DETERMINATION OF TRANSMISSION LINE LOSS CO-EFFICIENTS BY DIGITAL COMPUTER FOR OPTIMUM SCHEDULING OF GENERATION

BY

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CERTIFICATE

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

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ABSTRACT

Economic operation of power plants in a large integrated system involves the problem of determining the demands on the individual generating station for a given received load so as to achieve minimum fuel cost as well as minimum transmission losses. To express the total transmission losses as a function of plant loadings requires the calculation of the transmission line loss co-efficients or B-coefficients which are constant for a certain range of load variation.

The present (1980) system and future (1982-83) projected system network of the Western Grid of Bangladesh Power Development Board with three generating plants and thirteen major load centers and with five generating plants and eighteen major load centers respectively were considered to be the basis of the study.

Load-flow solutions of the systems with peak and off peak load conditions were performed to determine the voltage magnitudes with their associated angles at the various buses and the real and reactive power flows between the buses. The systems were simulated on an IBM-370 digital computer to determine the loss formula coefficients matrix, and hence to obtain transmission losses in terms of plants outputs. Computer programmes were developed for load flow studies as well as for B-coefficients matrix solution using the Gauss-Seidel iterative technique.

On the basis of input vs. output and incremental fuel cost vs. output curves of the plants under consideration, optimum generation schedules were obtained for cases (i) neglecting and (ii) including the transmission losses in scheduling formulations. It was observed that a considerable economy in terms of money could be achieved in the case of generation scheduling by considering the transmission losses over that when the losses are neglected and also over any other arbitrary methods of generation scheduling.

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LIST OF PRINCIPAL SYMBOLS

P	Real power
Q	Reactive power
P_m, P_n	Source powers (power supplied by generator m, generator n)
P_L	Total transmission line loss
B	Transmissionloss-formula coefficient matrix
V	Voltage magnitude/Nodal voltage
θ	Phase angle (symbol representing angle)
I	Current vector
Y	Nodal admittance matrix
I_k	Current at bus k
V_k	Voltage at bus k
P_k	Real power at bus k
Q_k	Reactive power at bus k
G	Conductance
G_{kk}	Self conductance of bus k
B	Susceptance
B_{kk}	Self susceptance of bus k
N	Total number of buses
ER	Real (component of) voltage
EI	Imaginary (component of) voltage
RL1(k) RL2(k)	Variables used in Eq. (2.8)
I_G	Generator current
I_L	Total load current
I_{LK}	Current of line or load k
R_k	Resistance of line k

I_k	Scalar line current in line k.
I_{dn}	Real part of generator n current
I_{qn}	Imaginary part of generator n current
Z	Impedance matrix
Z_3	Impedance matrix of reference frame 3.
Z_{m-n}	Impedance matrix for m and n number of sources
R_{m-n}	Real part of Z_{m-n} (as indicated in Eqn.3.6)
X_{m-n}	Imaginary part of Z_{m-n}(as indicated in Eqn.3.6)
A	Represents matrix A
V_m	Absolute value of the voltage of generator m
S	Source Reactive characteristic
S_m	Source reactive characteristic of generator m
F_{mn}	Variable used in Eqn. (3.17)
A_{mn}, H_{mn}	Represent matrices
$\frac{R_{m-n}+R_{n-m}}{2}$	Real symmetric part of Z_{m-n} as indicated Eqn.(3.17)
$\frac{X_{m-n}+X_{n-m}}{2}$	Imaginary symmetric part of Z_{m-n} as indicated Eqn.(3.17)
l_j	Denotes the complex rate of change of load current j with the total load current I_L indicated in Eqn.(3.28)
Q_{Lm}	Denotes part of reactive power of generator m which is included as part of the load at that bus.
Q_{Lom}	Equivalent reactive load at bus m
$Q_{L'm}$	Total reactive load at bus m
F_t	Total cost of fuel input to the system
P_R	Total received load (power)
λ	Incremental cost of received power
F_{nn}	Slope of incremental production cost curve

f_n	Intercept of incremental production cost curve
L_n	Penalty factor of plant n
Ψ	Parameter (Lagrangian multiplier) as indicated in equation 4.3
a, b	Parameters as given in Eqn.(A-1)
x	Variable used in Eqn. (A-1)
ϵ	Represents small positive number as indicated in Eqn. (A-12)
α	Reluxation parameter or acceleration factor as indicated in Eqn. (A-13)
M	Represents maximum number of iteration
m, n	Number of sources
j, k	Number of loads
C	Transformation matrix
C_k^j	Indicates the transformation from reference frame j to reference frame k.
E_R	Voltage at reference point R
E_L	Voltage at load point L
a_m, c_n, w	Variables used in Eqn. (B-14)

CHAPTER-1

INTRODUCTION

1.1 GENERAL

In any system in the present world, much efforts are expended to achieve a high ratio of return (output) to capital (direct or indirect) investment. For a power system to return a profit on the capital invested, proper operation is very important. Rates fixed by regulatory bodies and the importance of conservation of fossil fuels place extreme pressure on power authorities to ensure maximum efficiency of operation and to improve the efficiency continually. This is necessary inorder to maintain a reasonable relation between the price per unit of electrical energy (kwhr) charged to the consumer and the cost incurred by the power authority in delivering that unit of electrical energy (kwhr) in the face of constantly rising prices of fuel, labour, supplies, and maintenance.

Economic scheduling of power plants in an integrated power system presents a complex problem to the power system engineer. This is the problem of determining the demand on the individual generator for a given received load in order to achieve minimum fuel cost as well as minimum transmission losses.

Much effort has so far been expended in the analysis of incremental fuel costs (1) . However, in an integrated power system it is necessary to consider not only the incremental fuel cost but also the cost of transmission losses for optimum economy. Although the incremental fuel cost at one plant may be lower than that at another plant for a given distribution of load between them, the plant with lower incremental fuel cost may be so distant from the system load centre that the resulting transmission losses dictate, lowering the load at that plant with the higher incremental cost. The co-ordination of incremental fuel cost and incremental transmission losses results in a considerable amount of economy in terms of fuel savings.

In a complicated system, it becomes too laborious to determine the currents (I) in the various branches and to make a summation of the I^2R(power) losses of the whole system. In fact, if the system losses for many different generating conditions are required, the calculation involved in the summation method become practically prohibitive. It, therefore, becomes necessary to develop an expression for the total transmission loss as a function of plant loading in any problem involving the economic scheduling of plant generation in an integrated power system.

