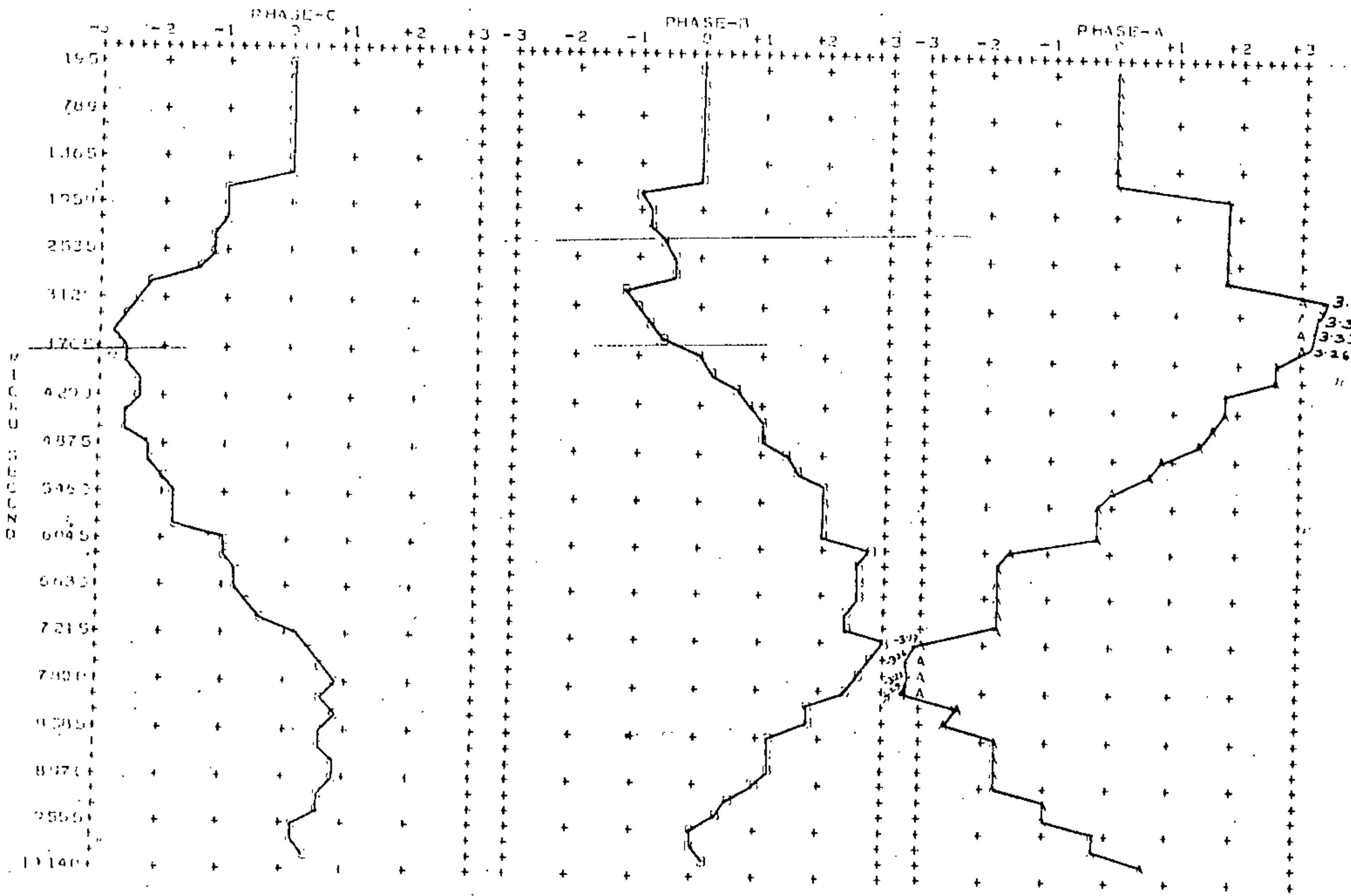


Fig. 4.24. Response at an open terminal (node no.2) of an initially relaxed system shown in Fig. 4.23 of Study-VIII.

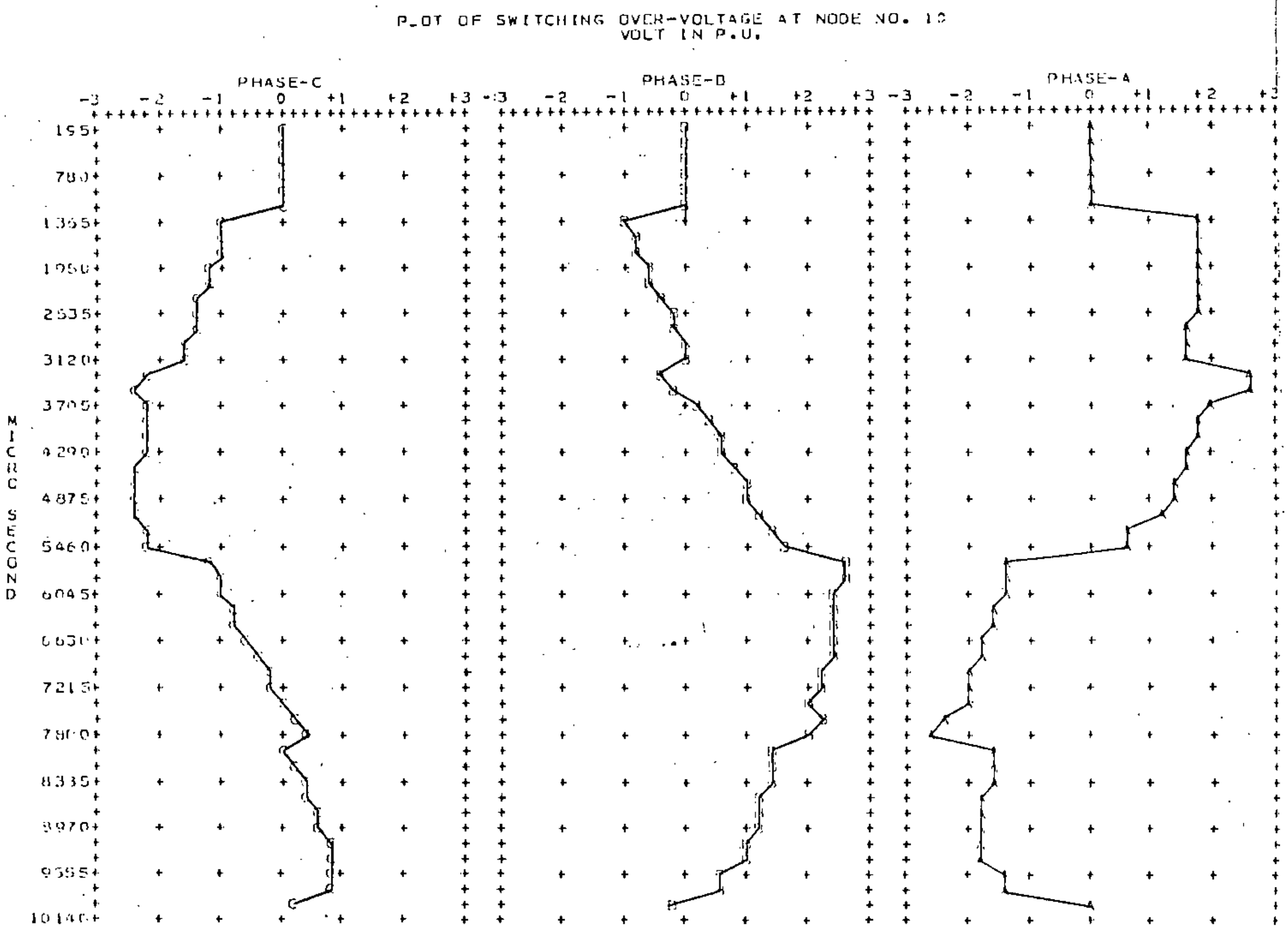


Fig. 4.25. Response at another open terminal (node no.10) of system shown in Fig. 4.23. of Study-VIII.

4.2.9 Study-IX

The system configuration of this study as in Fig.4.26a is same as that of preceding Study-VIII but with two lagging loads connected at Ishurdi and Thakurgaon. Prior to its energisation it was assumed to be in steady state under excitation from Goalpara. A load flow study is performed to obtain the initial conditions on node voltages and internode currents of the system configuration shown in Fig. 4.26b. where the source bus at Goalpara is considered as 'slack bus'.

The plots of over-voltages are provided in Fig. 4.27 and Fig. 4.28.

Due to loaded condition at Thakurgaon (node no.2) the over-voltages were diminished in magnitude as evident from Fig. 4.27 relative to that found by the preceding study. However, the non zero initial voltages caused the over-voltages of phase-A and phase-C at the open end of Goalpara (node no. 10) to be more than those obtained in Study-VIII of section 4.2.8. Even an over-voltage peak as high as 5.8 p.u. has resulted in phase-C as apparent from the plot of Fig. 4.28. This conforms to the view[7] that the magnitude of over-voltage produced depends on the magnitude of the initial voltage trapped on the line and are enhanced when the initial trapped-charge voltage in of opposite polarity. The waveforms of Fig.4.28 obtained with a trapped-charge (initial) voltage of 1.05 p.u. per phase at the node no.10 reveals this fact when compared with the waveforms of Fig. 4.25.

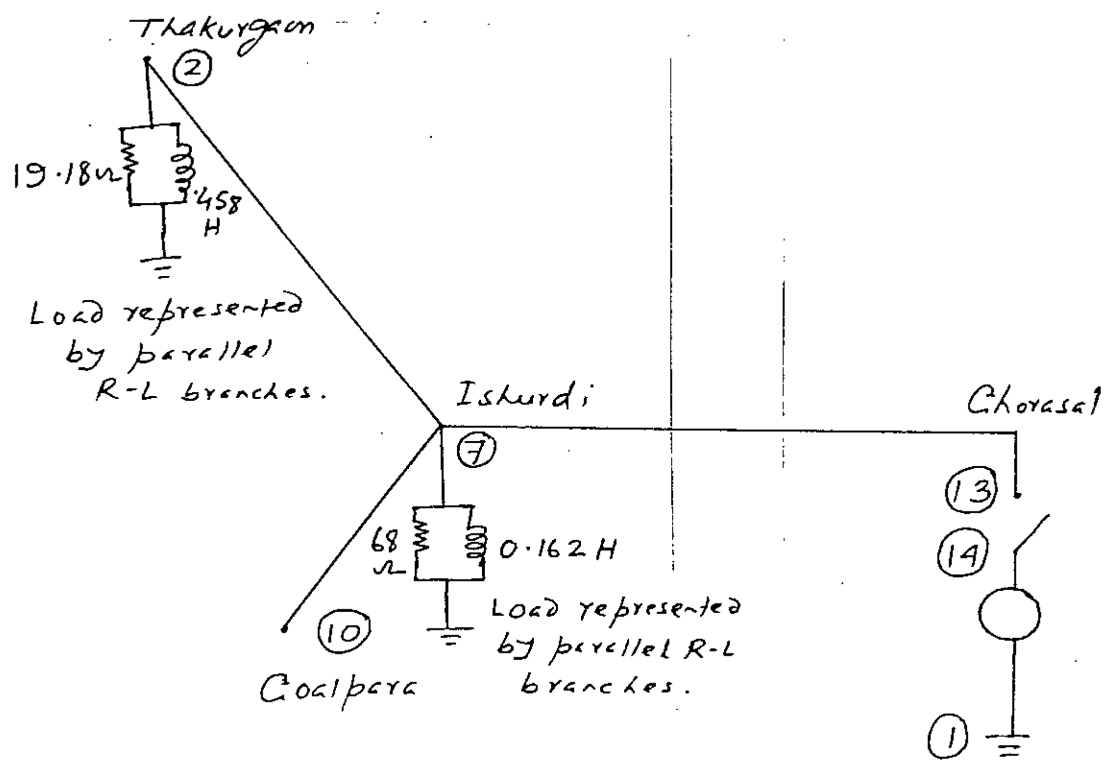


Fig. 4.26 a. System configuration of Study - IX.

System Data: same as for system configuration in Fig. 4.23. (Page 4-31) of Study - VIII.

Load at Ishurdi : 39 + j 29 MVA

Load at Thakurgaon: 11 + j 8.25 MVA

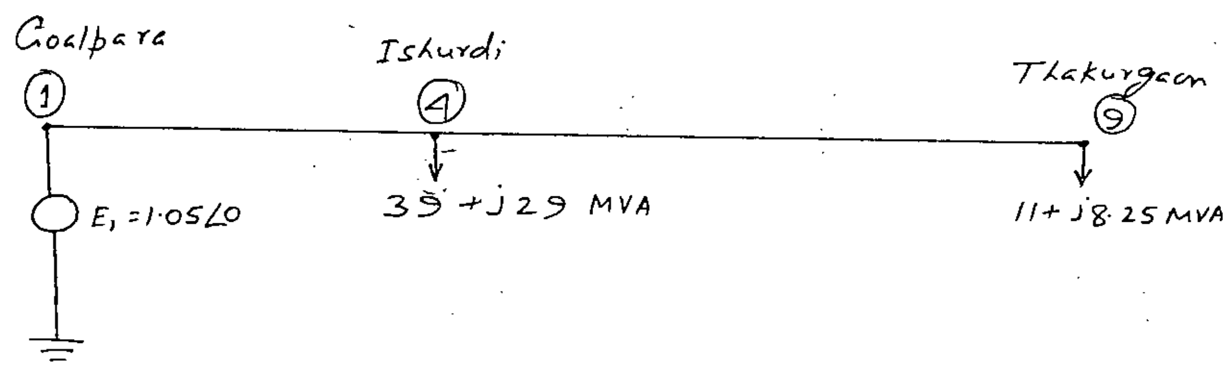


Fig 4.266. System configuration of that in Fig. 4.265 prior to excitation from Ghorasal.

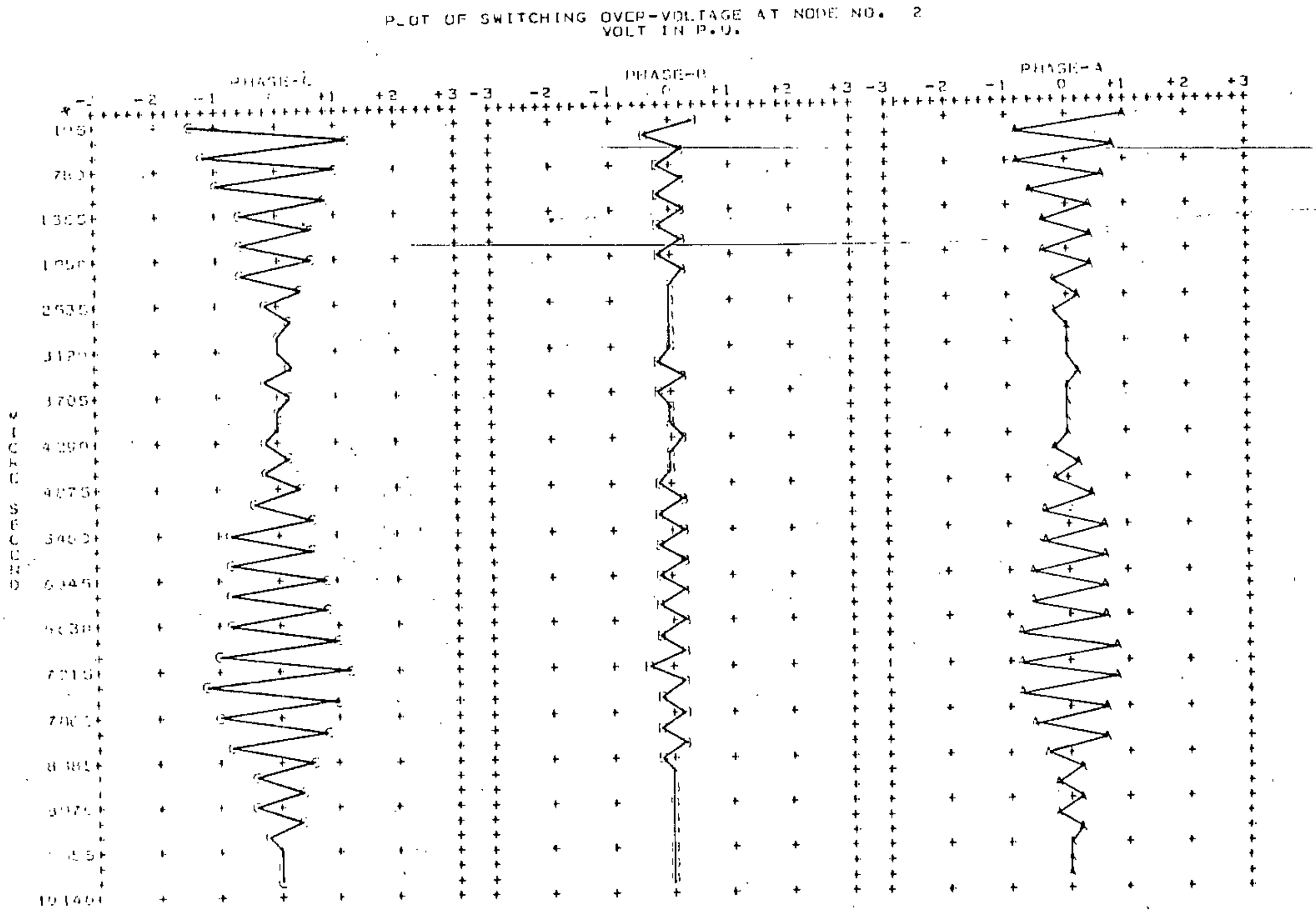


Fig. 4.27. Response at a loaded end (node no.2) of a system initially in steady state, shown in Fig.4.26 of Study-IX