1.2 LITERATURE REVIEW ON METHODS OF CALCULATING B-COEFFICIENTS

A transmission loss formula expressing the total transmission losses in terms of source powers was first presented by E.E. George(2) in 1943. The formula was of the following form:

$$P_L = \text{total transmission losses}$$

$$= B_{11}P_1^2 + B_{22}P_2^2 + B_{33}P_3^2 + \;\ldots\ldots\; + B_{nn}P_n^2$$

$$+ 2B_{12}P_1P_2 + 2B_{13}P_1P_3 + \;\ldots\;+ 2P_{23}P_2P_3 + \ldots + 2B_{mn}P_mP_n$$

$$= \sum_m \sum_n P_m B_{mn} P_n \qquad \ldots \qquad (1,1)$$

where

P_m, P_n = source powers,

B_{mn} = transmission line-loss-formula coefficients (usually transmission line loss coefficients are called "B-coefficient"). The determination of the B_{mn} coefficients was based on a longhand procedure which required two to three weeks work by two men for a system of eight to ten generators.

The application of the network analyzer to determine a similar loss formula was developed later by Ward, Eaton and Hale (3) of Purdue University and published in 1950.

At the 1951 AIEE summer convention, G. Kron, in conjunction with G.W. Stagg and L.K. Kirchmayer, presented companion papers (4, 5) which described an improved method of deriving a total transmission loss formula requiring considerably less network analyzer measurements and arithmetic calculations. Reference 4, in addition, evaluated the discrepancies introduced by the assumptions made in obtaining a loss formula.

The application of automatic digital computers to calculate a loss formula was presented by A.F. Glimn, R. Habermann, Jr., L.K. Kirchmayer, and G.W. Stagg in 1953 (6).

W.R. Brownless (7) indicated a method of expressing transmission losses in terms of generator voltages and angles and the X/R ratios of the transmission circuits.

The first major step in the development of corordinating incremental fuel costs and incremental transmission losses was presented in 1949 by E.E. George, H.W. Page, and J.B. Ward (8) in their use of the network analyzer to prepare predicted plant loading schedules for a large power system. At the same time the electrical engineering staff of the American Gas and Electric Service Corporation, also with the aid of the network analyzer, developed a method of modifying the incremental fuel costs of the various plants on an incremental slide rule in order to account for transmission losses. Next, the American Gas and Electric Service Corporation, in cooperation with the General Electric Company, successfully employed transmission loss formulas and punched card machines for the preparation of penalty factor charts to be used in the economic scheduling of generation (9). The incremental production cost of a given plant multiplied by the penalty factor for that plant gave the incremental cost of power delivered to the system load from that plant. Optimum economy, with the effect of transmission losses considered, was obtained when incremental cost of delivered power was the same from all sources.

In 1952, L.K. Kirchmayer, and G.W. Stagg (10) presented (i) a mathematical analysis of various methods of coordinating incremental fuel costs and incremental transmission losses, (ii) an evaluation of errors introduced in optimum system operation by assumptions involved in determining a loss formula, and (iii) an evaluation of the savings to be obtained by co-ordinating incremental fuel costs and incremental transmission losses.

Progress in the analysis of the economic operation of a combined thermal and hydro-electric power system was reported by W.G. Chandler, P.L. Dandeno, A.F. Glimn, and L.K. Kirchmayer(11).

An iterative method of calculating generation schedules suitable for the use of a high-speed automatic digital computer has been described by A.F. Glimn, R. Habermann, Jr., L.K. Kirchmayer, and R.W. Thomas (12) . For a given total load, the computer calculates and tabulates incremental cost of received power, total transmission losses, total fuel input, penalty factors, and received load, along with the allocation and summation of generation.

Early in 1955, the American Gas and Electric Service Corporation installed an incremental transmission loss computer for the use of the system load dispatcher (13,14) . This computer calculated incremental transmission losses and penalty factors for various system operating conditions. The coordinated operation of this computer and an incremental slide rule furnished a flexible and accurate method of taking into account the changing conditions in the plant and in the transmission system.

A digital computer method for direct calculation of loss formulae coefficients was presented by L.K. Kirchmayer, H. Happ, G.W. Stagg, J.F. Hohenstein (15) in 1960 which offered significant improvements over previous methods with respect to costs and data handling. In addition, improved accuracy was obtained by automatic determination of reactive output characteristics of generators (s-factors). This method utilized fully the unique capabilities of digital computers and directly determined the impedances between the sources and hypothetical load and projected these impedances to loss formulae coefficients.

A direct method for construction of loss formulas for systems containing off-nominal auto-transformers was presented by the same authors (16) in 1964. Another significant improvement realized through this method was a reduction in computer time, compared to that required previously.

An improved method of determining loss-formulae coefficients and hence the incremental transmission loss factor from power system admittances and voltages developed by E.F Hill and W.D. Stevenson Jr. (17) was published in June 1968. In the same year another suggestion that came from the same authors for finding the transmission loss-coefficients was to determine the second partial derivative of the system losses with respect to plant outputs (18).

The first published work on the construction of loss-formulae for the Eastern Grid of Bangladesh Power Development Board (BPDB) was undertaken by B.B. Saha (19) in 1972. He used a G.E.A.C. network analyzer to solve the transmission loss-matrix (B-matrix), but his method was subject to the inherent limitations at such analogue techniques.

In the year 1973, load flow studies (which are required in the determination of B-coefficients) in electrical networks was undertaken by A.N.M. Sadrul Ula (27) using FORTRAN II language on an IBM 1620 digital computer.

In the year 1975, a digital method of calculating the B-matrix for the Eastern Grid of BPDB was investigated by A.M.M. Khan (20) by considering a simplified version of the system with four generating plants and eight major load centres. An IBM 360 computer was used and the programme was developed in FORTRAN IV language.

The preceding summary and references are obviously not complete but they are intended to include much of the significant developments to date.

1.3 SCOPE OF THE PRESENT THESIS

The scope of this thesis includes the theory and practical applications in determining the transmission loss formulae co-efficients for the Western-Grid of Bangladesh Power Development Board (BPDB) using a high speed digital computer, and in the determination of the optimum generatior schedules for the generating plants of the same system. To be more specific, it involves:

1. Determination of the load-flows in various lines of the present (1980) and future expansion (including the East-West interconnector in the year 1982-83) system by digital computer.

2. Determination of B-coefficients for the systems with the help of a digital computer.

3. Determination of reactive characteristics(s-factors) of the various plants under investigation.

4. Determination of optimum scheduling of generation for the generating plants (1980) under consideration for different values of received load.

5. Evaluation of the savings made by such an optimum scheduling of generation.

1.4 SUMMARY

Chapter 1 presents, general approach for determining B-coefficients, literature review and scope of the thesis.

Chapter 2 presents, as a brief introduction, the development of an efficient load-flow (Gauss-Seidel iterative method) programme and its application to determine the unknown voltages will their associated angles at each bus and power-flow (real and reactive) in various lines of the systems.