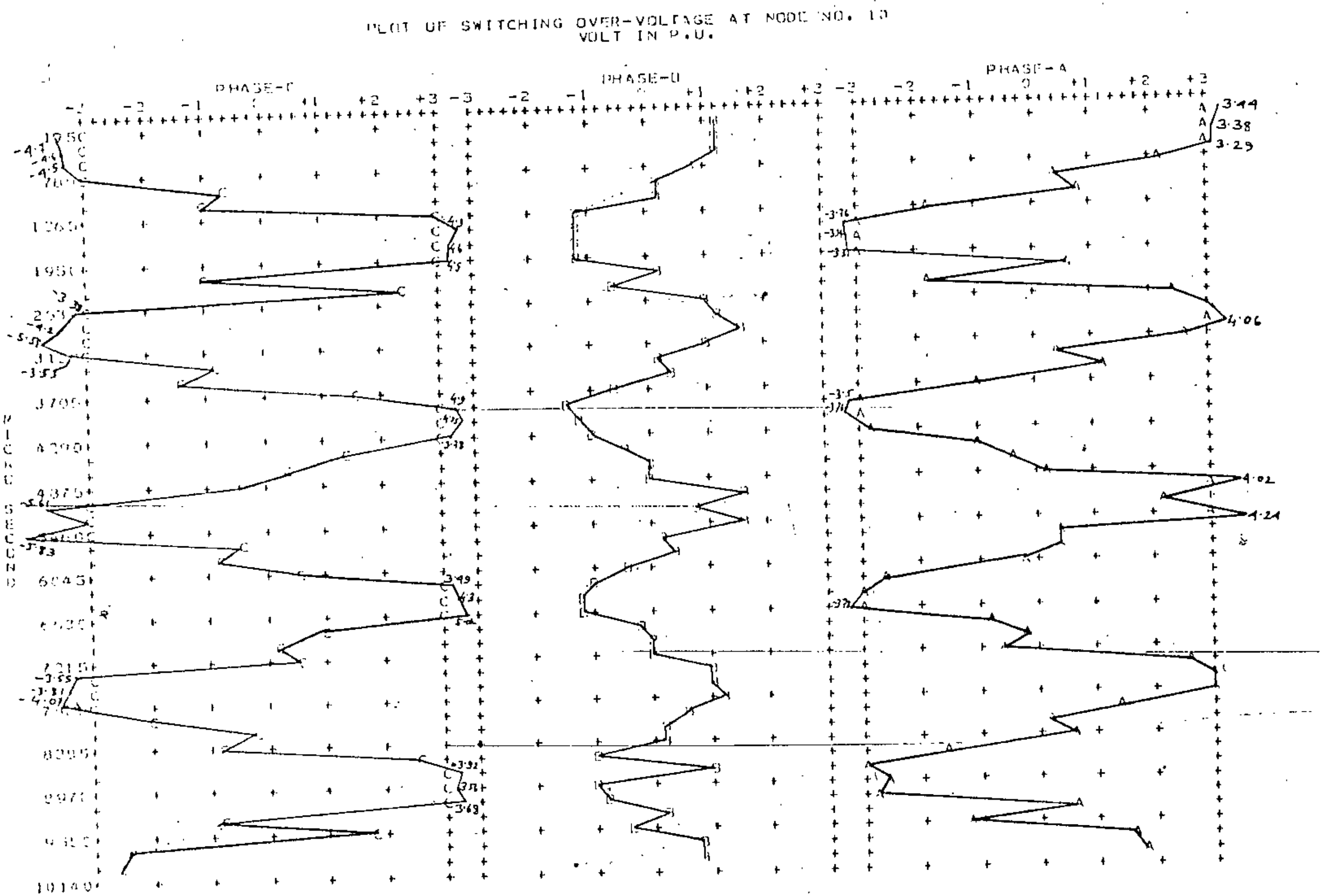


Fig.4.28. Response at open terminal (node no.10) of system shown in Fig. 4.26 of Study-IX.

4.2.10 Study-X

The system shown in Fig. 4.29 in this study comprises the Sylhet-Siddhirganj-Kaptai transmission line section of East grid of BPDB the three phases of which are simultaneously subjected to individual lightning impulses (1/50 μs). Double lightning strokes at an interval of 500 microseconds are considered to be incident at Sylhet end. The whole line was divided into 15 segments of 126 μs travel time (24.0 mile) each.

The computer plots in Fig. 4.30 and Fig.4.31 respectively shows over-voltages at an intermediate point (node no.6) and at a nearby open end (node no.16). The maximum peak found is 1.6 p.u. at node no.16.

The same system configuration on single phase and loss-less representation for lightning surge effect by a previous work[5]. But it did not consider the small cable section which would cause severe reflection of the travelling waves. Moreover the representation of the lightning impulse in that work was with a peak of approximately 1.016 p.u. of the base voltage (132 KV rms value). Whereas in this work the impulse peak is referred to the peak value[9-12] of system frequency (50 Hz) voltage (line to neutral) so that in p.u. of system base voltage (132 KV) the same becomes 1.016 X $\sqrt{2}$ p.u. If same reference for lightning impulse peak as in this work were adopted by the said work[5] the magnitude of over-voltages would have been more than that obtained by it without considering line resistances and lumped cable section (1.51 p.u.) at Ghorasal (node no.6 in Fig. 4.29). Then in an indirect way it can be inferred that line resistance has also got an effect in the attenuation of the over-voltage peak to some extent.

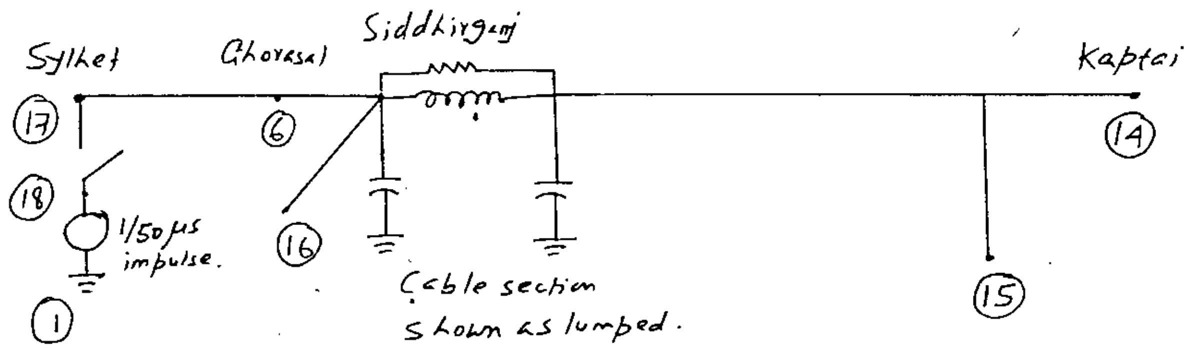


Fig. 4.29. System configuration of Study-X.

System parameters: same as for system configuration in Fig. 4.11 (Page 4-16) of Study-V.

System base data: 132 kV, 100 MVA, 174.24 ohms

PLOT OF LIGHTNING OVER-VOLTAGE AT NODE NO. 6
BASED ON THREE PHASES BEING EQUALLY AFFECTED

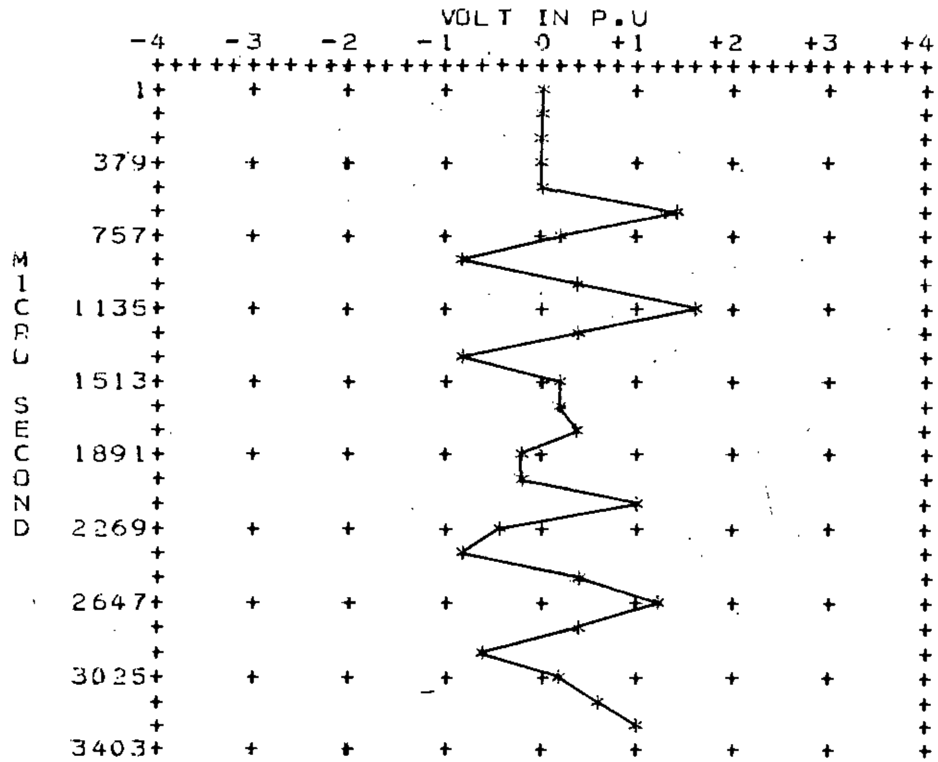


Fig. 4.30. Response at an intermediate node (node no.6) due to lightning surge in system shown in Fig.4.29 of Study-X.

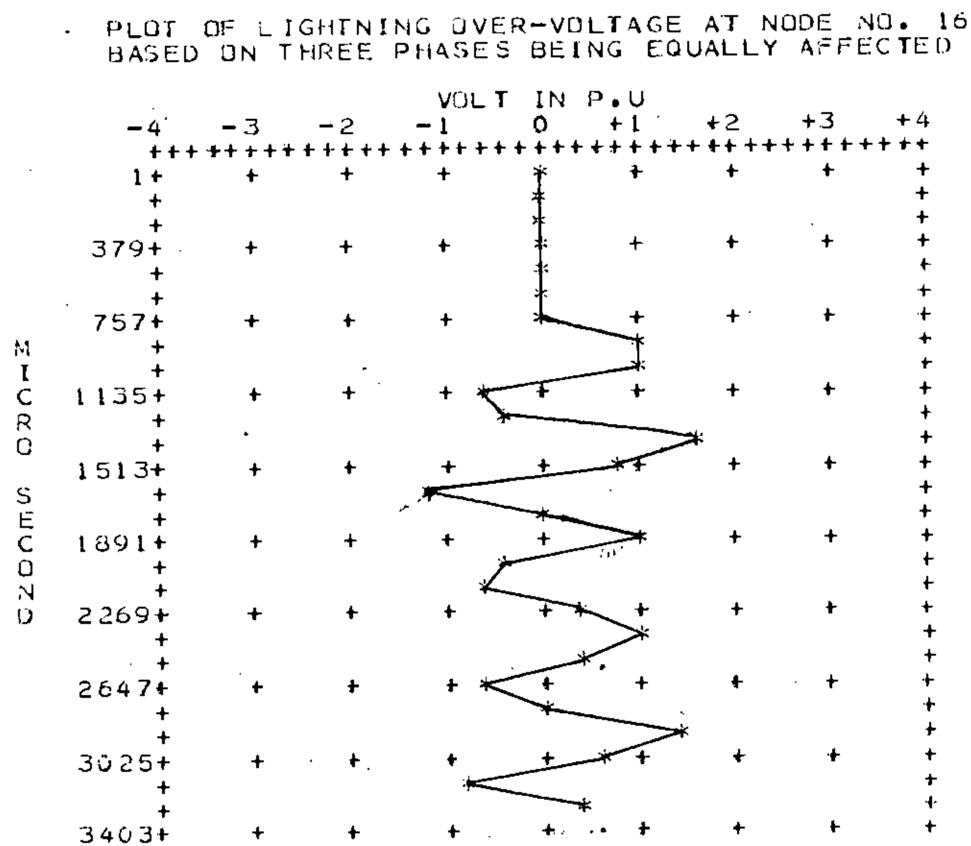


Fig.4.31. Response at an open terminal (node no.16) due to lightning surge in system shown in Fig.4.29 of Study-X.

4.2.11 Study-XI

Study-XI considers the system configuration of Fig. 4.32 which includes Thakurgaon-Mongla 132 KV transmission line of West grid of BPDB subjected to a double lightning stroke at an interval of 500 microseconds at Thakurgaon. The whole line was divided into 16 equal segments of 126 μs travel time (24.0 miles) each.

The open far ends, node no.15 and node no.17 are identified as points for voltage surge build up and plot of over-voltages respectively given in Fig. 4.33 and Fig.434. The maximum over-voltage obtained is 3.0 p.u. at Mongla(node no.15).

A previous work[6] on lightning transients on single phase basis shows an over-voltage of 3.577 p.u. at open end (node no.15) Mongla in the system of Fig. 4.32. In that work line resistance was neglected and also the representation of the lightning impulse was with a peak of approximately 1.016 p.u. of the system base voltage (usually rms value is meant) as discussed in section 4.2.10. This comparison also leads to an inference of the diminishing effect of line resistance on over-voltage peaks.

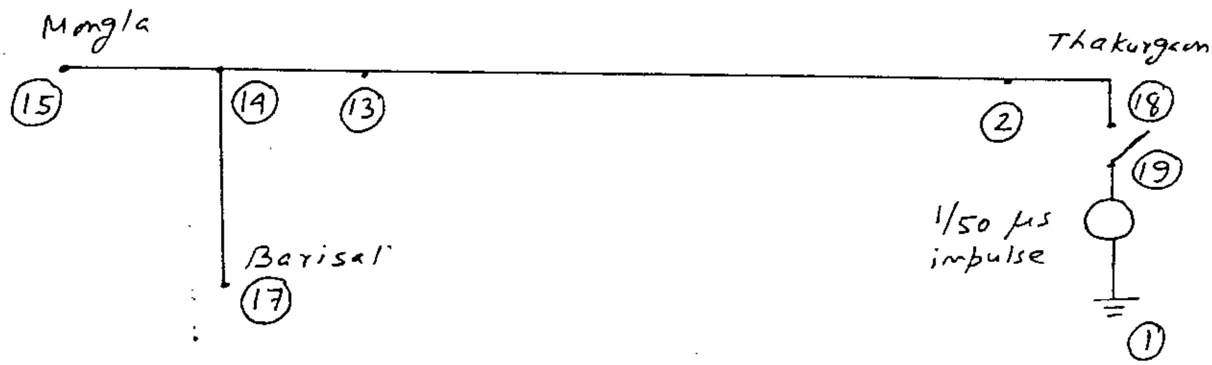


Fig. 4.32. System configuration of Study-XI

System base data: 132 kV, 100 MVA, 174.24 Ohms.

Transmission Line Data: Same as that for system configuration in Fig. 4.23. of Study-VIII. (Page 4-31).

Excepting that, length of each line segment = 24.0 miles.
and, travel time = 126 μs.

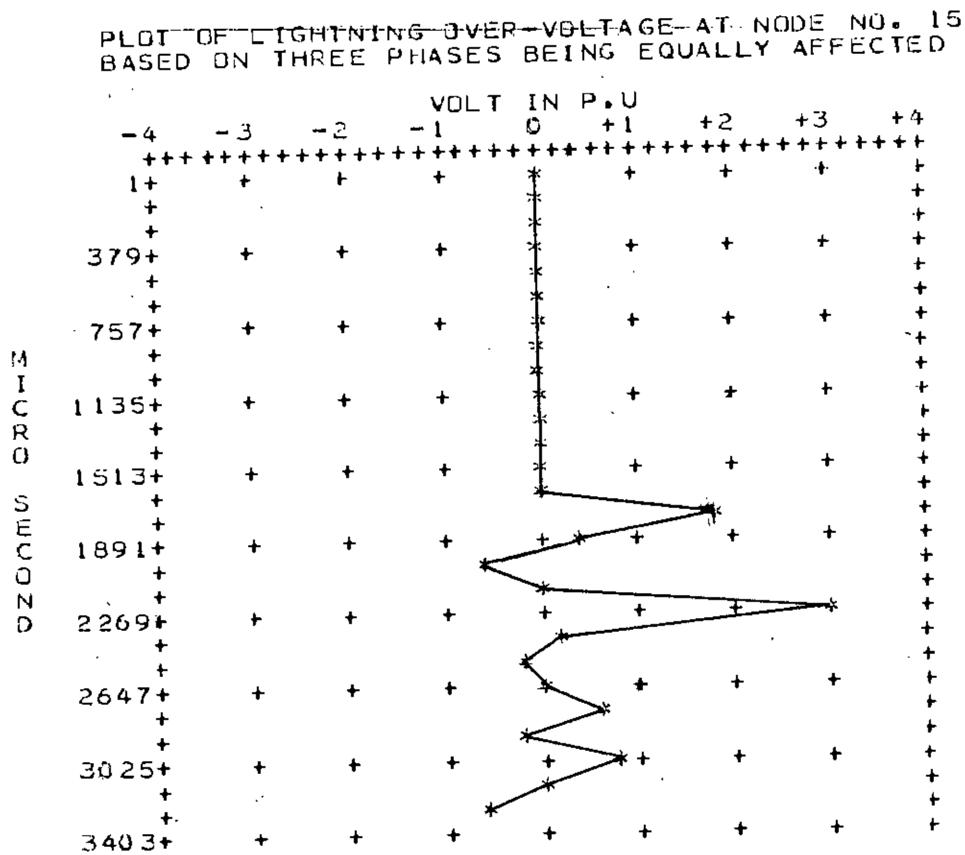


Fig. 4.33. Response at an open terminal (node no.15) due to lightning surge in system shown in Fig. 4.32 of Study-XI.