Chapter 3 discusses, the basic principles for calculating the transmission losses of a system in terms of the source loading and the B-coefficients. This chapter also covers the development of an efficient programme for automatic determination of the B-coefficients for the Western Grid of BPDB and for the determination of the reactive characteristics of various plants during the course of calculating B-coefficients.

Chapter 4 presents, a mathematic analysis of the various methods of coordinating incremental fuel cost and incremental transmission losses to prepare an optimum scheduling of generation.

Chapter 5 evaluates, the annual savings made under the most economic scheduling and compares the result with financial losses due to arbitrary scheduling.

Conclusions of the study are presented in Chapter 6 which also includes a few suggestions for possible future extension of the work.

CHAPTER-2

LOAD FLOW STUDY

2.1 INTRODUCTION

A load flow study is the determination of the voltage, current, power, and power factor or reactive power at various points in an electric network under existing or contemplated conditions of normal operation. Load-flow studies are essential in planning the future development of the system because satisfactory operation of the system depends on knowing the effects of interconnections with other power systems, of new loads, new generating stations, and new transmission lines before they are installed.

As a matter of practical interest on the determination of transmission line loss coefficients (B-coefficients) by digital computer, the transmission network of the Western-Grid of BPDB has been considered. The above study requires all load-flow data and results, so the author has taken a step to develop an efficient load-flow (Gauss-Seidel Iterative Method) programme for the existing (1980) system and the system that may exist in the year 1982-83, including the East-West interconnector. A hypothetical 60 MW generating unit at Tongi has been considered only to export energy from Eastern-Grid to the Western-Grid. The Power Development Authority of Bangladesh, supplied necessary data, such as, the transmission system configuration, line parameters, data of transformers and generators as well as projected load conditions upto 1983.

2.2 DATA FOR LOAD-FLOW STUDY

Either the bus self and mutual admittances which compose the bus admittance matrix, Y_{bus} or the driving point and transfer impedances which compose Z_{bus} may be used in solving the load-flow problem. We have confined our study to methods using admittances. The starting point in obtaining the data which must be furnished to the computer is the one-line diagram of the system. Values of series impedances and shunt admittances of transmission lines are necessary so that the computer can determine all the Y_{bus} or Z_{bus} elements. Other essential information includes transformer ratings and impedances, shunt capacitor ratings and transformer tap settings.

The quantities associated with a node or bus in any power network are:

1. Voltage magnitude, V
2. The phase angle, θ, relative to the phase angle of a reference bus
3. Net real power generation, P
4. Net reactive power generation, Q

Of the four quantities any two are the known quantities along with the configuration and circuit parameters of the power network.

Normally three types of nodes or buses are encountered in a load flow study (24, 27, 32). It is necessary to select one bus, called the swing or slack bus, to provide the additional real and reactive power to supply the transmission losses, since these are unknown until the final result is obtained. At this bus both voltage magnitude (V) and phase angle (θ) are specified. Real power (P) and reactive power (Q) at this bus are determined by the computer as part of the solution. The remaining buses are designated either as voltage controlled buses or load buses. The real power (P) and voltage magnitude (V) are specified at a voltage controlled bus. The real (P) and reactive (Q) powers are specified at a load bus. There is another type of bus called the passive bus which has neither load nor generator. These buses are usually treated as load buses with both P and Q equal to zero.

The load flow problem requires that the pair of unknown quantities at each bus be found. When all the unknown pairs, particularly the unknown voltages and phase angles are found; then the currents, real and reactive power flows, and losses in the various lines can be ascertained.

Network connections are described by using code numbers assigned to each bus. These numbers specify the terminals of transmission lines and transformers. Code numbers are used also to identify the types of buses, the location of static capacitors, shunt reactors, and those elements in which off-nominal turns ratios of transformers are to be represented.

The mathematical formulation of the load-flow problem results in a system of algebraic nonlinear equations. As the number of unknowns are large and the nonlinearity in the equations make it impracticable to use any direct method, such as Gaussian elemination (33) method or Cramer's rule (34) involving determinants. Iterative techniques are the only alternative and are of special help because of large number of zero elements in the nodal equations of the power network. The solution must satisfy Kirchhoff's Laws, i.e the algebraic sum of all flows at a bus must equal zero, and the algebraic sum of all voltages in a loop must equal zero. One or the other of these laws is used as a test for convergence of the solution in the iterative computational method. The author has used Gauss-Seidel iterative (27) method (Appendix-A(1)) for the numerical solution of algebraic equations describing the power system for load flow problem.

2.3 DERIVATION OF THE NODAL EQUATIONS

The complexity of obtaining a formal solution for load-flow in a power system arises because of the differences in the type of data specified for the different kinds of buses. Although the formulation of sufficient equations is not difficult, the closed form of solution is not practical. Digital solution of the load-flow problems we shall consider follow an iterative process by assigning estimated values to the unknown bus voltages and calculating a new value for each bus voltage from the estimated values at the other buses and the real and reactive power specified. A new set of values for voltage is thus obtained for each bus and is used to calculate still another set of bus voltages. Each calculation of a new set of voltages is called an iteration (Appendix-A). The iterative process is repeated until the difference between successive iteration at each bus is less than a specified minimum value.

We shall examine first the solution based on expressing the voltage of a bus as a function of the real and reactive power delivered to the bus from generators or supplied to the load connected to that bus, the estimated or previously calculated voltages at the other buses, and the self and mutual admittances of the nodes. We shall derive the node equations (32) for a four-bus system and write the general equations later. With the swing bus designated as number 1, computation starts with bus 2. If P_2 and Q_2 are the scheduled real and reactive power entering the system at bus 2,

$$V_2^* I_2 = P_2 - jQ_2 \qquad \ldots \qquad (2.1)$$

from which I_2 is expressed as

$$I_2 = \frac{P_2 - jQ_2}{V_2^*} \qquad \ldots \qquad (2.2)$$

and in terms of self and mutual admittances of the node, with generators and loads omitted since the current into each node is expressed (32) as in eqn. (2.2),

$$I_2 = \frac{P_2 - jQ_2}{V_2^*} = Y_{21}V_1 + Y_{22}V_2 + Y_{23}V_3 + Y_{24}V_4 \qquad \ldots \qquad (2.3)$$

solving for V_2 gives

$$V_2 = \frac{1}{Y_{22}} \left(\frac{P_2 - jQ_2}{V_2^*} - (Y_{21}V_1 + Y_{23}V_3 + Y_{24}V_4) \right) \qquad \ldots \qquad (2.4)$$

Equation (2.4) gives a corrected value for V_2 based upon scheduled P_2 and Q_2 when the values estimated originally are substituted for the voltage expressions on the right hand side of the equation.