PLOT OF LIGHTNING OVER=VOLTAGE AT NODE NO. 17
BASED ON THREE PHASES BEING EQUALLY AFFECTED

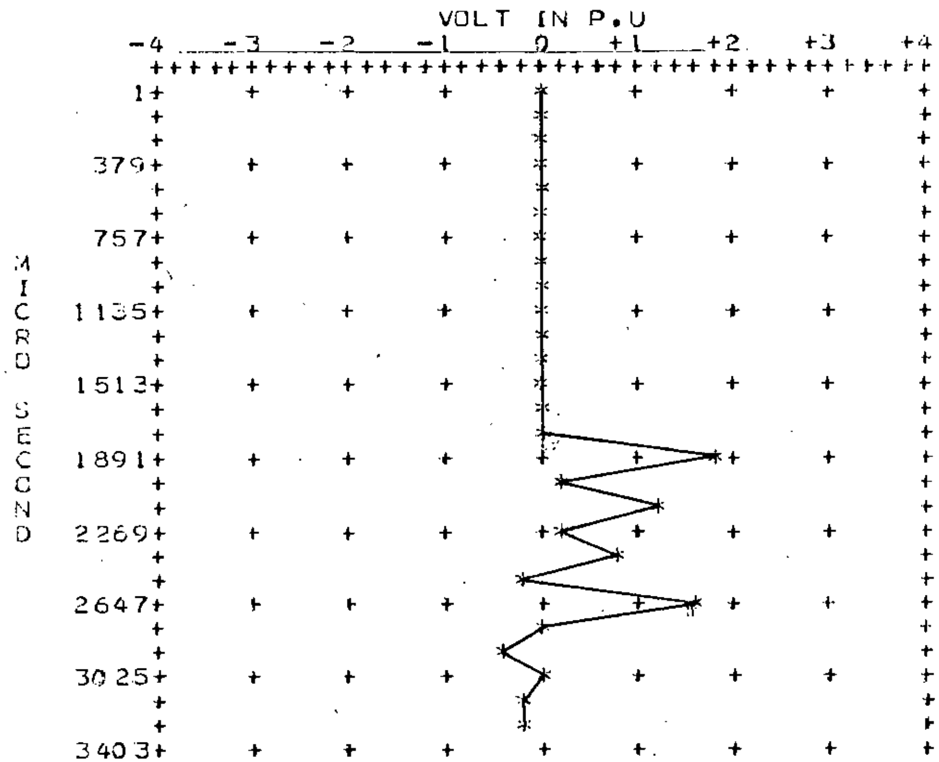


Fig.4.34. Response at another open terminal (node no.17) due to lightning surge in system shown in Fig. 4.32 of Study-XI.

CHAPTER 5

CONCLUSIONS

5.1 Conclusion

The mathematical basis for computation of switching and lightning transient over-voltages in a multiphase lossy power system network using the nodal admittance matrix method together with the method of modal analysis has been explained. Based on the mathematical formulations a computer program has been developed. Also two supporting programs have been developed respectively to obtain initial values of voltage and current in a system in steady state by a load flow study prior to the transient study, and to provide a plot of the over-voltages at selected nodes using data output (results on over-voltages) from the main program.

The response of a number of transmission systems to switching and lightning surges has been described through the use of the developed digital computer programs. The results obtained by the method of this work for some of the sample systems are in close agreement with results found by other works using different methods on the same systems of studies. This verifies the validity of the formulation of the nodal admittance matrix method by this work.

The plots of over-voltages for different system of studies under various operating conditions show that:

(i) The energy dissipation in series line resistances of the transmission line diminishes the over-voltage peak to some extent.

(ii) The mutual coupling between phases of a multiphase system leads to higher voltage transients.

(iii) The switching over-voltages in a system which was initially in steady stage may exceed those when the same was initially relaxed.

5.2 Future Research Area

The emphasis in this work was on technique of handling losses in series resistances of the transmission lines and three phase system network. For designing a more improved and reliable system from transient performance point of view it is suggested that future research works be undertaken in this field. Some of them are:

(i) Application of nodal admittance matrix method combined with transform method and convolution technique[15-19] to incorporate frequency dependence in transient analysis on mulliphase basis.

(ii) Incorporation of the problem of machine (generator) transients, non linear parameters and corona effect.

APPENDICES

A.1 COMPUTER PROGRAM NO. 1

MAIN PROGRAM ON STUDY OF ELECTROMAGNETIC TRANSIENTS

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CCCC  THIS PROGRAM HAS BEEN  DEVELOPED BY S.SHAHNAWAZ AHMED AS REQUIRED
CCC   BY HIS M.SC.ENGINEERING THESIS TITLED ''COMPUTER ANALYSIS OF
CCC   ELECTROMAGNETIC TRANSIENTS IN A MULTIPHASE LOSSY POWER SYSTEM
CCC   NETWORK'' UNDER THE GUIDANCE OF PROFESSOR SYED FAZL-I RAHMAN OF
CCC   ELECTRICAL AND ELECTRONIC ENGINEERING DEPARTMENT.B.U.E.T.IN 1984.
C
CCCC  THE PROGRAM COMPUTES TRANSIENT OVER-VOLTAGES DUE TO SWITCHING AND
CCC   LIGHTNING  IN A THREE PHASE SYSTEM CONSIDERING LOSS DUE TO ITS
CCC   LINE RESISTANCES BY FORMATION OF NODAL CONDUCTANCE MATRIX FOR  THE
CCC   SYSTEM UNDER TRANSIENT CONDITION USING BERGERON'S METHOD OF
CCC   CHARECTERISTIC FOR DISTRIBUTED PARAMETERS AND TRAPRZOIDAL RULE OF
CCC   INTEGRATION FOR LUMPED PARAMETERS.
C
CCCC  INPUT DATA REQUIREMENTS IN SEQUENCE.
CC    1ST DATA SET- COMMON FOR ANY TYPE OF TRANSIENT STUDY.
C     1.1.'ITYPTR'-TYPE OF TRANSIENT STUDY.
C     FOR EXAMPLE-
C     ='000'-FOR SWITCHING TRANSIENT STUDY IRRESPECTIVE OF WAVESHAPE
C             CONSIDERING INITIAL VALUES,PROVIDED AS INPUT DATA.
C     ='001'-FOR STUDY OF SWITCHING TRANSIENTS IRRESPECTIVE OF INPUT
C             WAVESHAPE.BUT ON THE ASSUMPTION OF ZERO INITIAL VALUES.
C     ='002'-FOR STUDY OF LIGHTNING TRANSIENT STUDY ON THE ASSUMPTION
C             OF ZERO INITIAL VALUES THAT IS INITIALLY RELAXED SYSTEM.
C     1.2.'ITOTND'=TOTAL NUMBER OF NODES INCLUDING DATUM NODE(NODE-1).
C     I.3.'NNODSV'=NUMBER OF NODES AT WHICH VOLTAGES ARE SPECIFIED OR
C     KNOWN IN ANY ONE OF THE FORMS VIZ.THREE PHASE SINE OR COSINE WAVE.
C     OR STEP INPUT,OR LIGTNING IMPULSE. THESE NODES REQUIRE TO BE
C     NUMBERED BY HIGHER NUMBERS IN THE PROCESS OF NUMBERING NODES IN AN
C     ASCENDING MANNER.
C     1.4.'IDELT'=TIME STEP IN MICRO SECONDS EQUUAL TO TRAVEL TIME OF
C     EACH OF THE LINE SECTIONS.
C     1.5.'ITMAX'=MAXIMUM TIME UPTO WHICH TRANSIENT STUDY BE PERFORMED
C     STEP BY STEP.
C     1.6.'ALENG'=LENGTH IN MILE COMMON FOR EACH LINE SECTION.
CCCC  2ND SET OF DATA EXCLUSIVELY FOR LIGTNING TRANSIENT SUBROUTINE
CCC   'LTNMOD'.
C     (NUMSTK(I),I=1,NNODSV)-NUMBER OF LIGHTNING STROKES INCIDENT AT
C     I-TH NODE WITH SPECIFIED VOLTAGE THAT IS AMONG 'NNODSV'.
CCCC  2ND SET OF DATA REQUIREMENTS EXCLUSIVELY FOR SWITCHING TRANSIENT
C     STUDY WITH NON ZERO INITIAL VALUES(TYPE='000').
C     (ENODAL(I),I=1,NROW)-INITIAL VOLTAGES AT NODES WHERE TRANSIENT
C     VOLTAGES ARE TO BE DETERMINED.THESE MUST BE IN MODAL VALUE WHICH
C     IS 1.732 TIMES THE PHASE VALUE OBTAINED BY LOAD FLOW STUDY
C     PERFORMED ON THE SYSTEM IN ITS STEADY STATE ON PER PHASE BASIS.
C
CCCC  ANOTHER COMMON DATA SET FOR SWITCHING TRANSIENT(BOTH TYPE '000'
C     AND '001').
C     'NSLNOD'= NUMBER OF SWITCHLESS NODES INCLUDING DATUM NODE (NO.1).
C     SUCH TYPE OF NODES SHOULD HAVE LOWER SERIAL STARTING FROM '1' IN
C     THE PROCESS OF NUMBERING THE NODES.
C     'NNODWS'=NUMBER OF NODES TO WHICH  SWITCHES ARE CONNECTED
C     EXCLUDING SOURCE NODES WITH SPECIFIED VOLTAGES. THEIR SERIAL
C     SHOULD BE IN BETWEEN SWITCHLESS NODES AND NODES WITH SPECIFIED
C     VOLTAGES.
C
CCCC  COMMON DATA REQUIREMENTS FOR ANY TYPE OF TRANSIENT STUDY.
C         'NDATCD'=NUMBER OF DATA CARDS  EACH OF WHICH RELATES TO A
C     BRANCH OR ELEMENT BETWEEN A PAIR OF NODES IN THE SYSTEM OF STUDY.
CC    FOLLOWING DATA (A)THROUGH(D) RELATES TO ANY TYPE OF TRANSIENT
C    STUDY REQUIRING TO BE FURNISHED IN ONE RECOD CORRESPONDING TO ONE
C     PARTICULAR BRANCH.
C     (A).'ITYPBR'='01' IF NO BRANCH EXISTS BETWEEN A PAIR OF NODES.
C     ELSE='02' IF RESISTANCE(LUMPED PARAMETER).
C     ELSE='03'IF INDUCTANCE(LUMPED).
C     ELSE='04' IF CAPACITANCE(LUMPED).
C    ='05' IF TRANSMISSION LINE SECTION(DISTRIBUTED PARAMETER).
C     ELSE='06'IF SWITCH.
C     (B).'NODEK' AND'NODEM'= PAIR OF NODES BETWEEN WHICH A BRANCH IS
C     SPECIFIED.
C     (C).'ZBASE'= CORRESPONDING BASE IMPEDANCE TO WHICH BRANCH
C     PARAMETERS ARE REFFERED.
C     (D).(PRAMET(J),J=1,3))-RESPECTIVELY REFERS TO R.L.C PARAMETERS
C     OF A LINE SECTION.THEIR VALUES BEING FURNISHED IN OHMS PER MILE.
C     MICRO-HENRY PER MILE,AND MICRO-FARAD PER MILE RESPECTIVELY.
C     HOWEVER FOR LUMPED PARAMETERS BETWEEN TWO NODES ONLY R(OHM) OR
C     L(MICRO-HENRY) OR C(MICRO-FARAD) IS REQUIRED TO BE FURNISHED.
C     (E).(ISWSTP(L),L=1,2)- THIS DATA IS REQUIRED ONLY FOR SWITCHING
C     TRANSIENTS. ISWSTP(1) REFERS TO THE TIME STEP IN WHICH THE SWITCH
```

```
C       (IF 'ITYPBR'=06) CLOSES WHILE  ISWSTP(2) REFERS TO THAT IN WHICH
C       THE SWITCH OPENS.
C
CCCC    A NOTE ON LUMPED PARAMETERS.
C       IF THERE BE A RESISTANCE AND A REACTIVE ELEMENT (L OR C) IN
C       PARALLEL BETWEEN A PAIR OF NODES  THAN THE DATA CARD ON THE
C       RESISTANCE SHALL PRECEDE THAT ON THE REACTIVE ELEMENT.
C
CCCC LAST SET OF DATA REQUIREMENTS EXCLUSIVELY FOR SWITCHING TRANSIENT
C       WITH REFERENCE TO NON ZERO INITIAL VALUES('ITYPTR'=00).
C       INITIAL VALUES OF INTERNODE CURRENTS OR CURRENTS THAT WERE FLOWING
C       FROM NODE TO NODE UNDER STEADY STATE CONDITION OF THE SYSTEM.
C       THESE NEED ONE DATA CARD FOR INITIAL CURRENT IN REACTIVE BRANCHES
C       (TYPE=03 AND 04) AND TRANSMISSION LINR SECTIONS(TYPE=05) ONLY.
C       CORRESPONDING DATA'AIKMAL'(INITIAL CURRENT FROM NODES-'K'TO 'M')
C       SHOULD BE INPUT AS 1.732 TIMES THE PHASE VALUE OBTAINED BY LOAD
C       FLOW STUDY AND ALSO WITH DUE REGARD TO SIGN ON ITS FLOW-DIRECTION.
C
CCCC    DIMENSION-THIS PROGRAM PRESENTLY HANDLES A SYSTEM CONSISTING OF
C       20 SWITCHLESS NODES  INCLUDING DATUM (NODE.1).3 SWITCHED NODES AND
C       2 SOURCE NODES(KNOWN VOLTAGES). MORE NODES CAN BE DEALT WITH
C       SIMPLY BY INCREASING THE DIMENSION OF DIFFERENT SUBSCRIPTED
C       VARIABLES OF MAINPROGRAM AND SUBROUTINES. HOWEVER FOLLOWING
C       SUBSCRIPTED VARIABLES (MATRICES) NEED TO BE DIMENSIONED IN
C       SPECIFIED WAYS AS BELOW.
C       'STOREY(I,J)'--TWO DIMENSIONAL MATRIX USED IN SUBROUTINE 'LTNMOD'.
C       WHERE I='ITOTND'.    J=((ITOTND-NNODSV-1)*(ITOTND-NNODSV)/2)+NNODSV.
C
C       THE FOLLOWING MATRICES ARE USED BY SUBROUTINE 'SWITCH'.
C       'STYFAL(I,J)'. WHEN I='NSLNOD'.    J=((NSLNOD-1)*NSLNOD/2)+(NSLNOD*
C       NNODWS)+ITOTND
C       STYSAL(I,J). I=NNODWS.  J=((NSLNOD-1)*NSLNOD)/2)+NSLNOD.
C       YIMAGE(I,J). I=NSLNOD.    J=NNODWS+NNODSV.
C       ICLOSE(I,J). I=NNODWS.  J=NNODSV.
C       'SEREFL(I,J)'. I=NNODWS.   J=NNODWS+NNODSV.
C       'STYVAL(I,J)'. I=NNODWS.     J=NNODWS+NNODSV
C       ISWMOD(I,J,2).   I=NNODWS.   J=NNODSV+NNODWS.
C       ISWSTP(I).   I= 2 (ALWAYS).
C       ISWCH(I,J). I=NNODWS.      J=NNODWS.
        DIMENSION ENDDEA(25),ENODEB(25),ENODEC(25)
        COMMON NROW,NNODSV,ITOTND,IDELT,ITMAX,ITIME,IBRTYP(25,25)
       +/LGHTNG/        PIKMO(25,25),PIDISO(25,25),ENODO(25),YLUMPO(25,25),
       +YDISTO(25,25),HDISTO(25,25)/SWCHNG/PIKMAL(25,25),PIKMBE(25,25),
       +PIDISA(25,25),PIDISB(25,25),HDISTA(25,25),          YLUMPA(25,25),
       +YDISTA(25,25),ENODAL(25),ENODBE(25)
        COMMON        ALENG /LGHTNG/NODVR1,NODVR2
       +           /SWCHNG/NNODWS,NSLNOD,NODVA1,NODVA2,NODVA3,NODVA4,
       +AIKM(25,25)
C
9900    READ(1,1,END=105)ITYPTR,ITOTND,NNODSV,IDELT,ITMAX,ALENG
        WRITE(3,2)
      2 FORMAT('1'5X,'TIME IN MICRO-SEC.'10X,'VOLTAGE AT NODES IN P.U.'/
       +25X,'NODE NO.'3X,'PHASE-A'15X,'PHASE-B'15X,'PHASE-C'//)
C
C
      1 FORMAT(4I3, I8, F10.6)
        NROW=ITOTND-NNODSV
        ITIME=0
        IF(ITYPTR.EQ.0)GO TO 8501
        IF(ITYPTR .EQ.1)GO TO 101
        NODVR1=NROW-1
        NODVR2=((NROW-1)*NROW/2)+NNODSV
        ENODO(1)=0.0
        CALL LTNMOD
C
C
        DO 201 I=1,NROW
        DO 201 J=1,NROW
        PIKMO(I,J)=0.0
        PIDISO(I,J)=0.0
201     CONTINUE
        DO 202 ITIME=     1,ITMAX,IDELT
        CALL LTNMOD
C
C
        DO 203 I=2,NROW
        ENODEA(I)=0.5773502*ENODO(I)
        ENODEB(I)=ENODEA(I)
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      ENODEC(I)=ENODEA(I)
      WRITE(3,3)ITIME,I,ENODEA(I),ENODEB(I),ENODEC(I)
    3 FORMAT(10X,I8,10X,I3,3(5X,F17.12))
      DO 203 J=1,NROW
      IF (J.NE.I)GO TO 1101
      GO TO 1102
 1101 IF (J.LE.I)GO TO 203
C
C
 1102 IBR=IBRTYP(I,J)
      GO TO (203,203,102,103,104,203),IBR
  102 AIJT=PIKMO(I,J)+YLUMPO(I,J)*(ENODO(I)-ENODO(J))
      PIKMO(I,J)=PIKMO(I,J)+2*YLUMPO(I,J)*(ENODO(I)-ENODO(J))
      PIKMO(J,I)=-PIKMO(I,J)
C
C
      GO TO 203
  103 AIJT=PIKM (I,J)+YLUMPO(I,J)*(ENOD (I)-ENODO(J))
      PIKMO(I,J)=-PIKMO(I,J)-2*YLUMPO(I,J)*(ENODO(I)-ENODO(J))
      PIKMO(J,I)=-PIKMO(I,J)
C
      GO TO 203
  104 AIJT=ENODO(I)*YDISTO(I,J)+PIDISO(I,J)
      AJIT=ENODO(J)*YDISTO(I,J)+PIDISO(J,I)
      PIIDSO=      -ENODO(J)*YDISTO(I,J)-AJIT
      PIJDSO=      -ENODO(I)*YDISTO(I,J)-AIJT
      PIDISO(I,J)=((1+HDISTO(I,J))/2)*PIIDSO+      ((1-HDISTO(I,J))/2)*
     +PIJDSO
      PIDISO(J,I)=((1+HDISTO(I,J))/2)*PIJDSO+      ((1-HDISTO(I,J))/2)*
     +PIIDSO
C
C
  203 CONTINUE
  202 CONTINUE
      GO TO 9003
 8501 READ(1,8502)(ENODAL(I),I=1,NROW)
    4 FORMAT(2I3)
  101 READ(1,4)NSLNOD,NNODWS
      NODVA1=NSLNOD-1
      NODVA2=NNODWS+NNODSV
      NODVA3=(NSLNOD*(NSLNOD-1)/2)
      NODVA4=((NSLNOD-1)*NSLNOD/2)+NSLNOD*NNODWS+NNODSV
      ENODAL(1)=0.0
      ENODBE(1)=0.0
      CALL SWITCH
 8502 FORMAT(8F10.5)
C
      DO 206 I=1,NROW
      DO 206 J=1,ITOTND
      PIKMAL(I,J)=0.0
      PIKMBE(I,J)=0.0
      PIDISA(I,J)=0.0
      PIDISB(I,J)=0.0
  206 CONTINUE
      IF(ITYPTR .EQ.0)GO TO 8504
      GO TO 8503
 8504 DO 8505 I =1,NROW
      DO 8505 J=1,ITOTND
      IF(J.LE.I)GO TO 8505
      IBR=IBRTYP(I,J)
      GO TO(8505,8505,8506,8506,8507,8505),IBR
 8506 READ(1,8502)AIKMAL
      AIKM(I,J)=AIKMAL
      PIKMAL(I,J)=AIKM(I,J)-YLUMPA(I,J)*(ENODAL(I)-ENODAL(J))
      PIKMAL(J,I) =-PIKMAL(I,J)
      PIKMBE(I,J) =PIKMAL(I,J)
      PIKMBE(J,I)=-PIKMBE(I,J)
      GO TO 8505
 8507 READ(1, 8502)AIKMAL
      AIKM(1,J)=AIKMAL
      AIKM(J,I) = -AIKM(I,J)
      PIDISA(I,J)=AIKM(J,I)-YDISTA(I,J)*ENODAL(J)
      PIDISA(J,I)=AIKM(I,J)-YDISTA(I,J)*ENODAL(I)
      PIDISB(I,J)=PIDISA(I,J)
      PIDISB(J,I)=PIDISA(J,I)
 8505 CONTINUE
C
C
```

```
C
8503  DO 204 ITIME=IDELT,ITMAX,IDELT
      CALL SWITCH
      DO 205 I=2,NROW
C     THE FOLLOWING TWO  STATEMENTS  APPLY EXCLUSIVELY FOR STEP INPUT
C     AND 'C' IN COL.1. OF THOSE SHOULD BE OMITTED WHILE DEALING WITH
C     STEP INPUT.BUT SIMILAR STATEMENTS AS FOLLOWS FOR 3- PHASE
C     SINUSOIDAL  INPUT SHOULD BE MADE INEFFECTIVE BY PUTTING 'C' IN COL.1
C     ENODEA(I)=ENODAL(I)
C     WRITE(3,3)ITIME, I,ENODEA(I)
C     THE FOLLOWING 4 CONSECUTIVE STATEMENTS APPLY  EXCLUSIVELY TO
C     3-PHASE SINUSOIDAL INPUT.
C
C
      ENODEA(I)=0.8164965*ENODAL(I)
      ENODEB(I)=-0.4082482*ENODAL(I)+0.7071067*ENODBE(I)
      ENODEC(I)=-0.4082482*ENODAL(I)-0.7071067*ENODBE(I)
      WRITE(3,3)ITIME,I,ENODEA(I),ENODEB(I),ENODEC(I)
      DO 205 J=1,ITOTND
      IF(J.NE.1)GO TO 1108
      GO TO 1109
1108  IF(J.LE.I)GO TO 205
C
C
1109  IBR=IBRTYP(I,J)
      GO TO(205,205,106,107,108,205),IBR
106   AIJTA=PIKMAL(I,J)+YLUMPA(I,J)*(ENODAL(I)-ENODAL(J))
      PIKMAL(I,J)=  PIKMAL(I,J)+2*YLUMPA(I,J)*(ENODAL(I)-ENODAL(J))
      PIKMAL(J,I)=-PIKMAL(I,J)
      AIJTB=PIKMBE(I,J)+YLUMPA(I,J)*(ENODBE(I)-ENODBE(J))
      PIKMBE(I,J)=PIKMBE(I,J)+2*YLUMPA(I,J)*(ENODBE(I)-ENODBE(J))
      PIKMBE(J,I)=-PIKMBE(I,J)
C
C
      GO TO 205
107   AIJTA=PIKMAL(I,J)+YLUMPA(I,J)*(ENODAL(I)-ENODAL(J))
      PIKMAL(I,J)=-PIKMAL(I,J)-2*YLUMPA(I,J)*(ENODAL(I)-ENODAL(J))
      PIKMAL(J,I)=-PIKMAL(I,J)
      AIJTB=PIKMBE(I,J)+YLUMPA(I,J)*(ENODBE(I)-ENODBE(J))
      PIKMBE(I,J)=-PIKMBE(I,J)-2*YLUMPA(I,J)*(ENODBE(I)-ENODBE(J))
      PIKMBE(J,I)=-PIKMBE(I,J)
C
      GO TO 205
108   AIJTA=ENODAL(I)*YDISTA(I,J)+PIDISA(I,J)
      AJITA=ENODAL(J)*YDISTA(I,J)+PIDISA(J,I)
      PIIDSO=      -ENODAL(J)*YDISTA(I,J)-AJITA
      PIJDSO=      -ENODAL(I)*YDISTA(I,J)-AIJTA
      PIDISA(I,J)=((1+HDISTA(I,J))/2)*PIIDSO+       ((1-HDISTA(I,J))/2)*
     +PIJDSO
      PIDISA(J,I)=((1+HDISTA(I,J))/2)*PIJDSO+       ((1-HDISTA(I,J))/2)*
     +PIIDSO
      AIJTB=ENODBE(I)*YDISTA(I,J)+PIDISB(I,J)
      AJITB=ENODBE(J)*YDISTA(I,J)+PIDISB(J,I)
      PIIDSO=      -ENODBE(J)*YDISTA(I,J)-AJITB
      PIJDSO=      -ENODBE(I)*YDISTA(I,J)-AIJTB
      PIDISB(I,J)=((1+HDISTA(I,J))/2)*PIIDSO+       ((1-HDISTA(I,J))/2)*
     +PIJDSO
      PIDISB(J,I)=((1+HDISTA(I,J))/2)*PIJDSO+((1-HDISTA(I,J))/2)*PIIDSO
C
205   CONTINUE
204   CONTINUE
      GO TO 9000
105   STOP
      END
```

A.1.1 SUBROUTINE ON LIGHTNING TRANSIENTS

```
      SUBROUTINE  LTNMOD
      COMMON NROW,NNODSV,  ITOTND,IDELT,ITMAX,ITIME,IBRTYP(25,25)
     +/LGHTNG/        PIKMO(25,25),PIDISO(25,25),ENODO(25),YLUMPO(25,25),
     +YDISTO(25,25),HDISTO(25,25),NODVR1,NODVR2
      COMMON  ALENG
      DIMENSION  PRAMET(3),NUMSTK(25),TOTI(25),STOREY(25,280)
      ELSTRK(ATIME)=1.0166702*(EXP(-0.0141936*ATIME)-EXP(-6.0730104*
     +ATIME))
      ELITN(ATIME)=1.0166702*(EXP(-0.0141936*ATIME))
C
      IF(ITIME.NE.0)GO TO 100
      READ(1,2)(NUMSTK(I),I=1,NNODSV)
      READ(1,1)    NDATCD
C
C
      DO 200  I=2,ITOTND
      DO 200  J=1,ITOTND
      YLUMPO(I,J)=0.0
      YDISTO(I,J)=0.0
      HDISTO(I,J)=0.0
200   IBRTYP(I,J)=1
      DO 201  I=1,NDATCD
      READ(1,1)ITYPBR,NODEK,NODEM,ZBASE,(PRAMET(J),J=1,3)
C
1     FORMAT(3I2,4E10.6)
      IBRTYP(NODEK,NODEM)=ITYPBR
      IBRTYP(NODEM,NODEK)=ITYPBR
      GO TO (201,101,102,103,104,150),ITYPBR
101   YLUMPO(NODEK,NODEM)=(1/PRAMET(1))*ZBASE+YLUMPO(NODEK,NODEM)
      YLUMPO(NODEM,NODEK)=YLUMPO(NODEK,NODEM)
      GO TO 201
102   YLUMPO(NODEK,NODEM)=(IDELT/( PRAMET(1)*2))*ZBASE+YLUMPO(NODEK,
     +NODEM)
      YLUMPO(NODEM,NODEK)=YLUMPO(NODEK,NODEM)
      GO TO 201
103   YLUMPO(NODEK,NODEM)=(2*PRAMET(1)*ZBASE)/IDELT+YLUMPO(NODEK,NODEM)
      YLUMPO(NODEM,NODEK)=YLUMPO(NODEK,NODEM)
      GO TO 201
104   YDISTO(NODEK,NODEM)=(1/((SQRT(PRAMET(2)/ PRAMET(3)))+((PRAMET(1)*
     +ALENG)/4)))*ZBASE
      YDISTO(NODEM,NODEK)=YDISTO(NODEK,NODEM)
      HDISTO(NODEK,NODEM)=((1/YDISTO(NODEK,NODEM))-(PRAMET(1)*ALENG)/(4*
     +ZBASE))/((1/YDISTO(NODEK,NODEM))+(PRAMET(1)*ALENG)/(4*ZBASE))
      HDISTO(NODEM,NODEK)=HDISTO(NODEK,NODEM)
      GO TO 201
150   YLUMPO(NODEK,NODEM)=1000.00
      YLUMPO(NODEM,NODEK)=1000.00
201   CONTINUE
      LOCVAR=NROW-1
      LOCCV=(NROW*(NROW-1))/2
      DO 202  IPIVOT=1,NROW
C
C
      ISUMPD=0
      IDIFF=IPIVOT-1
      IDIFF1=IDIFF-1
      IF (IDIFF1)105,105,106
106   DO 203 LL =1,IDIFF1
203   ISUMPD=ISUMPD+LL
105   INDEX=IDIFF*LOCVAR-ISUMPD
      IF (IPIVOT.NE.1)GO TO 107
      DO 212 I=2,NROW
      DUMSTR=YLUMPO(I,1)
      DO 204 J=2,ITOTND
      IF (J.EQ.1)GO TO 108
      IF (J.GT.NROW)GO TO 109
      ICOL1=INDEX+J-IPIVOT
      GO TO 110
109   ICOL1=LOCCV+J-NROW
110   STOREY(I-1,ICOL1)=-YLUMPO(I,J)
C
C
      GO TO 111
108   ICOL2=INDEX+J-IPIVOT
      GO TO 204
111   DUMSTR=DUMSTR+YLUMPO(I,J)+YDISTO(I,J)
C
C
```

```
204     CONTINUE
212     STOREY(I-1,ICOL2)=DUMSTR
C
C
        INDXPR=INDEX
        GO TO 202
107     DO 205 J=2,ITOTND
        IF(J-IPIVOT)205,205,122
122     IF(J.GT.NROW)GO TO 112
        ICOL1=INDEX+J-IPIVOT
        ICOLPR=INDXPR+J-(IPIVOT-1)
        GO TO 113
112     ICOL1=LOCCV+J-NROW
        ICOLPR=LOCCV+J-NROW
113     ICOLPV=INDXPR+1
        STOREY(IPIVOT-1,ICOL1)=STOREY(IPIVOT-1,ICOLPR)/STOREY(IPIVOT-1,
       +ICOLPV)
C
C
205     CONTINUE
        DO 206 I=2,NROW
        IF(I.EQ.IPIVOT)GO TO 206
        DO 206 J=2,ITOTND
        IF(J-IPIVOT)206,206,115
115     IF(J.GT.NROW)GO TO 116
        ICOL1=INDEX+J-IPIVOT
        ICOLPR=INDXPR+J-(IPIVOT-1)
        GO TO 117
116     ICOL1=LOCCV+J-NROW
        ICOLPR=ICOL1
117     ICOLPV=INDXPR+1
        STOREY(I-1,ICOL1)=STOREY(I-1,ICOLPR)-STOREY(I-1,ICOLPV)*STOREY
       +(IPIVOT-1,ICOL1)
C
C
206     CONTINUE
        INDXPR=INDEX
202     CONTINUE
C
2       FORMAT(10I2)
        DO 207 I=1,NNODSV
207     NUMSTK(I)=NUMSTK(I)-1
        RETURN
100     DO 208 I=1,NNODSV
        KI =NROW+I
        ZTIME=ITIME
        TESTSW=0.0
1204    IF((ZTIME*6.0730104).LT.160.0)GO TO 1201
        IF((ZTIME*.0141936).LT.160.0)GO TO 1202
        GO TO 1207
1201    ENODO(KI)=(ELSTRK(ZTIME))*1.7320508*1.4142135
        IF(ENODO(KI).LT.1.E-20)ENODO(KI)=0.0
C
C
        GO TO 1206
1202    ENODO(KI)=(ELITN(ZTIME))*1.7320508*1.4142135
        IF(ENODO(KI).LT.1.E-20)ENODO(KI)=0.0
C
        GO TO 1206
1207    ENODO(KI)=0.0
C
C
1206    IF(TESTSW.EQ.1.0)GO TO 1205
C
        IF (ITIME.GE.500)GO TO 118
        GO TO 208
118     IF(NUMSTK(I).EQ.0)GO TO 208
        ZTIME=ITIME-500
        TESTSW=1.0
        ESTORE=ENODO(KI)
C
C
        GO TO 1204
1205    ENODO(KI)=ENODO(KI)+ESTORE
C
        NUMSTK(I)=NUMSTK(I)-1
208     CONTINUE
        DO 209 I=2,NROW
```