The calculated value for V_2 and the estimated value for V_2^* will not agree. By substituting the conjugate of the calculated value of V_2 for V_2^* in Eqn. (2.4) to calculated another value for V_2, agreement would be reached to a good degree of accuracy after several iterations and would be the correct value for V_2 with estimated voltages and without regard to power at the other buses. This value would not be the solution for V_2 for the specific load-flow conditions, however, because the voltages upon which this calculation for V_2 depends are the estimated values at the other buses and the actual voltages are not yet known. Two successive calculations of V_2 (the second being the first except for the correction of V_2^*.) are recommended at each bus before proceeding to the next one.

As the corrected voltage is found at each bus, it is used in calculating the corrected voltage at the next. The process is repeated at each bus consecutively throughout the network (except at the swing bus) to complete the first iteration. Then the entire process is carried out again and again until the amount of correction in voltage at every bus is less than some predetermined precision index.

This process of solving linear algebraic equations is known as the Gauss-Seidel iterative method (Appendix-A(1)). If the same set of voltage values is used throughout the complete iteration (instead of immediately substituting each new value obtained to calculate the voltage at the next bus) the process is called the Gauss iterative method.

Convergence (Appendix-A(2)) upon an erroneous solution may occur if the original voltages are widely different from the correct values. Erroneous convergence is usually avoided if the original values are of reasonable magnitude and do not differ too widely in phase. Any unwanted solution is usually detected (32) easily by inspection of the results since the voltages of the system do not normally have a range in phase wider than 45^{o} and the difference between nearby buses is less than about 10^{o} and are often very small.

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

$$P_k - jQ_k = V_k^{*} I_k \qquad \ldots \qquad \ldots \quad (2.5)$$

where P_k is the real power at the bus k, Q_k is the reactive power at the bus k, V_k and I_k are the voltage and current at the bus k, and V_k^{*} is the complex conjugate of V_k.

For a total of N buses the current at the bus k can also be expressed (27,32) in terms of admittances and voltages of the adjacent buses n as given by:

$$I_k = \sum_{n=1}^{N} Y_{kn} V_n \qquad \ldots \quad (2.6)$$

or $$I_k = Y_{kk} V_k + \sum_{\substack{n=1 \\ n \neq k}}^{N} Y_{kn} V_n \qquad \ldots \qquad \ldots \quad (2.6)$$

where $Y_{kn} = G_{kn} + jB_{kn}$ = mutual admittance between bus k and bus n(G being the conductance and B being the susceptance), and $Y_{kk} = G_{kk} + jB_{kk}$ = self admittance of bus k that is sum of the admittances of all branches terminating at bus k.

Equation (2.6) can be rewritten as:

$$V_k = \frac{1}{Y_{kk}} \left(I_k - \sum_{\substack{n=1 \\ n \neq k}}^{N} Y_{kn} V_n \right) \quad \ldots \quad (2.7)$$

Combining equations (2.5) and (2.7)

$$V_k = \frac{1}{Y_{kk}} \left(\frac{P_k - jQ_k}{V_k^*} - \sum_{\substack{n=1 \\ n \neq k}}^{N} Y_{kn} V_n \right) \quad \ldots\ldots \quad (2.7a)$$

Substituting the real and imaginary components of the admittances and expanding (27) different terms, the above expression becomes:

$$V_k = \frac{RL1(k) + jRL2(k)}{V_k^*} - \sum_{\substack{n=1 \\ n \neq k}}^{N} (YL1(k,n) + jYL2(k,n))V_n \quad (2.8)$$

where $RL1(k) = P_k G1(k) - Q_k B1(k)$,

$RL2(k) = -Q_k G1(k) - P_k B1(k)$,

$YL1(k,n) = G_{kn} G1(k) + B_{kn} B1(k)$,

$YL2(k,n) = B_{kn} G1(k) - G_{kn} B1(k)$.

and $G1(k) = G_{kk}/(G_{kk}^2 + B_{kk}^2)$,

$B1(k) = B_{kk}/(G_{kk}^2 + B_{kk}^2)$.

Substituting the real and imaginary components of the voltages and solving for real and imaginary terms, the above expression (20,27,28) becomes:

$$ER(k) = \frac{RL1(k)ER(k) - RL2(k)\ EI(k)}{ER(k)^2 + EI(k)^2}$$

$$- \sum_{\substack{n=1 \\ n \neq k}}^{N} (YL1(k,n)\ ER(n) - YL2(k,n)EI(n)) \quad \ldots \quad (2.9)$$

$$EI(k) = \frac{RL2(k)ER(k) + RL1(k)\ EI(k)}{ER(k)^2 + EI(k)^2}$$

$$- \sum_{\substack{n=1 \\ n \neq k}}^{N} (YL2(k,n)ER(n) + YL1(k,n)EI(n)) \quad .. \quad (2.10)$$

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

The above two equations are solved by Gauss-Seidel iterative method.

The line flows are obtained (28, 32) from the equation

$$P_{(k,L)} - jQ_{(k,L)} = V_k^{*}(V_k - V_L)Y_{(k,L)} + V_k^{*}V_k\frac{Y'_{(k,L)}}{2}$$

where $Y_{(k,L)}$ is the line admittance $\frac{Y'_{(k,L)}}{2}$ is the line charging admittance.

2.4 DESCRIPTION OF THE SYSTEM

Due to the barrier presented by the wide flowing Brahmaputra-Jamuna river, Bangladesh Electricity system has to be developed in two main separate parts, East and West Zones. However, Bangladesh Power Development Board (BPDB) has recently entered into a contract to construct a 230 KV double-circuit interconnector to link the two zones. Construction work of this project has already been taken up and is expected to be completed by 1982-83. The lines will, however, be energized (36) initially at 132 KV with loading capacity of 350 MW and about 500 MW when energized on 230 KV.

The system chosen for the study is the existing (1980) Western-Grid of BPDB with the exception of a few radial feeders and with the inclusion of some immediate future expansion schemes in the year 1982-83 including the initial (132 KV) East-West interconnector, which is expected to import 189 GWH of energy from the East-Zone.

The main generating station is located at Goalpara near khulna town at the sourth of the zone. The total installed capacity of the plants comprises of a mixture of steam, diesel and gas turbine driven generators. The steam plant uses furnace oil as fuel whereas the gas turbines run on naptha or diesel and the diesel engines on diesel distillate. The second major power station is located at Bheramara about 90 miles north of Khulna where two units of 20 MW gas turbine generators are installed. This station burns H.S.D as fuel. Small diesel stations of various sizes are located at Saidpur and Barisal (isolated).