```
      TOTI(I)=0.0
      DO 209 J=1,NROW
209   TOTI(I)=TOTI(I)-PIDISO(I,J)-PIKMO(I,J)
C
C
      DO 210  IPIVOT=1,NROW
C
C
      ISUMPD=0
      IDIFF=IPIVOT-1
      IDIFF1=IDIFF-1
      IF(IDIFF1)119,119,120
120   DO 211 LL=1,IDIFF1
211   ISUMPD=ISUMPD+LL
119   INDEX=IDIFF*LOCVAR-ISUMPD
      IF(IPIVOT.EQ.1)GO TO 121
      ICOLPV=INDXPR+1
      TOTI(IPIVOT)=TOTI(IPIVOT)/STOREY(IPIVOT-1,ICOLPV)
C
C
C
      DO 299 I=2,NROW
      IF (I.EQ.IPIVOT)GO TO 299
      TOTI(I)=TOTI(I)-STOREY(I-1,ICOLPV)*TOTI(IPIVOT)
C
C
299   CONTINUE
121   INDXPR=INDEX
210   CONTINUE
      DO 275 I=2,NROW
      ENODO(I)=TOTI(I)
C
C
      DO 275 J=1,NNODSV
      KKI=J+NROW
      ICOLI=LOCCV+J
      ENODO(I)=ENODO(I)-STOREY(I-1,ICOLI)*ENODO(KKI)
C
C
275   CONTINUE
      RETURN
      END
```

A.1.2. SUBROUTINE ON SWITCHING TRANSIENTS

```
      SUBROUTINE SWITCH
      COMMON NROW,NNODSV, ITOTND,IDELT,ITMAX,ITIME,IBRTYP(25,25)/SWCHNG/
     +PIKMAL(25,25),PIKMBE(25,25),PIDISA(25,25),PIDISB(25,25),HDISTA(25,
     +25),YLUMPA(25,25),YDISTA(25,25),ENODAL(25),ENODBE(25),NNODWS,
     +NSLNOD,NODVA1,NODVA2,NODVA3,NODVA4,AIKM(25,25)//ALENG
      DIMENSION  STYFAL(20,275),STYSAL(3,193),YIMAGE(20,5),ICLOSE(3,2),
     +SWREFL(3,5),STYVAL(3,5),ISWMOD(3,5,2),          TOTIAL(25),TOTIBE
     +(25),PRAMET(3),ISWSTP(2),ISWCH(3,3)
C     IF INPUT IS SINE WAVE WITH 1.0 P.U. PEAK VALUE FOLLOWING TWO
C     STATEMENTS APPLY.
C     EALPHA(ZTIME)=1.22474487*SIN(ZTIME)
C     EBETA(ZTIME)=-1.22474487*COS(ZTIME)
C     THE FOLLOWING TWO STATEMENTS  APPLY FOR COSINE WAVE INPUT WITH 1.0
C     P.U. R.M.S.VALUE.
      EALPHA(ZTIME)=1.7320508*COS(ZTIME)
      EBETA(ZTIME)=1.7320508*SIN(ZTIME)
      IF(ITIME.NE.0)GO TO 100
      READ(1,1)   NDATCD
      DO 200  I=1,ITOTND
      DO 200  J=1,ITOTND
      YLUMPA(I,J)=0.0
      YDISTA(I,J)=0.0
      HDISTA(I,J)=0.0
200   IBRTYP(I,J)=1
      DO 212  I=1,NNODWS
      DO 212  J=1,NODVA2
      ISWMOD(I,J,1)=0
212   ISWMOD(I,J,2)=0
      DO 201  I=1,NDATCD
      READ(1,1)ITYPBR,NODEK,NODEM,ZBASE,(PRAMET(J),J=1,3),(ISWSTP(L),
     +L=1,2)
      IBRTYP(NODEK,NODEM)=ITYPBR
      IBRTYP(NODEM,NODEK)=ITYPBR
      GO TO (201,101,102,103,104,105),ITYPBR
101   YLUMPA(NODEK,NODEM)=ZBASE/PRAMET(1)+YLUMPA(NODEK,NODEM)
      YLUMPA(NODEM,NODEK)=YLUMPA(NODEK,NODEM)
      GO TO 201
102   YLUMPA(NODEK,NODEM)=IDELT/(2*PRAMET(1)*(1/ZBASE))+YLUMPA(NODEK,
     +NODEM)
      YLUMPA(NODEM,NODEK)=YLUMPA(NODEK,NODEM)
      GO TO 201
103   YLUMPA(NODEK,NODEM)=(2*PRAMET(1))/(IDELT*(1/ZBASE))+YLUMPA(NODEK,
     +NODEM)
      YLUMPA(NODEM,NODEK)=YLUMPA(NODEK,NODEM)
      GO TO 201
104   YDISTA(NODEK,NODEM)=1/((SQRT(PRAMET(2)/PRAMET(3)))+(PRAMET(1)*
     +ALENG)/4)
      YDISTA(NODEK,NODEM)=YDISTA(NODEK,NODEM)*ZBASE
      ZLENG=ALENG/ZBASE
      YDISTA(NODEM,NODEK)=YDISTA(NODEK,NODEM)
      HDISTA(NODEK,NODEM)=((1/YDISTA(NODEK,NODEM))-(PRAMET(1)*ZLENG)/4)
     +/((1/YDISTA(NODEK,NODEM))+(PRAMET(1)*ZLENG)/4)
      HDISTA(NODEM,NODEK)=HDISTA(NODEK,NODEM)
      GO TO 201
105   YLUMPA(NODEK,NODEM)=0.0
      YLUMPA(NODEM,NODEK)=0.0
      K=NODEK-NSLNOD
      M=NODEM-NSLNOD
      ISWMOD(K,M,1)=ISWSTP(1)
      ISWMOD(K,M,2)=ISWSTP(2)
      IF (M.LE.NNODWS)GO TO 4111
      GO TO 201
4111  ISWMOD(M,K,1)=ISWSTP(1)
      ISWMOD(M,K,2)=ISWSTP(2)
201   CONTINUE
      LOCVAR=NROW-1
      LOCCV=(NSLNOD*(NSLNOD-1))/2+NSLNOD*NNODWS
      LOCVR=NSLNOD-1
      DO 202 IPIVOT=1,NSLNOD
      ISUMPD=0
      IDIFF=IPIVOT-1
      IDIFF1=IDIFF-1
      IF(IDIFF1)108,108,109
109   DO 203 LL=1,IDIFF1
203   ISUMPD=ISUMPD+LL
108   INDEX2=IDIFF*LOCVR-ISUMPD
      INDEX1=IDIFF*LOCVAR-ISUMPD
      IF(IPIVOT.NE.1)GO TO 110
```

```
      DO 206 I=2,NROW
      DUMSTR=YLUMPA(I,1)
      IF(I.GT.NSLNOD)GO TO 115
      DO 204 J=2,ITOTND
      IF (J.EQ.I)GO TO 111
      IF (J.GT.NROW)GO TO 112
      ICOL1=INDEX1+J-IPIVOT
      GO TO 113
112   ICOL1=LOCCV+J-NROW
113   STYFAL(I-1,ICOL1)=-YLUMPA(I,J)
      GO TO 114
111   ICOL2=INDEX1+J-IPIVOT
      GO TO 204
114   DUMSTR=DUMSTR+YLUMPA(I,J)+YDISTA(I,J)
204   CONTINUE
      STYFAL(I-1,ICOL2)=DUMSTR
      GO TO 206
115   II=I-NSLNOD
      DO 205 J=2,NSLNOD
      ICOL1=INDEX2+J-IPIVOT
      STYSAL(II,ICOL1)=-YLUMPA(I,J)
205   CONTINUE
206   CONTINUE
      INDXP1=INDEX1
      INDXP2=INDEX2
      GO TO 202
110   DO 207 J=2,ITOTND
      IF(J-IPIVOT)207,207,118
118   IF(J.GT.NROW)GO TO 119
      ICOL1=INDEX1+J-IPIVOT
      ICOLPR=INDXP1+J-(IPIVOT-1)
      GO TO 120
119   ICOL1=LOCCV+J-NROW
      ICOLPR=ICOL1
120   ICOLPV=INDXP1+1
      STYFAL(IPIVOT-1,ICOL1)=STYFAL(IPIVOT-1,ICOLPR)/STYFAL(IPIVOT-1,
     +ICOLPV)
207   CONTINUE
      DO 208 I=2,NROW
      IF(I.EQ.IPIVOT)GO TO 208
      IF(I.GT.NSLNOD)GO TO 121
      DO 209 J=2,ITOTND
      IF(J-IPIVOT)209,209,122
122     IF(J.GT.NROW)GO TO 123
      ICOL1=INDEX1+J-IPIVOT
      ICOLPR=INDXP1+J-(IPIVOT-1)
      GO TO 124
123   ICOL1=LOCCV+J-NROW
      ICOLPR=ICOL1
124   ICOLPV=INDXP1+1
      STYFAL(I-1,ICOL1)=STYFAL(I-1,ICOLPR)-STYFAL(I-1,ICOLPV)*STYFAL
     +(IPIVOT-1,ICOL1)
209   CONTINUE
      GO TO 208
121   II=I-NSLNOD
      ICOLPV=INDXP2+1
      DO 210 J=2,NSLNOD
      IF(J-IPIVOT)210,210,125
125   ICOL1=INDEX2+J-IPIVOT
      ICOLPR=INDXP2+J-(IPIVOT-1)
      ICOL2=INDEX1+J-IPIVOT
      STYSAL(II,ICOL1)=STYSAL(II,ICOLPR)-STYSAL(II,ICOLPV)*STYFAL(IPIVOT
     +-1,ICOL2)
210   CONTINUE
208   CONTINUE
      INDXP1=INDEX1
      INDXP2=INDEX2
202   CONTINUE
      MINDEX=INDEX1
      DO 211 I=1,NNODWS
      KI=I+NSLNOD
      SWREFL(I,1)=YLUMPA(KI,I)
      DO 211 J=2,ITOTND
      ICOLMJ=J-NSLNOD
      IF( ICOLMJ )211,211,127
127   IF(J.EQ.KI)GO TO 211
      SWREFL(I,ICOLMJ)=-YLUMPA(KI,J)
1     FORMAT(3I2,4E10.6,2I4)
```

```
C
C
211    SWREFL(I,I)=SWREFL(I,I)+YLUMPA(KI,J)+YDISTA(KI,J)
C
       RETURN
100    IPIVOT=NSLNOD
       DO 231 I=2,NSLNOD
       JK=NSLNOD+1
       DO 231 J=JK,ITOTND
       IF(J.GT.NROW)GO TO 153
       ICOL1=MINDEX+J-IPIVOT
       GO TO 150
153    ICOL1=LOCCV+J-NROW
150    JJ=J-NSLNOD
       YIMAGE(I-1,JJ)=STYFAL(I-1,ICOL1)
231    CONTINUE
       DO 7000 IROW=1,NNODWS
       DO 7000 JCOL=1,NODVA2
7000   STYVAL(IROW,JCOL)=SWREFL(IROW,JCOL)
       DO 213 I=1,NNODSV
       KI=NROW+I
       NTIME=ITIME-IDELT
C      FOR 60 CYCLES PER SECOND INPUT FOLLOWING STATEMENT SHALL BE MADE
C      EFFECTIVE.OTHERWISE NEXT STATEMENT FOR 50 C.P.S. IS EFFECTIVE.
C      XTIME= 376.99111*(NTIME*1.E-06)/6.2831853
       XTIME=314.15926*(NTIME*1.E-06)/6.2831853
       LTIME=XTIME
       YTIME=XTIME-LTIME
       ZTIME=YTIME*6.2831853
C      IF THE INPUT BE A STEP INPUT TO A 1-PHASE SYSTEM FOLLOWING PAIR OF
C      STATEMENTS APPLY.OTHERWISE FOR 3-PHASE SINUSOIDAL INPUT NEXT PAIR
C      IS EFFECTIVE.
C      ENODAL(KI)=1.0
C      ENODBE(KI)=1.0
C
C
C
       ENODAL(KI)=EALPHA(ZTIME)
       ENODBE(KI)=EBETA(ZTIME)
213    CONTINUE
       DO 214 I=2,NROW
       TOTIAL(I)=0.0
       TOTIBE(I)=0.0
       DO 214 J=1,ITOTND
       TOTIAL(I)=TOTIAL(I)-PIDISA(I,J)-PIKMAL(I,J)
       TOTIBE(I)=TOTIBE(I)-PIDISB(I,J)-PIKMBE(I,J)
214    CONTINUE
       ISTEP=(ITIME/IDELT)
       DO 6002 IDO=1,NNODWS
       DO 6002 JDO=1,NNODSV
6002   ICLOSE(IDO,JDO)=0
       DO 8032 IDO=1,NNODWS
       DO 8033 JDS=1,NNODWS
8033   ISWCH(IDO,JDS)=0
8032   CONTINUE
C
       DO 215 I=1,NNODWS
       IJMOD=0
       DO 215 J=   1,NODVA2
       IF(ISWMOD(I,J,1).EQ.0)GO TO 2150
       IF(ISWMOD(I,J,1).LE.ISTEP)IJMOD=1
       IF(ISWMOD(I,J,2).NE.0.AND.ISWMOD(I,J,2).LE.ISTEP)IJMOD=0
       IF(IJMOD.EQ.1)GO TO 6000
C
C
C
       IF(J.GT.NNODWS)GO TO 6001
       ISWCH(I,J)=0
       ISWCH(J,I)=0
       GO TO 2150
6001   JACT=J-NNODWS
       ICLOSE(I,JACT)=0
       GO TO 2150
6000   STYVAL(I,J)=-1000.00
       STYVAL(I,I)=STYVAL(I,I)+1000.00
       IF(J.GT.NNODWS)GO TO 6003
       STYVAL(J,I)=-1000.00
       STYVAL(J,J)=STYVAL(J,J)+1000.00
```

```
      ISWCH(I,J)=1
      ISWCH(J,I)=1
      GO TO 2150
6003  JACT=J-NNODWS
      ICLOSE(I,JACT)=1
2150  IJMOD=0
215   CONTINUE
      KPIVOT=NSLNOD+1
      DO 219 IPIVOT=1,NROW
      ISUMPD=0
      IDIFF=IPIVOT-1
      IDIFF1=IDIFF-1
      IF(IDIFF1)133,133,134
134   DO 220 LL=1,IDIFF1
220   ISUMPD=ISUMPD+LL
133   INDEX1=IDIFF*LOCVAR-ISUMPD
      INDEX2=IDIFF*LOCVR-ISUMPD
      IF(IPIVOT.EQ.1)GO TO 135
      IF(IPIVOT.GE.KPIVOT)GO TO 136
      ICOLPV=INDXP1+1
      ICOLPV=INDXP1+1
      TOTIAL(IPIVOT)=TOTIAL(IPIVOT)/STYFAL(IPIVOT-1,ICOLPV)
      TOTIBE(IPIVOT)=TOTIBE(IPIVOT)/STYFAL(IPIVOT-1,ICOLPV)
      GO TO 137
135   INDXP1=INDEX1
      INDXP2=INDEX2
      GO TO 219
136   ISW=IPIVOT-NSLNOD
C
      JP=ISW+1
      DO 221 J=JP,NODVA2
      IF(STYVAL(ISW,J).LT.1.E-75)STYVAL(ISW,J)=0.0
      STYVAL(ISW,J)=STYVAL(ISW,J)/STYVAL(ISW,ISW)
      IF(STYVAL(ISW,J).LT.1.E-75)STYVAL(ISW,J)=0.0
221   CONTINUE
C
      TOTIAL(IPIVOT)=TOTIAL(IPIVOT)/STYVAL(ISW,ISW)
      TOTIBE(IPIVOT)=TOTIBE(IPIVOT)/STYVAL(ISW,ISW)
      IF(TOTIAL(IPIVOT).LT.1.E-75)TOTIAL(IPIVOT)=0.0
      IF(TOTIBE(IPIVOT).LT.1.E-75)TOTIBE(IPIVOT)=0.0
      GO TO 138
137   DO 222 I=2,NROW
      IF(I.EQ.IPIVOT)GO TO 222
      IF(I.GT.NSLNOD) GO TO 139
      TOTIAL(I)=TOTIAL(I)-STYFAL(I-1,ICOLPV)*TOTIAL(IPIVOT)
      TOTIBE(I)=TOTIBE(I)-STYFAL(I-1,ICOLPV)*TOTIBE(IPIVOT)
      GO TO 222
139   KSW=I-NSLNOD
      ICOLP=INDXP2+1
149   DO 223 J=1,NODVA2
      IF(J.GT.NNODWS)GO TO 145
      ICOLI=INDEX1+J+NSLNOD-IPIVOT
      GO TO 146
145   ICOLI=LOCCV+J+NSLNOD-NROW
      IF(STYVAL(KSW,   J   ).LT.1.E-75)STYVAL(KSW,J)=0.0
146   STYVAL(KSW,J)=STYVAL(KSW,J)- STYSAL(KSW,ICOLP)  *   STYFAL(IPIVOT
     +-1,ICOLI)
      IF (STYVAL(KSW,J).LT.1.E-75)STYVAL(KSW,J)=0.0
223   CONTINUE
      TOTIAL(I)=TOTIAL(I)- STYSAL(KSW,ICOLP)      *TOTIAL(IPIVOT)
      TOTIBE(I)=TOTIBE(I)- STYSAL(KSW,ICOLP)      *TOTIBE(IPIVOT)
222   CONTINUE
      INDXP1=INDEX1
      INDXP2=INDEX2
      GO TO 219
138   DO 227 I=2,NROW
      IF(I.EQ.IPIVOT)GO TO 227
      IF(I.LE.NSLNOD)GO TO 154
      ISW=I-NSLNOD
C
      JC=IPIVOT-NSLNOD
      JI=JC+1
      DO 232 J=JI,NODVA2
      IF(STYVAL(JC,J).LT.1.E-75)STYVAL(JC,J)=0.0
      IF(STYVAL(ISW,JC).LT.1.E-75)STYVAL(ISW,JC)=0.0
      IF(STYVAL(ISW,J).LT.1.E-75)STYVAL(ISW,J)=0.0
232   STYVAL(ISW,J)=STYVAL(ISW,J)-STYVAL(ISW,JC)*STYVAL(JC,J)
      TOTIAL(I)=TOTIAL(I)-STYVAL(ISW,JC)*TOTIAL(IPIVOT)
```