The total available capacity of West Zone at present (1980) is 140 MW. At Goalpara one 2x28 MW(G.T) and another 1x110 MW (steam) stations are now under construction and expected to be completed by June 1980 and June 1982 respectively.

The 132 KV grid runs from Khulna in the South for almost the whole length (300 miles) of the West Zone to Thakurgaon in the North. From Goalpara to the North is presently a single circuit but work is proceeding on the construction of a second circuit upto Ishurdi. Second circuit extention upto Saidpur will be taken up during the second five-year plan period and upto Thakurgaon at a later stage. Work is also proceeding to complete the grid in Khulna-Bagerhat-Barisal section in the south of the zone (total of 510 miles). The details of existing installed plants and transmission lines in this zone and details of the future (1982-83) extension programmes are shown in Fig. 2.1 and 2.2 respectively.

2.5 FEATURES OF THE COMPUTER PROGRAMME

Large-scale load-flow computer programmes incorporate many automatic features to facilitate their use in power system planning, operating and interconnection studies. The principal objectives of these features are to make maximum use of the computer's capability and to minimize the number of manual operations required by the engineer in specifying and maintaining system data for the initial and subsequent load-flow cases.

The programme was developed in FORTRAN IV language incorporating the theory developed in the previous sections for running with the IBM 370 computer available at the Computer Centre, BUET.

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

The system connecting lines are read in next. This is in the form of an NXN matrix (where N is the total number of buses) having as elements either zero or one. One represents a connecting line between two buses and zero represents no connection between them. At every calculation step, the computer compares

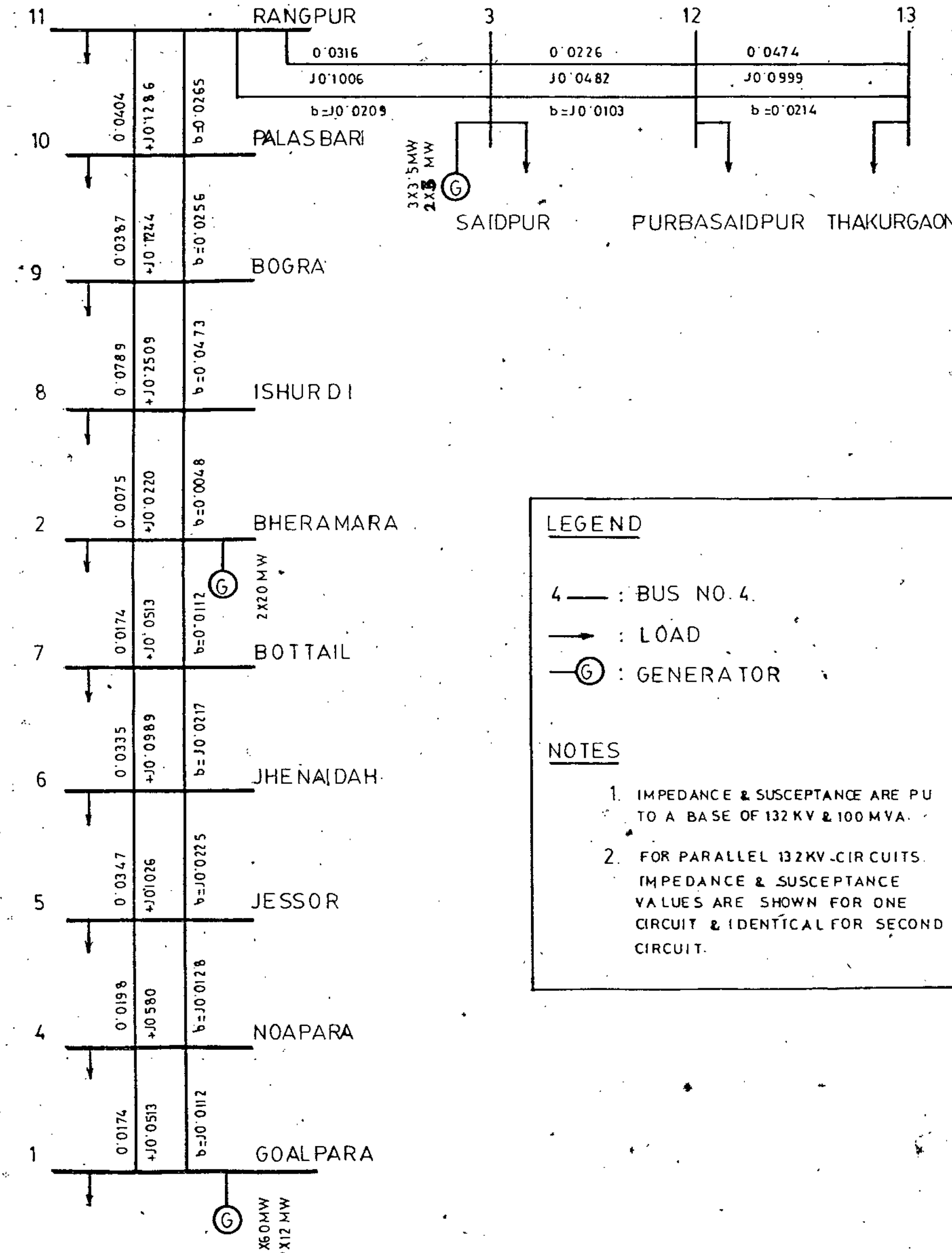


FIG. 2.1 SIMPLIFIED IMPEDANCE DIAGRAM OF THE SYSTEM (W.G.; BPDB, 1980)