```
      TOTIBE(I)=TOTIBE(I)-STYVAL(ISW,JC)*TOTIBE(IPIVOT)
      GO TO 227
154   JC=IPIVOT-NSLNOD
      JI=JC+1
      DO 233 J=JI,NODVA2
      IF(STYVAL(JC,J).LT.1.E-75)STYVAL(JC,J)=0.0
233   YIMAGE(I-1,J)=YIMAGE(I-1,J)-YIMAGE(I-1,JC)*STYVAL(JC,J)
      TOTIAL(I)=TOTIAL(I)-YIMAGE(I-1,JC)*TOTIAL(IPIVOT)
      TOTIBE(I)=TOTIBE(I)-YIMAGE(I-1,JC)*TOTIBE(IPIVOT)
227   CONTINUE
219   CONTINUE
C VOLTAGE SOLUTIONS
      DO 234 I=2,NROW
      ENODAL(I)=TOTIAL(I)
      ENODBE(I)= TOTIBE(I)
      IF(I.GT.NSLNOD)GO TO 155
      DO 235 J=1,NNODSV
      KKI=J+NNODWS
      KI=J+NROW
      ENODAL(I)=ENODAL(I)-YIMAGE(I-1,KKI)*ENODAL(KI)
235   ENODBE(I)=ENODBE(I)-YIMAGE(I-1,KKI)*ENODBE(KI)
      GO TO 234
155   ISW=I-NSLNOD
C
      GO TO 156
160   DO 236 J=1,NNODSV
      KKI=J+NNODWS
      KI=J+NROW
      ENODAL(I)=ENODAL(I)-STYVAL(ISW,KKI)*ENODAL(KI)
236   ENODBE(I)=ENODBE(I)-STYVAL(ISW,KKI)*ENODBE(KI)
      GO TO 234
156   DO 237 JSW=1,NNODSV
      IF(ICLOSE(ISW,JSW).EQ.1)GO TO 159
237   CONTINUE
      GO TO 160
159   IEQ= JSW +NROW
      ENODAL(I)=ENODAL(IEQ)
      ENODBE(I)=ENODBE(IEQ)
234   CONTINUE
      DO 8050 ITR=1,NNODWS
      KTR=ITR+NSLNOD
C
      DO 8050 LWS= 1,NNODWS
      KWS=LWS+NSLNOD
      IF(ISWCH(ITR,LWS).EQ.1)GO TO 8051
      GO TO 8050
8051  IF(ENODAL(KTR).NE.0.0 .OR.ENODBE(KTR).NE.0.0) GO TO 8052
      ENODAL(KTR)=ENODAL(KWS)
      ENODBE(KTR)=ENODBE(KWS)
      GO TO 8050
8052  ENODAL(KWS)=ENODAL(KTR)
      ENODBE(KWS)=ENODBE(KTR)
8050  CONTINUE
      RETURN
      END
```

SAMPLE RESULTS ON

STUDY - V

PROVIDED BY COMPUTER

PROGRAM - A.1

TIME IN MICRO-SEC.	NODE NO.	VOLTAGE AT NODES IN P.U. PHASE-A	PHASE-B	PHASE-C
126	2	0.0	0.0	0.0
126	3	0.0	0.0	0.0
126	4	0.0	0.0	0.0
126	5	0.0	0.0	0.0
126	6	0.0	0.0	0.0
126	7	0.0	0.0	0.0
126	8	0.0	0.0	0.0
126	9	0.0	0.0	0.0
126	10	0.0	0.0	0.0
126	11	0.0	0.0	0.0
126	12	1.414212226868	-0.707106232643	-0.707106232643
252	2	0.530626058578	-0.265312969685	-0.265312969685
252	3	0.526609122753	-0.263304531574	-0.263304531574
252	4	0.0	0.0	0.0
252	5	0.0	0.0	0.0
252	6	0.0	0.0	0.0
252	7	0.0	0.0	0.0
252	8	0.0	0.0	0.0
252	9	0.0	0.0	0.0
252	10	0.0	0.0	0.0
252	11	0.0	0.0	0.0
252	12	1.413104057312	-0.658084571362	-0.755019783974
378	2	0.987857997417	-0.475743412971	-0.512114346027
378	3	0.992656171322	-0.478280127048	-0.514375805855
378	4	0.525203347206	-0.262601613998	-0.262601613998
378	5	0.0	0.0	0.0
378	6	0.0	0.0	0.0
378	7	0.0	0.0	0.0
378	8	0.0	0.0	0.0
378	9	0.0	0.0	0.0
378	10	0.0	0.0	0.0
378	11	1.058418273926	-0.529209315777	-0.529209315777
378	12	1.409782409668	-0.608032166958	-0.801750361919
504	2	1.461104393005	-0.678525567055	-0.782579243183
504	3	1.452311515808	-0.674102306366	-0.778209745884
504	4	0.990005552769	-0.477003037930	-0.513002276421
504	5	0.523801326752	-0.261900603771	-0.261900603771
504	6	0.0	0.0	0.0
504	7	0.0	0.0	0.0
504	8	0.0	0.0	0.0
504	9	0.0	0.0	0.0
504	10	0.0	0.0	0.0
504	11	1.970438003540	-0.948945403099	-1.021492958069
504	12	1.404252052307	-0.557027161121	-0.847225248814
630	2	1.915246963501	-0.855562865734	-1.059683799744
630	3	1.924726486206	-0.860577106476	-1.064148902893

630	4	1.448436737061	-0.672303676605	-0.776132881641
630	5	0.987361192703	-0.475728869438	-0.511632025242
630	6	0.522403120995	-0.261201500893	-0.261201500893
630	7	0.0	0.0	0.0
630	8	0.0	0.0	0.0
630	9	0.0	0.0	0.0
630	10	0.0	0.0	0.0
630	11	1.86163[illegible]22827	-0.827043592930	-1.034594535828
630	12	1.39652[illegible]68298	-0.505149185658	-0.891372621059
756	2	1.99014[illegible]14917	-0.827450811863	-1.162690162659
756	3	1.979866981506	-0.822262942791	-1.157603263855
756	4	1.919592857361	-0.858281910419	-1.061310768127
756	5	1.444571495056	-0.670510053635	-0.774061977863
756	6	0.984724581242	-0.474458515644	-0.510265827179
756	7	0.521008491516	-0.260504186153	-0.260504186153
756	8	0.0	0.0	0.0
756	9	0.0	0.0	0.0
756	10	0.0	0.0	0.0
756	11	1.860349655151	-0.762678980827	-1.097670555115
756	12	1.386602401733	-0.452479779720	-0.934123337269
882	2	1.750432968140	-0.639522492886	-1.110910415649
882	3	1.763224601746	-0.646219611168	-1.117004394531
882	4	1.974593162537	-0.820073723793	-1.154519081116
882	5	1.914473533630	-0.855993509293	-1.058480262756
882	6	1.440717697144	-0.668721139431	-0.771996498108
882	7	0.982094228268	-0.473191142082	-0.508902847767
882	8	0.519617617130	-0.259808719158	-0.259808719158
882	9	0.0	0.0	0.0
882	10	0.0	0.0	0.0
882	11	2.117959022522	-0.827855885029	-1.290102005005
882	12	1.374512672424	-0.399101793766	-0.975410878658
1008	2	1.608171463013	-0.508585512638	-1.099585533142
1008	3	1.594059944153	-0.501392543316	-1.092666625977
1008	4	1.758537292480	-0.644503533840	-1.114032745361
1008	5	1.969333648682	-0.817889928818	-1.151443481445
1008	6	1.909366607666	-0.853710114956	-1.055656433105
1008	7	1.436873435974	-0.666937291622	-0.769936800003
1008	8	0.979470908642	-0.471927165985	-0.507543563843
1008	9	0.518230497837	-0.259115219116	-0.259115219116
1008	10	0.0	0.0	0.0
1008	11	1.641105651855	-0.517024397850	-1.124080657959
1008	12	1.360268592834	-0.345098197460	-1.015170097351
1134	2	1.424461364746	-0.361846566200	-1.062614440918
1134	3	1.440991401672	-0.370458424091	-1.070532798767
1134	4	1.589829444885	-0.500065088272	-1.089763641357
1134	5	1.753861427307	-0.642791867256	-1.111069679260
1134	6	1.964089393616	-0.815712749958	-1.148376464844
1134	7	1.904273986816	-0.851433396339	-1.052840232849
1134	8	1.433039665222	-0.665157735348	-0.767882108688
1134	9	0.976855337620	-0.470666885376	-0.506188213825
1134	10	1.033693313599	-0.516846776009	-0.516846776009
1134	11	1.101110458374	-0.191021442413	-0.910089492798
1134	12	1.343893051147	-0.290554106236	-1.053338050842
1260	2	1.172248840332	-0.187195777893	-0.985053062439
1260	3	1.155414581299	-0.178558647633	-0.976856052876
1260	4	1.437174797058	-0.369482219219	-1.067692756653
1260	5	1.585612297058	[illegible]	[illegible]

1260	6	1.749196052551	-0.641083240509	-1.108112335205
1260	7	1.958856582642	-0.813540160656	-1.145316123962
1260	8	1.899195671082	-0.849162995815	-1.050031661987
1260	9	1.944683074951	-0.921116590500	-1.023566246033
1260	10	1.948492050171	-0.938819766045	-1.009672164917
1260	11	1.208973884583	-0.207497358322	-1.001476287842
1260	12	1.325412750244	-0.135555052757	-1.089857101440
1386	2	1.070366859436	-0.106392750740	-0.973974704742
1386	3	1.087874412537	-0.105503141880	-0.982371151447
1386	4	1.152367591858	-0.178097069263	-0.974270641804
1386	5	1.433368682861	-0.368508219719	-1.064860343933
1386	6	1.581406593323	-0.497422814369	-1.083983421326
1386	7	1.744546890259	-0.639381289482	-1.105165481567
1386	8	2.467730522156	-1.068418502808	-1.399310112000
1386	9	2.865773200989	-1.315052986145	-1.550718307495
1386	10	2.850807189941	-1.323225975037	-1.527578353882
1386	11	1.243006706238	-0.183390378952	-1.059616088867
1386	12	1.304854393005	-0.180186629295	-1.124668121338
1512	2	1.174030303955	-0.111884236336	-1.062146186829
1512	3	1.155315399170	-0.102283716202	-1.053031921387
1512	4	1.085008621216	-0.105235874653	-0.979772865772
1512	5	1.149328231812	-0.177636563778	-0.971692025661
1512	6	1.429574012756	-0.367538094521	-1.062035560608
1512	7	2.089929580688	-0.752465724945	-1.337463378906
1512	8	2.708957672119	-1.104587554932	-1.604367256165
1512	9	3.370036125183	-1.469060897827	-1.900973320007
1512	10	3.778159141541	-1.689279556274	-2.088877677917
1512	11	0.932500660419	0.014118909836	-0.946619391441
1512	12	1.282253265381	-0.124535679817	-1.157716751099
1638	2	1.170731544495	-0.070370554924	-1.100360870361
1638	3	1.190446853638	-0.080626428127	-1.109820365906
1638	4	1.152277946472	-0.102027535439	-1.050250053406
1638	5	1.082154273987	-0.104971468449	-0.977183520794
1638	6	1.657645225525	-0.432851314545	-1.224793434143
1638	7	2.392252922058	-0.832229793072	-1.560021400452
1638	8	2.990836143494	-1.152881622314	-1.837952613831
1638	9	3.619325637817	-1.478377342224	-2.140947341919
1638	10	3.886495590210	-1.614119529724	-2.272375106812
1638	11	1.105422019958	-0.040759801865	-1.064661979675
1638	12	1.257642745972	-0.068690359592	-1.188952445984
1764	2	1.193135261536	-0.041852772236	-1.151282310486
1764	3	1.172596931458	-0.031306445599	-1.141290664673
1764	4	1.187317848206	-0.080427885056	-1.106889724731
1764	5	1.659230232239	-0.356763064861	-1.302467346191
1764	6	2.043190956116	-0.569123268127	-1.474066734314
1764	7	2.557300567627	-0.833052456379	-1.724247932434
1764	8	3.301035881042	-1.205747604370	-2.095286369324
1764	9	3.506927490234	-1.298396110535	-2.208530426025
1764	10	3.461338996887	-1.268599510193	-2.192737579346
1764	11	1.407691955566	-0.154409170151	-1.253282546997
1764	12	1.231061935425	-0.012737274170	-1.218324661255
1890	2	1.282484054565	-0.046071052551	-1.236413002014
1890	3	1.302860260010	-0.056685030460	-1.246174812317
1890	4	1.678142547607	-0.285550653934	-1.392591476440

1890	5	2.145506858826	-0.543405413628	-1.602100372314
1890	6	2.556478500366	-0.756098151207	-1.80[illegible]379753113
1890	7	2.959479507446	-0.942346394062	-2.008131027222
1890	8	3.073172569275	-0.979031383991	-2.094140052795
1890	9	3.144321441650	-0.997258484364	-2.147060394287
1890	10	3.129388809204	-0.984358787537	-2.145028114319
1890	11	1.280378341675	-0.042939603329	-1.23[illegible]439155579
1890	12	1.202552795410	0.043236374855	-1.24[illegible]89527893
2016	2	1.513174057007	-0.117928206921	-1.395245552063
2016	3	1.495164871216	-0.108651876450	-1.386512756348
2016	4	2.258180618286	-0.518489718437	-1.739690780640
2016	5	2.572944641113	-0.684009850025	-1.888934135437
2016	6	3.050099372864	-0.915700852871	-2.134397506714
2016	7	3.070975303650	-0.901892662048	-2.169081687927
2016	8	2.795118331909	-0.735116302967	-2.059999465942
2016	9	2.697796821594	-0.666684269905	-2.031110763550
2016	10	2.828994750977	-0.727365911007	-2.101628303528
2016	11	1.157944679260	0.061689019203	-1.219634056091
2016	12	1.172159194946	0.099142074585	-1.271301269531
2142	2	1.736459732056	-0.178212821484	-1.558246612549
2142	3	1.756958961487	-0.188807487488	-1.568150520325
2142	4	2.388065338135	-0.506518542767	-1.881546020508
2142	5	3.160058975220	-0.889857590199	-2.270198822021
2142	6	3.086023330688	-0.829607963562	-2.256415367126
2142	7	2.894888877869	-0.709096074104	-2.185791015625
2142	8	2.696607589722	-0.590585649014	-2.106019973755
2142	9	2.481565475464	-0.466645121574	-2.014920234680
2142	10	2.268508911133	-0.350706279278	-1.917801856995
2142	11	1.744725227356	-0.192516148090	-1.552208900452
2142	12	1.139928817749	0.154891550541	-1.294820785522
2268	2	2.005912780762	-0.253969967365	-1.751942634583
2268	3	1.987592697144	-0.244451820850	-1.743140220642
2268	4	2.657769203196	-0.560065746307	-2.097702026367
2268	5	2.900268554688	-0.652201950550	-2.248064041138
2268	6	3.004966735840	-0.683873713017	-2.321092605591
2268	7	2.712615013123	-0.519325435162	-2.193287849426
2268	8	2.581907272339	-0.441410660744	-2.149494346619
2268	9	2.268469810486	-0.275655448437	-1.992813110352
2268	10	2.135992050171	-0.207316160202	-1.928673744202
2268	11	2.311880111694	-0.416830539703	-1.895047187805
2268	12	1.105913162231	0.210399270058	-1.316312789917
2394	2	2.271055221558	-0.318381309509	-1.952673912048
2394	3	2.291321754456	-0.328785181046	-1.962534904480
2394	4	2.499500274658	-0.390447974205	-2.109049797058
2394	5	2.504431724548	-0.355512022972	-2.148918151855
2394	6	2.528351783752	-0.343222439289	-2.185128211975
2394	7	2.692527770996	-0.416971266270	-2.275555610657
2394	8	2.285579681396	-0.205426335335	-2.080150604248
2394	9	2.236988067627	-0.182842314243	-2.054144859314
2394	10	2.268431663513	-0.201006114483	-2.067423820496
2394	11	2.265708923340	-0.315097212791	-1.950611114502
2394	12	1.070164680481	0.265577316284	-1.335741996765
2520	2	2.192430496216	-0.201877534389	-1.990552902222
2520	3	2.174837112427	-0.192654371262	-1.982180595398
2520	4	2.139372825623	-0.125395774841	-2.013976097107

2520	5	2.129646301270	-0.082992613316	-2.046652793884
2520	6	2.194162368774	-0.090199470520	-2.103962898254
2520	7	2.102948188782	-0.030632019043	-2.072315216064
2520	8	2.348233222961	-0.159157752991	-2.189074516296
2520	9	2.285493850708	-0.131163597107	-2.154330253601
2520	10	2.337444305420	-0.15[illegible]97810364	-2.178946495056
2520	11	2.230449676514	-0.22[illegible]36609189	-2.009999692139
2520	12	1.032740592957	0.320338904858	-1.353078842163
2646	2	1.651802062988	0.142875313759	-1.794676780701
2646	3	1.669384956360	0.133903384209	-1.803287506104
2646	4	1.806838989258	0.113451063633	-1.920289039612
2646	5	1.830906867981	0.138594150543	-1.969500541687
2646	6	1.706441879272	0.228069424629	-1.934510231018
2646	7	1.852116584778	0.166054368019	-2.018170356750
2646	8	2.103349685669	0.042966842651	-2.146316528320
2646	9	2.448124885559	-0.134941101074	-2.313182830811
2646	10	2.302465438843	-0.061693191528	-2.240772247314
2646	11	2.119543075562	-0.089262664318	-2.030280113220
2646	12	0.993697226048	0.374599099159	-1.368295669556
2772	2	1.122200965881	0.463527083397	-1.585727691650
2772	3	1.105982780457	0.472061514854	-1.578043937683
2772	4	1.362998008728	0.396496117115	-1.759493827820
2772	5	1.385623931885	0.423159420490	-1.808783531189
2772	6	1.490744590759	0.393551170826	-1.884295463562
2772	7	1.707901954651	0.300780892372	-2.008682250977
2772	8	1.953067779541	0.189336657524	-2.142404556274
2772	9	2.120762825012	0.111785888672	-2.232547760010
2772	10	2.558217048645	-0.111511230469	-2.446704864502
2772	11	1.076249122620	0.504265129566	-1.580513954163
2772	12	0.953097283840	0.428272604942	-1.381369590759
2898	2	0.584301710129	0.770137488842	-1.354438781738
2898	3	0.600458800793	0.761924445629	-1.362382888794
2898	4	0.687765359879	0.779985368252	-1.467750549316
2898	5	1.024993896484	0.650085270405	-1.675079345703
2898	6	1.387939453125	0.495155394077	-1.883093833923
2898	7	1.592391014099	0.416164815426	-2.008555412292
2898	8	1.726324081421	0.368728518486	-2.095052719116
2898	9	2.064186096191	0.211839675903	-2.276023864746
2898	10	1.940032005310	0.284338355064	-2.224370002747
2898	11	0.130187273026	1.013363838196	-1.143550872803
2898	12	0.911003828049	0.481274724007	-1.392277717590
3024	2	0.060069508851	1.051444053650	-1.111513137817
3024	3	0.044897645712	1.059453010559	-1.104351043701
3024	4	0.265393316746	1.013858795166	-1.279252052307
3024	5	0.691938519478	0.850835800171	-1.542774200439
3024	6	1.127612113953	0.671953618526	-1.799565315247
3024	7	1.407166481018	0.562403321266	-1.969569206238
3024	8	1.704176902771	0.438009977039	-2.142177581787
3024	9	1.547128677368	0.540134489536	-2.087262153625
3024	10	1.572795867920	0.533462524414	-2.106258392334
3024	11	0.094980180264	1.034589767456	-1.129569053650
3024	12	0.867483913898	0.533522725105	-1.401005744934
3150	2	-0.087657749653	1.126520156860	-1.038863182068
3150	3	[illegible]	[illegible]	[illegible]

3150	3	-0.075315713882	1.120248794556	-1.044932365417
3150	4	0.050776235759	1.129367828369	-1.180144309998
3150	5	0.369766473770	1.034697532654	-1.404464721680
3150	6	0.712972164154	0.916955292225	-1.629926681519
3150	7	1.240338325500	0.693050563335	-1.933388710022
3150	8	1.229301452637	0.732833921909	-1.962134361267
3150	9	1.215060234070	0.758162081242	-1.973221778870
3150	10	1.156326293945	0.794563174248	-1.950889587402
3150	11	-0.009673662484	1.089320182800	-1.079647064209
3150	12	0.822604358196	0.584935247898	-1.407539367676
3276	2	0.203091979027	0.977292418480	-1.180383682251
3276	3	0.191433548927	0.983448743820	-1.174881935120
3276	4	0.029690682888	1.140746116638	-1.170436859131
3276	5	0.073467016220	1.194567680359	-1.268033981323
3276	6	0.484215736389	1.054769515991	-1.538985252380
3276	7	0.537435829639	1.085982322693	-1.623418807983
3276	8	0.753770291805	1.011672019958	-1.765441894531
3276	9	0.840392351151	0.986069142818	-1.826460838318
3276	10	0.859234631062	0.981661498547	-1.840895652771
3276	11	-0.269320368767	1.217962265015	-0.948642313480
3276	12	0.776436150074	0.635430276394	-1.411866188049

A.2. COMPUTER PROGRAM NO.2

PROGRAM TO COMPUTE CURRENTS AND VOLTAGES IN A SYSTEM IN STEADY STATE BY A LOAD FLOW STUDY

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CCCC  THIS PROGRAM PERFORMS A SIMPLE LOAD FLOW STUDY BY GAUSS SEIDEL
C     ITERATION  METHOD ON A SYSTEM TO COMPUTE ITS STEADY STATE NODAL
C     VOLTAGES  AND CURRENTS FROM NODE TO NODE WHICH WILL BE USED AS
C     INITIAL VALUES IN THE TRANSIENT STUDY.
C
CCCC  DIMENSION--THIS PROGRAM CAN HANDLE PRESENTLY A SYSTEM CONSISTING
C     OF 10 BUSES(NODES).THIS CAN BE EXTENDED SIMPLY BY CHANGING THE
C     DIMENSIONS OF SUBSCRIPTED VARIABLES.
C
CCCC  INPUT DATA REQUIREMENTS IN SEQUENCE.
C     1.1.NDATCD=NUMBER OF BRANCHES (ELEMENTS) BETWEEN TWO BUSES
C     REQUIRING A RECORD TO PROVIDE DATA ON ITSELF.
C     1.2. NBUS= NUMBER OF BUSES OR NODES IN THE SYSTEM STARTING WITH
C          SERIAL '1' BUT EXCLUDING DATUM NODE.
C     1.3.ITRMAX=MAXIMUM NUMBER OF ITERATIONS.
C     1.4.ACCLRN=ACCELRATION FACTOR.
C     1.5.ALWDEV=TOLERANCE VALUE TO TEST CONVERGENCE.
C
CCCC THE FOLLOWING DATA REQUIRE TO BE FURNISHED  CORRESPONDING TO ONE
C     BRANCH.SIMILAR ONE RECORD FOR EACH OF OTHER BRANCHES.
C     2.1.IBRTYP='00' IF NO BRANCH EXISTS BETWEEN A PAIR OF NODES.
C     2.2.ELSE='01'.
C     2.3. 'IP'AND'IQ' =PAIRS OF NODES BETWEEN WHICH A BRANCH EXISTS.
C     A BRANCH SHOULD BE SPECIFIED ONLY ONCE THAT IS THE ORDER'IQ-IP'
C     NEED NOT BE MENTIONED IN ANOTHER RECORD.
C     2.4. ZIPIQ=IMPEDANCE IN P.U.BETWEEN BUSES 'IP'AND 'IQ'.
C     2.5.ADCHRG=SHUNT CAPACITIVE ADMITTANCE FROM EACH OF THE BUSES
C     'IP'AND 'IQ' TO DATUM (THAT IS  EQUAL TO  HALF THE TOTAL
C     ADMITTANCE  OF THE LINE SECTION BETWEEN 'IP' AND 'IQ' TO DATUM).
C
CCCC  THE LAST DATA SET COMPRISES AS MANY RECORDS AS THE NUMBER OF
C     BUSES IS(=NBUS)STARTING FROM BUS NO.1. EACH RECORD NEEDS FOLLOWING
C     DATA ON THE CORRESPONDING BUS.
C     3.1.'IBSTYP'='01' IF THE BUS BE A SLACK BUS.
C     ELSE='02'.
C     3.2.'EPTHBS'=SPECIFIED VOLTAGE IN P.U. AT THE BUS.
C     3.3.'WVAR'=NET REAL AND REACTIVE POWER FLOW INTO OR OUT OF THE BUS.
      DIMENSION ITYPBS(10),ITYPBR(10,10)
      COMPLEX EBUS(10),BUSMVA(10),AKLP(10),AYPQLP(10,10),YCHARG(10,10),
     +YBUS(10,10),AIPQ(10,10),EPTHBS,WVAR,BUSY,ZIPIQ,EBUSPR,ABUS,ADCHRG,
     +DELEBS,VAMP
6600  READ(1,100),END= 9001 )NDATCD,NBUS,ITRMAX,ACCLRN,ALWDEV
100   FORMAT(3I3,2F10.8)
      DO 1100 I=1,NBUS
      BUSMVA(I)=CMPLX(0.0,0.0)
      DO 1100 J=1,NBUS
      YCHARG(I,J)=CMPLX(0.0,0.0)
      YBUS(I,J)=CMPLX(0.0,0.0)
1100  ITYPBR(I,J)=0
      DO 200 ID=1,NDATCD
      READ(1,101)IBRTYP,IP,IQ,ZIPIQ,ADCHRG
101   FORMAT(3I2,4F10.5)
      ITYPBR(IP,IQ)=IBRTYP
      ITYPBR(IQ,IP)=IBRTYP
      YBUS(IP,IQ)=-1./ZIPIQ
      YBUS(IQ,IP)=YBUS(IP,IQ)
      YCHARG(IP,IQ)=ADCHRG
      YCHARG(IQ,IP)=ADCHRG
      YCHARG(IP,IP)=YCHARG(IP,IP)+YCHARG(IP,IQ)
      YCHARG(IQ,IQ)=YCHARG(IQ,IQ)+YCHARG(IP,IQ)
200   CONTINUE
      DO 1101 I=1,NBUS
      READ(1,102)IBSTYP,EPTHBS,WVAR
102   FORMAT(I2,4F10.5)
      ITYPBS(I)=IBSTYP
      EBUS(I)=EPTHBS
      BUSMVA(I)=WVAR
      BUSY=YCHARG(I,I)
      DO 1102 J=1,NBUS
1102  BUSY=BUSY-YBUS(I,J)
      YBUS(I,I)=BUSY
      VAMP=CONJG(BUSMVA(I))
1101  AKLP(I)=     VAMP /YBUS(I,I)
      DO 1103 I=1,NBUS
      DO 1103 J=1,NBUS
      IF(J.EQ.I)GO TO 1103
      AYPQLP(I,J)=YBUS(I,J)/YBUS(I,I)
1103  CONTINUE
```

```
      DO 1104 ITR=1,ITRMAX
      DEV =   0.0
C
      DO 1105 I=1,NBUS
      EBUSPR=EBUS(I)
      IF(ITYPBS(I).EQ.01)GO TO 1105
      ABUS=CONJG(EBUS(I))
      EBUS(I) =AKLP(I)/ABUS
      DO 1107 I1=1,NBUS
      IF(I1.EQ.I)GO TO 1107
      EBUS(I)=EBUS(I)-AYPQLP(I,I1)*EBUS(I1)
 1107 CONTINUE
      DELEBS=EBUS(I)-EBUSPR
      EBUS(I)=EBUSPR+ACCLRN*(EBUS(I)-EBUSPR)
C
      DELABS=CABS(DELEBS)
      IF(DELABS.LE.DEV)GO TO 1105
      DEV=DELABS
C
C
 1105 CONTINUE
      IF    (DEV.LE.ALWDEV)    GO TO 9000
 1104 CONTINUE
      WRITE(3,500)
 500  FORMAT('1'5X,'NO CONVERGENCE')
31000 FORMAT(5X,I2,2X,2(E14.8,3X) )
 9000 WRITE(3,310)
 310  FORMAT('1'T2,'BUS CODE'T20,'BUS-VOLTAGE'T68,'BUS CODE'T90,'LINE AM
     +P.'/T21,'IN P.U.'T68, 'FROM'T73,'TO'T92,'IN P.U.'/)
      DO 1200 I=1,NBUS
      WRITE(3,31000)I,EBUS(I)
      DO 1209 J=1,NBUS
      IF(ITYPBR(I,J).EQ.0)GO TO 1209
      IF(J.LE.I)GO TO 1200
      AIPQ(I,J)=-(EBUS(I)-EBUS(J))*YBUS(I,J)+EBUS(I)*YCHARG(I,J)
      WRITE(3,311)                 I,J,AIPQ(I,J)
 311  FORMAT                          (68X,2(I2,2X),3X,2(E14.8,3X) )
 1200 CONTINUE
      GO TO 6600
 9001 STOP
      END
```