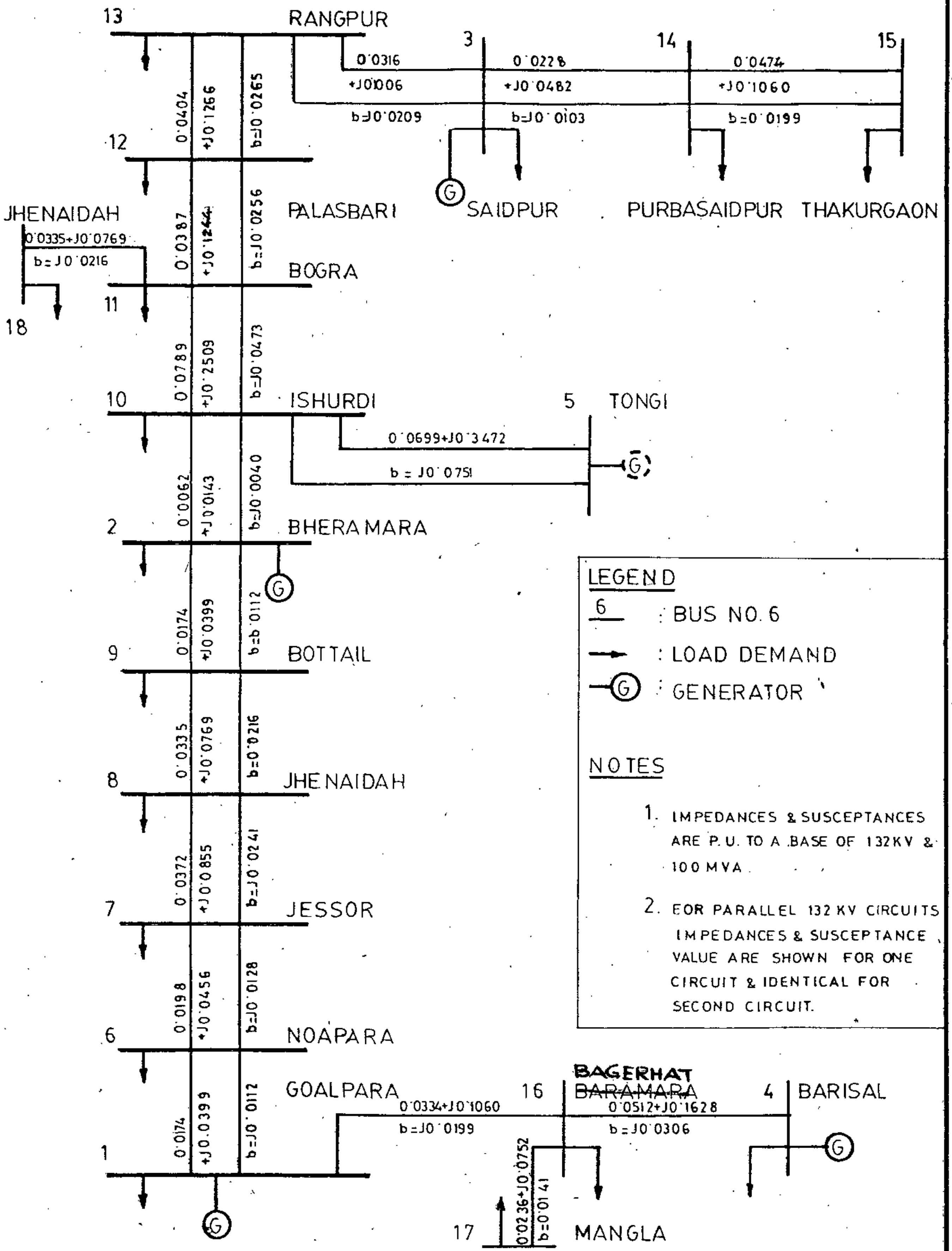


FIG. 2·2. SIMPLIFIED IMPEDANCE DIAGRAM OF THE SYSTEM (W.G., BPDB, 1982-1983)

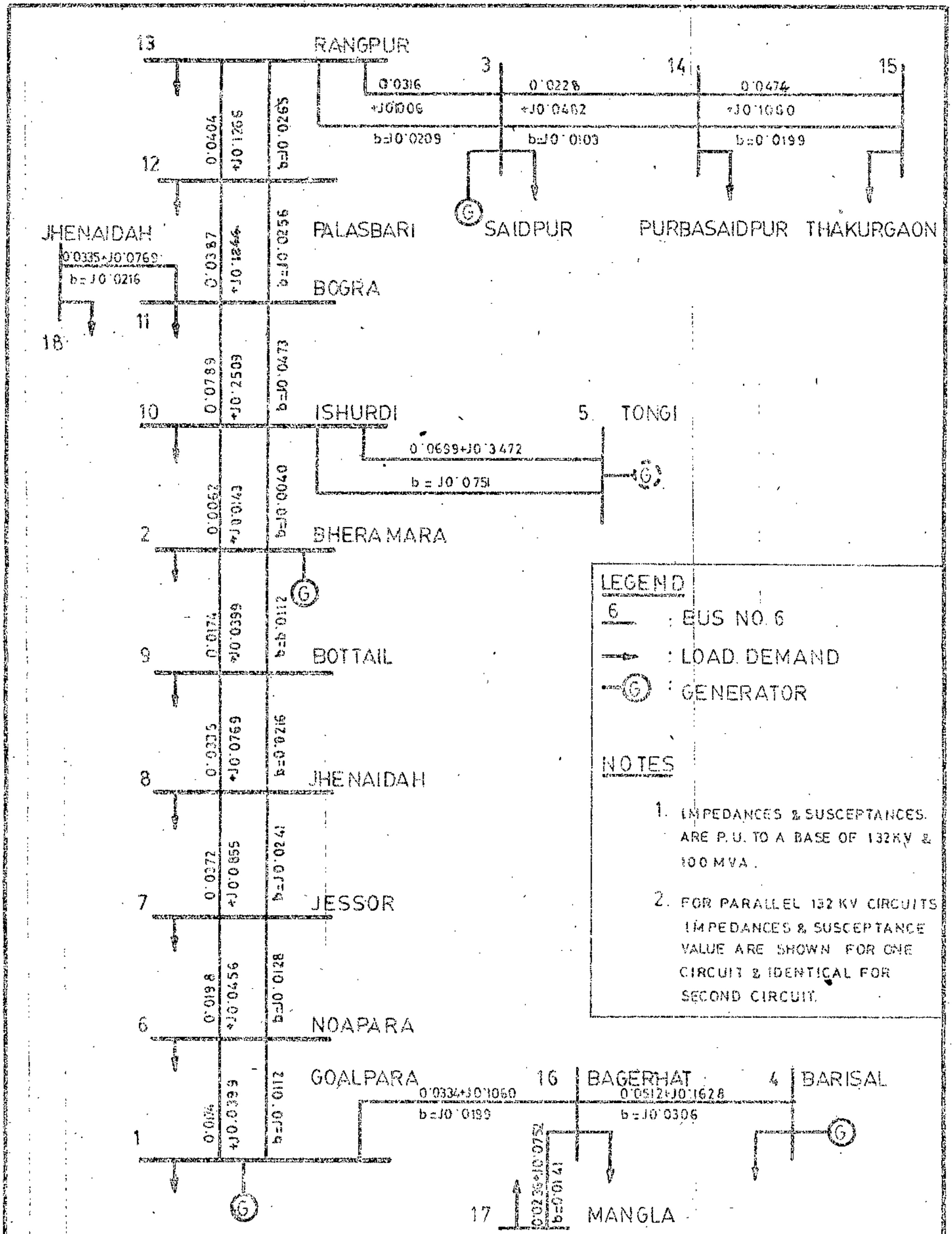


FIG. 2.2. SIMPLIFIED IMPEDANCE DIAGRAM OF THE SYSTEM (W.G., BPDB, 1982-1983)

the two concerned buses against this matrix and if there is no connection between them, the calculation proceeds to the next bus, thus saving an enormous amount of computer time as very few buses have interconnecting lines between them. This matrix also helps in huge savings of computer storage by reading-in the line parameters-resistance, reactance and line charging reactance (shunt susceptance), and calculating and storing only the nonzero elements of conductance, susceptance and line charging susceptance.

Next input data are the real and reactive power generated at the generator bus and the real and reactive parts of loads demand/at each bus. Voltage magnitude of the swing-bus is then specified and then initial voltages of all other buses are assumed. To perform as many operations as possible before the beginning of the iteration loop, some voltage equation parameters are calculated with the help of input data. These calculated values along with all or any of the previous data could be printed with appropriate captions. This provides an opportunity for checking any errors in the reading-in, writing or formatting of data. The programme upto this is performed only once in any load-flow problem and is never repeated.

The next part of the programme is the iterative part. For simplification, the real and reactive components of voltages are solved separately with the help of equations (2.9) and (2.10). Then the changes in bus voltages from the previous iteration are calculated. The bus voltages are than replaced by the bus voltage in the previous iteration plus the changes in bus voltage multiplied by the acceleration factor. The real and reactive components of voltages are then tested against a predetermined precision index called tolerance. If the change is not within this tolerance, the iteration count is advanced by one and the iteration portion is repeated again.

When the changes in voltage are within tolerance, the number of iterations required to converge the problem, and the real and reactive parts of voltage along with the bus numbers are printed.

Next, voltage magnitudes and angles associated with them are calculated and printed along with the bus numbers.

Then, the line flows are calculated and real and reactive power-flows along with bus numbers are printed.

2.6 RESULTS

The computer programme described in the last section has been used to find the complete automatic load-flow solution of the Western-Grid of Bangladesh Power Development Board. Figs.2.1 and 2.2 shows the one-line impedance diagrams of the systems for 1980 and 1982-83 respectively. The systems chosen contain present and future projects of power stations and transmission lines. Load flow studies were performed with 13 buses including 3 generator buses and 18 buses including 5 generator buses for present and future systems respectively. For convenience of the programmes the generator buses were coded as bus number 1 to 3 and 1 to 5 respectively. In both the systems, the Goalpara bus, designated as bus number 1, was considered as the swing bus and its voltage

TABLE: 2.1A

MAXIMUM (PEAK) LOAD CONDITION
(FOR THE YEAR 1980)

SPECIFIED TERMINAL CONDITIONS (P.U.)

BASE MVA = 100; BASE KV = 132

Bus No.	Voltage components		Power Generated		Power Demand	
	Real	Reactive	Real (PG)	Reactive (QG)	Real (PD)	Reactive (QD)
1	1.05	0.0	0.84	0.63	0.55	0.4125
2	1.0	0.0	0.40	0.30	0.11	0.0825
3	1.0	0.0	0.165	0.12375	0.06	0.045
4	1.0	0.0	0.0	0.0	0.06	0.045
5	1.0	0.0	0.0	0.0	0.10	0.075
6	1.0	0.0	0.0	0.0	0.04	0.03
7	1.0	0.0	0.0	0.0	0.06	0.045
8	1.0	0.0	0.0	0.0	0.08	0.06
9	1.0	0.0	0.0	0.0	0.065	0.04875
10	1.0	0.0	0.0	0.0	0.05	0.0375
11	1.0	0.0	0.0	0.0	0.06	0.045
12	1.0	0.0	0.0	0.0	0.05	0.0375
13	1.0	0.0	0.0	0.0	0.08	0.06

TABLE: 2.1B

MINIMUM (OFF-PEAK) LOAD CONDITION
(FOR THE YEAR 1980)

SPECIFIED TERMINAL CONDITIONS (p.u.)

BASE MVA = 100 ; BASE KV = 132

Bus No.	Voltage components		Power Generated		Power Demand	
	Real	Reactive	Real (PG)	Reactive (QG)	Real (PD)	Reactive (QD)
1	1.05	0.0	0.588	0.441	0.385	0.28875
2	1.0	0.0	0.40	0.30	0.077	0.05775
3	1.0	0.0	0.1155	0.086625	0.042	0.0315
4	1.0	0.0	0.0	0.0	0.042	0.0315
5	1.0	0.0	0.0	0.0	0.070	0.0525
6	1.0	0.0	0.0	0.0	0.028	0.0210
7	1.0	0.0	0.0	0.0	0.042	0.0315
8	1.0	0.0	0.0	0.0	0.056	0.042
9	1.0	0.0	0.0	0.0	0.0455	0.034125
10	1.0	0.0	0.0	0.0	0.035	0.02625
11	1.0	0.0	0.0	0.0	0.042	0.0315
12	1.0	0.0	0.0	0.0	0.035	0.02625
13	1.0	0.0	0.0	0.0	0.056	0.042

TABLE: 2.2A

MAXIMUM (PEAK) LOAD CONDITION
(FOR THE YEAR 1982-83)

SPECIFIED TERMINAL CONDITIONS (P.U.)

BASE MVA = 100; BASE KV = 132

Bus No.	Voltage components		Power Generated		Power Demand	
	Real	Reactive	Real (PG)	Reactive (QG)	Real (PD)	Reactive (QD)
1	1.05	0.0	2.5000	1.8750	0.66	0.495
2	1.0	0.0	0.6000	0.4500	0.130	0.0975
3	1.0	0.0	0.2150	0.16125	0.075	0.05625
4	1.0	0.0	0.2550	0.19125	0.100	0.0750
5	1.0	0.0	0.6000	0.4500	0.0	0.0
6	1.0	0.0	0.0	0.0	0.080	0.060
7	1.0	0.0	0.0	0.0	0.120	0.090
8	1.0	0.0	0.0	0.0	0.050	0.0375
9	1.0	0.0	0.0	0.0	0.070	0.0525
10	1.0	0.0	0.0	0.0	0.420	0.3150
11	1.0	0.0	0.0	0.0	0.095	0.07125
12	1.0	0.0	0.0	0.0	0.060	0.0450
13	1.0	0.0	0.0	0.0	0.080	0.060
14	1.0	0.0	0.0	0.0	0.080	0.060
15	1.0	0.0	0.0	0.0	0.110	0.0825
16	1.0	0.0	0.0	0.0	0.040	0.030
17	1.0	0.0	0.0	0.0	0.045	0.03375
18	1.0	0.0	0.0	0.0	0.030	0.0225

TABLE: 2.2B

MINIMUM (OFF-PEAK) LOAD CONDITION
(FOR THE YEAR 1982-83)

SPECIFIED TERMINAL CONDITIONS (P.U.)