A.3. COMPUTER PROGRAM NO. 3

PROGRAM TO LOCATE THE DATA POINTS IN A PLOT OF VOLTAGE VS. TIME IN MICRO SECONDS

```
CCCC   THIS PROGRAM PLOTS LIGTNING OR SWITCHING OVER-VOLTAGES IN P.J.VS.
C      TIME IN MICRO SECOND.
C
CCCC   DIMENSION-THE PROGRAM HAS A PROVISION TO PLUT 300 DATA POINTS
C      WHICH IF NEEDED CAN BE INCREASED SIMPLY BY INCREASING DIMENSION
C      OF THREE ARRAY VARIABLES ONLY VIZ.'VOLTPA(300)','VOLTPB(300)',
C      'VOLTPC(300)'.
C
CCCC   THIS PROGRAM HAS A LIMITATION TO PLOT OVER-VOLTAGES DUE TO
C      LIGHTNING STROKE OR STEP INPUT IN EXCESS OF 4.0 P.U. WHILE THREE
C      PHASE SWITCHING OVER-VOLTAGES IN EXCESS OF 3.0 P.U. THIS
C      LIMITATION CAN BE OVERCOME BY CHOOSING SMALLER SCALE. PRESENT
C      CHOICE IS 0.2 P.U.PER SMALLER DIVISION TO GIVE PLOTS IN STANDARD
C      CONFIGURATION.
C
CCCC   INPUT DATA REQUIREMENTS IN SEQUENCE.
CC     1ST DATA SET -COMMON FOR ANY TYPE OF PLOT.
C      1.1.'NODE'=SERIAL NUMBER OF THE PARTICULAR NODE IN THE SYSTEM
C      UNDER STUDY,AT WHICH PLOT OF OVER-VOLTAGE IS DESIRED.
C      1.2.'NDATA'=NUMBER OF DATA POINTS THAT IS OVER-VOLTAGE
C      CORRESPONDING TO EACH TIME STEP(MICRO SECOND).FOR LIGHTNING OR
C      STEP INPUT TIME SHOULD BE RECKONED FROM 1 MICRO SECOND AND THE
C      CORRESPONDING OVER-VOLTAGE. IF NOT AVAILABLE THE OVER-VOLTAGE
C      AT 1 MICRO SECOND SHOULD BE GIVEN AS 0.0 P.U.
C      1.3.'ITYPTR'-TYPE OF TRANSIENT.
C          ='001' IF THREE PHASE SWITCHING TRANSIENT PLOT.
C      ELSE ='002' IF LIGHTNING OVER-VOLTAGE PLOT.
C      = '003' IF STEP INPUT TO A SINGLE PHASE SYSTEM AND PLOT OF
C      CORRESPONDING OVER-VOLTAGES.
C      1.4.'IDELT'=TIME STEP LENGTH OR TIME INTERVAL(MICRO SECOND) TO BE
C      USED IN THE PLOT.
C      1.5.'ITMAX'=MAXIMUM TIME(MICRO SECOND)UPTO WHICH PLOTTING DESIRED
C      1.6.'PUMAX'=MAXIMUM VALUE AMONG THE OVER-VOLTAGES IN PER UNIT(P.U.)
C
CCCC   2ND AND LAST SET OF DATA REQUIRED EXCLUSIVELY FOR PLOT OF
C      TRANSIENTS DUE TO LIGHTNING AND STEP INPUT.
C      2.0. (VOLTPA(I),I=1,NDATA) MEANS SPECIFIED NUMBER (=NDATA) OF DATA
C      ON OVER-VOLTAGES IN P.U. AT THE CONCERNED NODE AND TO BE FURNISHED
C      AS 8 DATA SET (ONE DATA PER SET) PER RECORD.
C
CCCC   2ND AS WELL AS LAST SET OF DATA EXCLUSIVELY FOR SWITCHING
C      TRANSIENT DUE TO THREE PHASE SINUSOIDAL INPUT ('ITYPTR'='001').
C      2.0. (VOLTPA(I),VOLTPB(I),VOLTPC(I),I=1,NDATA)-- MEANS THREE PHASE
C      OVER-VOLTAGES ('PHASE-A','PHASE-B','PHASE-C') IN P.U. AT THE
C      CONCERNED NODE  CORRESPONDING TO EACH TIME STEP AND TO BE
C      FURNISHED  AS TWO SETS OF DATA(EACH SET COMPRISES 3 DATA) PER
C      RECORD. TOTAL NUMBER OF DATA SET IS 'NDATA'.
       DIMENSION              VOLTPA(300),VOLTPB(300),VOLTPC(300),JPLOTS(3)
      +,VOLTS(3),ICOL(6)
       INTEGER PHASEA,PHASEB,PHASEC,BLANK,      LINE(41),LINEY(41),ASTER,
      +DUMLIN(12),PLUS,PHASE3(32),LINESW(132)
       DATA PHASEA,PHASEB,PHASEC,LINEY,         BLANK,ASTER,PLUS,DUMLIN/'A'
      +,'B','C',41*'+',' ','*','+',                                   'M',
      +'I','C','R','O',' ','S','E','C','O','N','D'/
       DATA  PHASE3/'-','3',' ',' ',' ','-','2',' ',' ',' ','-','1',' ',
      +' ',' ',' ','0',' ',' ',' ','+','1',' ',' ',' ','+','2',' ',' ',
      +' ','+','3'/
100    READ(1,1,END=101)NODE,NDATA,ITYPTR,IDELT,ITMAX,PUMAX
1      FORMAT(3I3,I4,I8,F10.6)
       IF(NDATA.LT.12)GO TO 1007
C
C
       D=(NDATA-12)/2
       D=D+0.5
       JD=D
       JL=JD+13
       IF(ITYPTR.EQ.1)GO TO 112
       LINE(1)=PLUS
       LINE(41)=PLUS
       IF(PUMAX.GT.4.0)GO TO 1006
       IF(ITYPTR.EQ.2)GO TO 895
       WRITE(3,491)NODE,LINEY
       GO TO 693
C
895    WRITE(3,2) NODE,LINEY
2      FORMAT('1'///////////////////////////////////
      +                  23X,'PLOT OF LIGHTNING OVER-VOLTAGE AT NODE NO.'I3/28X
      +,'BASED ON THREE PHASES BEING EQUALLY AFFECTED'//45X,'VOLT IN P.U'
```

```
      +/ 29X,            '-4    -3    -2    -1     0    +1    +2    +3    +4'
      +    /30X,41A1)
693    READ(1,3) (VOLTPA(I),I=1,NDATA)
3      FORMAT(8F10.6)
       JCOL=1
       ITMCNT=0
       LINCNT=0
       DO 201 ITIME=     1,ITMAX,IDELT
       I=(ITIME/IDELT)+1
       IF(IDELT.LE.1)I=I-1
       SCALE=(VOLTPA(I)+4)*5+.5
       JSCALE=SCALE+1
       DO 701 IDD=2,40
701    LINE(IDD)=BLANK
       LINE(JSCALE)=ASTER
       LINCNT=LINCNT+1
       ITMCNT=ITMCNT+1
       IF(ITMCNT.EQ.1.OR.ITMCNT.EQ.4)GO TO 1204
       IF(LINCNT.GT.JD.AND.LINCNT.LT.JL)GO TO 1205
C
       WRITE(3,4) LINE
4      FORMAT(30X,41A1)
       GO TO 201
1204   IF(LINCNT.GT.JD.AND.LINCNT.LT.JL)GO TO 1207
       DO 1203 ICLL=1,41,5
1203   LINE(ICLL)=PLUS
       LINE(JSCALE)=ASTER
       WRITE(3,5)ITIME,LINE
5      FORMAT(24X,I6,41A1)
       IF(ITMCNT.EQ.4)ITMCNT=1
       GO TO 201
1205   WRITE(3,6)DUMLIN(JCOL),LINE
6      FORMAT(23X,A1,6X,41A1)
       JCOL=JCOL+1
       GO TO 201
1207   DO 1301 ICLL=1,41,5
1301   LINE(ICLL)=PLUS
       LINE(JSCALE)=ASTER
       WRITE(3,7)DUMLIN(JCOL),ITIME,LINE
7      FORMAT(23X,A1,    I6,41A1)
       JCOL=JCOL+1
       IF(ITMCNT.EQ.4)ITMCNT=1
201    CONTINUE
3000   ITIME=ITIME+  IDELT
       ITTEST=4-ITMCNT
       IF(ITTEST)1208,1208,1209
1208   GO TO 100
1209   GO TO (1210,1211,100   ),    ITTEST
1210   DO 1601 ID=2,40
1601   LINE(ID)=BLANK
1960   DO 1302 ICLL=1,41,5
1302   LINE(ICLL)=PLUS
       WRITE(3,5)ITIME,LINE
       GO TO 100
1211   DO 1303 IDD=2,40
1303   LINE(IDD)=BLANK
       WRITE(3,4)LINE
       ITIME=ITIME+IDELT
       GO TO 1960
491    FORMAT('1'/////////////////////////////////////28X,'PLOT OF SWITCHING
      + OVER-VOLTAGE AT NODE NO.'I3/28X,'DUE TO STEP INPUT IN A 1-PHASE
      +SYSTEM'//45X,'VOLT IN P.U.'/29X,'-4    -3    -2    -1     0    +1    +2
      +    +3    +4'/30X,41A1)
C
112    READ(1,10)(VOLTPA(I),VOLTPB(I),VOLTPC(I),I=1,NDATA)
10     FORMAT(6F10.6)
       IF(PUMAX.GT.3.0)GO TO 1005
       LMTPU=PUMAX
       DIFFPU=PUMAX-LMTPU
       IF(DIFFPU)901,901,902
901    MAXPU=PUMAX
       GO TO 903
902    MAXPU=PUMAX+1.0
903    GO TO (904,905,906),MAXPU
904    WRITE(3,5001)NODE,(PHASE3(I),I=11,22),(PHASE3(I),I=11,22),(PHASE3(
      +I),I=11,22),(LINEY(I),I=16,26),(LINEY(I),I=16,26),  (LINEY(I),
      + I=16,26)
5001   FORMAT('1'//37X,'PLOT OF SWITCHING OVER-VOLTAGE AT NODE NO.'I3/54X
```

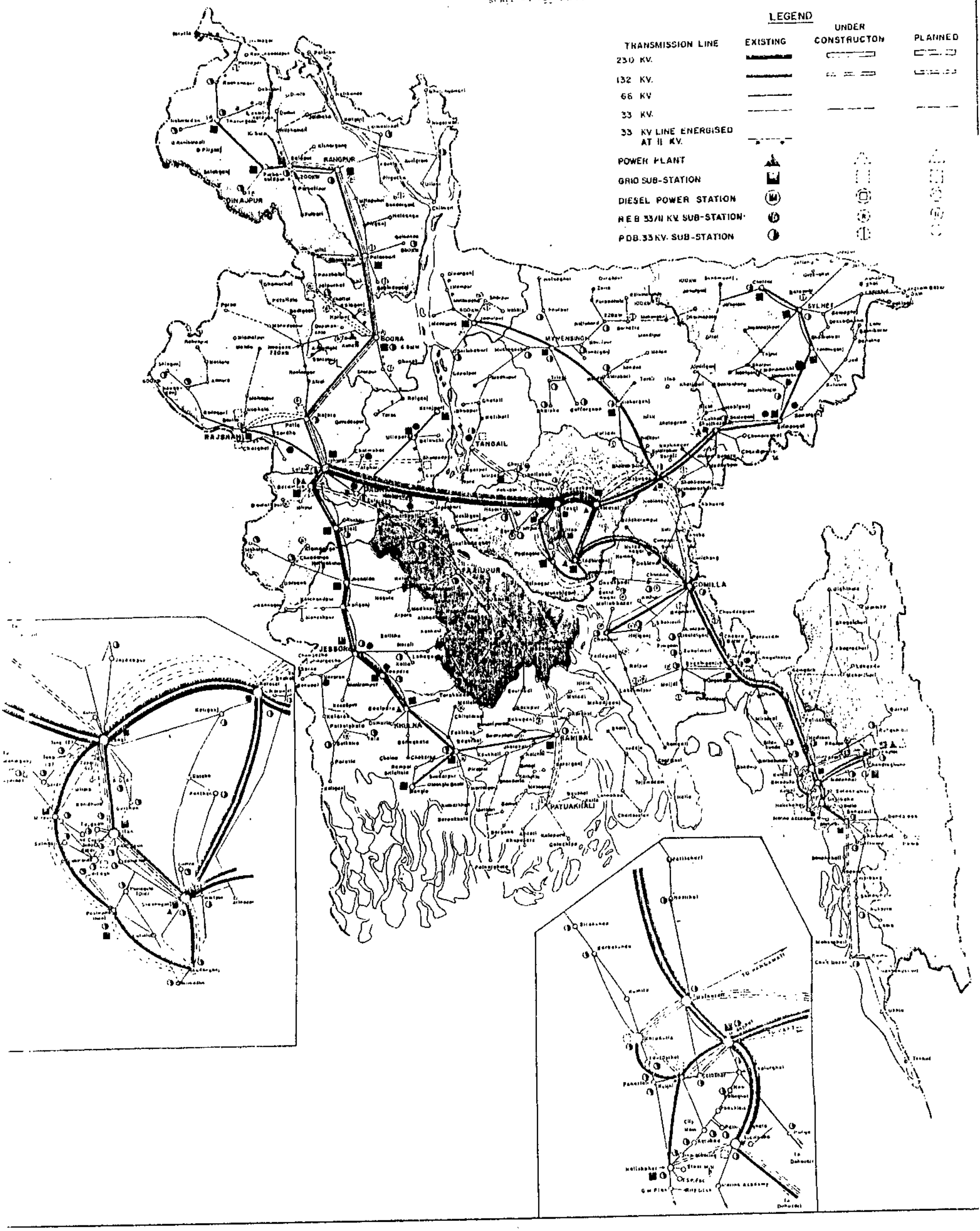
```
      +,'VOLT  IN P.U.'///T44,'PHASE-C',T57,'PHASE-B',T70,'PHASE-A'/
      +40X,12A1,1X,12A1,1X,12A1/41X,11A1,2X,11A1,2X,11A1)
       ISKIP=41
       IWIDTH=11
       ICOL(1)=42
       ICOL(2)=52
       ICOL(3)=55
       ICOL(4)=65
       ICOL(5)=68
       ICOL(6)=78
C
C
C
       GO TO 8987
 905   WRITE(3,3510)NODE,(PHASE3(I),I=6,27),(PHASE3(I),I=6,27),
      +(PHASE3(I),I=6,27),(LINEY(I),I=11,31),(LINEY(I),I=11,31),
      +(LINEY(I),I=11,31)
 3510  FORMAT('1'//T36,'PLOT OF SWITCHING OVER-VOLTAGE AT NODE NO.'I3/
      +T54,'VOLT  IN P.U.'///T33,'PHASE-C'T56,'PHASE-B',T79,'PHASE-A'/24X,
      +22A1,1X,22A1,1X,22A1/25X,21A1,2X,21A1,2X,21A1)
       ISKIP=25
       IWIDTH=21
       ICOL(1)=26
       ICOL(2)=46
       ICOL(3)=49
       ICOL(4)=69
       ICOL(5)=72
       ICOL(6)=92
C
C
C
       GO TO 8987
 906   WRITE(3,3539)NODE,(PHASE3(I),I=1,32),(PHASE3(I),I=1,32),
      +(PHASE3(I),I=1,32),(LINEY(I),I=6,36),(LINEY(I),I=6,36),
      +(LINEY(I),I=6,36)
 3539  FORMAT('1'//T40,'PLOT OF SWITCHING OVER-VOLTAGE AT NODE NO.'I3/
      +T58,'VOLT  IN P.U.'///T27,'PHASE-C'T60,'PHASE-B'T93,'PHASE-A'/
      +13X,32A1,1X,32A1,1X,32A1/14X,31A1,2X,31A1,2X,31A1)
       ISKIP=14
       IWIDTH=31
       ICOL(1)=15
       ICOL(2)=45
       ICOL(3)=48
       ICOL(4)=78
       ICOL(5)=81
       ICOL(6)=111
C
C
C
C
C
 8987  ISWTCH=0
       JCOL=1
       ITMCNT=0
       LINCNT=0
       DO 205 ITIME=IDELT,ITMAX,IDELT
       DO 8001 IDD =1,132
 8001  LINESW(IDD)=BLANK
       DO 3333 IC=1,6
       ICO=ICOL(IC)
 3333  LINESW(ICO) =PLUS
       I=(ITIME/IDELT)
       VOLTS(1)=VOLTPA(I)
       VOLTS(2)=VOLTPB(I)
       VOLTS(3)=VOLTPC(I)
       DO 204 J=1,3
       SCALE=(VOLTS(J)+MAXPU)*5+0.5
 204   JPLOTS(J)=SCALE+1
C
       K=JPLOTS(3)+ISKIP
       L=JPLOTS(2)+ISKIP+IWIDTH+2
       M=JPLOTS(1)+ISKIP+2*IWIDTH+4
 5004  FORMAT(132A1)
C
       LINESW(K)=PHASEC
       LINESW(L)=PHASEB
       LINESW(M)=PHASEA
       LINCNT=LINCNT+1
```

```
      ITMCNT=ITMCNT+1
      IF(ITMCNT.EQ.1.OR.ITMCNT.EQ.4)GO TO 2101
      IF (LINCNT.GT.JD.AND.LINCNT.LT.JL)GO TO 2102
      WRITE(3,5004)LINESW
      GO TO 205
2101  IF(LINCNT.GT.JD.AND.LINCNT.LT.JL)GO TO 2103
      ISWDUM=0
7395  DO 3334 ICL=1,6,2
      INTL=ICOL(ICL)
      LIMIT=ICOL(ICL+1)
      DO 3334 JCL=INTL,LIMIT,5
3334  LINESW(JCL)=PLUS
      IF(ISWTCH.EQ.1)GO TO 5311
      LINESW(K)=PHASEC
      LINESW(L)=PHASEB
      LINESW(M)=PHASEA
      IF(ISWDUM .EQ.1)GO TO 7249
5311  GO TO (911,912,913),MAXPU
911   WRITE(3,5005)ITIME,(LINESW(I),I=42,132)
5005  FORMAT(35X,I6,91A1)
      IF(ISWTCH.EQ.1)GO TO 100
      GO TO 8988
912   WRITE(3,5006)ITIME,(LINESW(I),I=26,132)
5006  FORMAT(19X,I6,107A1)
      IF(ISWTCH.EQ.1)GO TO 100
      GO TO 8988
913   WRITE(3,5007) ITIME,(LINESW(I),I=15,132)
5007  FORMAT( 8X,I6,118A1)
      IF(ISWTCH.EQ.1)GO TO 100
C
C
C
8988  IF(ITMCNT.EQ.4)ITMCNT=1
      GO TO 205
2102  GO TO(921,922,923),MAXPU
921   WRITE(3,6001)DUMLIN(JCOL),(LINESW(I),I=42,132)
6001  FORMAT(34X,A1,6X,91A1)
      GO TO 8989
922   WRITE(3,6002)DUMLIN(JCOL),(LINESW(I),I=26,132)
6002  FORMAT(18X,A1,6X,107A1)
      GO TO 8989
923   WRITE(3,6003)DUMLIN(JCOL),(LINESW(I),I=15,132)
6003  FORMAT( 7X,A1,6X,118A1)
C
8989  JCOL=JCOL+1
      GO TO 205
2103  ISWDUM=1
      ISWTCH=0
      GO TO 7395
C
C
C
7249  GO TO (931,932,933),MAXPU
931   WRITE(3,6901)DUMLIN(JCOL),ITIME,(LINESW(I),I=42,132)
6901  FORMAT(34X,A1,I6,91A1)
      GO TO 8990
932   WRITE (3,6902)DUMLIN(JCOL),ITIME,(LINESW(I),I=26,132)
6902  FORMAT(18X,A1,I6,107A1)
      GO TO 8990
933   WRITE(3,6903)DUMLIN(JCOL),ITIME,(LINESW(I),I=15,132)
6903  FORMAT( 7X,A1,I6,118A1)
C
8990  JCOL=JCOL+1
      IF(ITMCNT.EQ.4)ITMCNT=1
205   CONTINUE
      ITIME=ITIME+IDELT
      ITTEST=4-ITMCNT
      IF(ITTEST)9208,9208,9209
9208  GO TO 100
9209  GO TO(7977,7978,100),ITTEST
7977  DO 9513 IK=1,132
9513  LINESW(IK)=BLANK
C
C
      ISWDUM=0
      ISWTCH=1
      GO TO 7395
7978  DO 9711 IJ=1,132
```

```
 9711  LINESW(IJ)=BLANK
       DO 9712 IJ=1,6
       IJO=ICOL(IJ)
 9712  LINESW(IJO)=PLUS
       WRITE(3,5004)LINESW
       ITIME=ITIME+IDELT
       GO TO 7977
 1005  WRITE(3,7777)
 7777  FORMAT('1'5X,'SWITCHING OVER-VOLTAGE EXCEEDS 3.0 P.U.PLOT CONFORM
      +ABLE TO THIS PROGRAM IS NOT FEASIBLE'//)
       GO TO 100
 1006  WRITE(3,8888)
 8888  FORMAT('1'5X,'OVER-VOLTAGE DUE TO LIGTNING OR STEP INPUT EXCEEDS
      +4.0 P.U.PLOT CONFORMABLE TO THIS PROGRAM IS NOT FEASIBLE'//)
       GO TO 100
 1007  WRITE(3,7788)
 7788  FORMAT('1'5X,'MINIMUM NUMBER(12) OF DATA POINTS IS NOT GIVEN
      + AS INPUT.PLOT CONFORMABLE TO THIS PROGRAM IS NOT FEASIBLE'//)
       GO TO 100
 101   STOP
       END
```

B.1 MAP SHOWING BANGLADESH
POWER DEVELOPMENT BOARD (BPDB)
PROJECTS

BPDB
BANGLADESH POWER PROJECTS



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