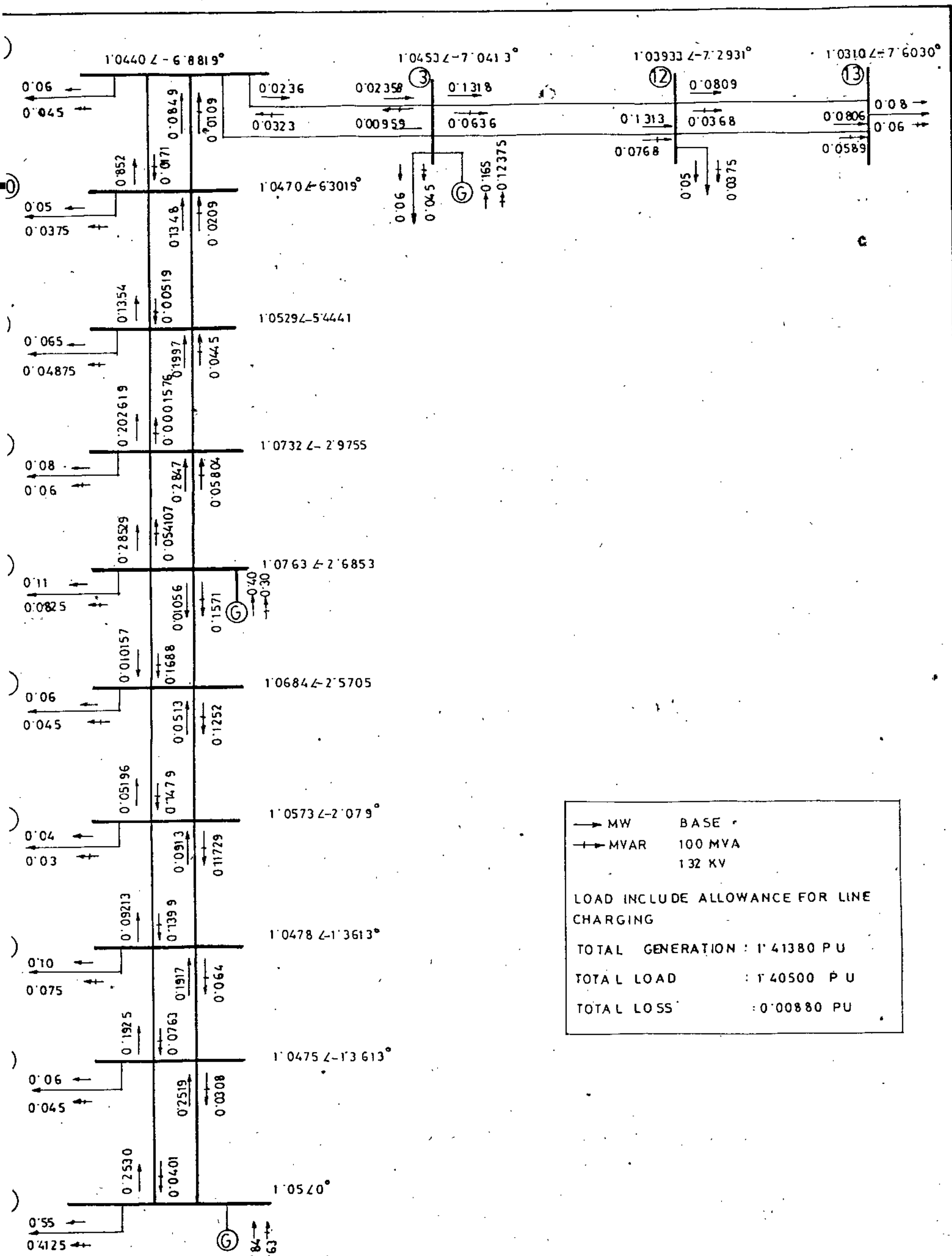
BASE MVA = 100; BASE KV = 132

Bus No.	Voltage components		Power Generated		Power Demand	
	Real	Reactive	Real (PG)	Reactive (QG)	Real (PD)	Reactive (QD)
1	1.05	0.0	2.50	1.875	0.462	0.3465
2	1.0	0.0	0.60	0.45	0.091	0.06825
3	1.0	0.0	0.215	0.16125	0.0525	0.039375
4	1.0	0.0	0.255	0.19125	0.07	0.0525
5	1.0	0.0	0.60	0.45	0.00	0.0000
6	1.0	0.0	0.0	0.0	0.056	0.042
7	1.0	0.0	0.0	0.0	0.084	0.063
8	1.0	0.0	0.0	0.0	0.035	0.02625
9	1.0	0.0	0.0	0.0	0.049	0.03675
10	1.0	0.0	0.0	0.0	0.294	0.2205
11	1.0	0.0	0.0	0.0	0.0665	0.049875
12	1.0	0.0	0.0	0.0	0.042	0.0315
13	1.0	0.0	0.0	0.0	0.056	0.042
14	1.0	0.0	0.0	0.0	0.056	0.042
15	1.0	0.0	0.0	0.0	0.077	0.05775
16	1.0	0.0	0.0	0.0	0.028	0.021
17	1.0	0.0	0.0	0.0	0.0315	0.023625
18	1.0	0.0	0.0	0.0	0.021	0.01575

magnitude was held constant at $1.05\angle 0^{\circ}$ p.u. The line parameters consisting of resistance, reactance and line charging (shunt) susceptance are shown in the impedance diagrams of Figs.2.1 and 2.2. The terminal conditions specified by peak and off-peak loading conditions are given in Tables 2.1A and 2.1B and 2.2A and 2.2B respectively.

The peak and off-peak load-flows were excecuted separately. Complete load-flow results and voltage magnitude with associated angles are shown in Figs. 2.3A/2.3B and 2.4A/2.4B for present and future systems respectively.

Tolerance limit was set at 0.0002 which is fairly good for accuracy in the solution by Gauss-Seidel iterative method (28). The maximum number of iteration was at 400. A number of acceleration factors 1.4, 1.5, 1.6, 1.7, 1.85 were given as input, but the solution converged in 50/65 iterations with acceleration factor of 1.6 for the present (1980) peak/off-peak systems and 66/77 iterations with acceleration factor of 1.6 for the future (1982-83) peak/off peak systems respectively. (Time taken by computer for the complete load-flow solutions were noted as 2-03/2-06 and 2-11/2-14 seconds respectively).



-G. 2'3A: BASE PEAK LOAD-FLOW, WESTERN GRID, BPDB (1980).

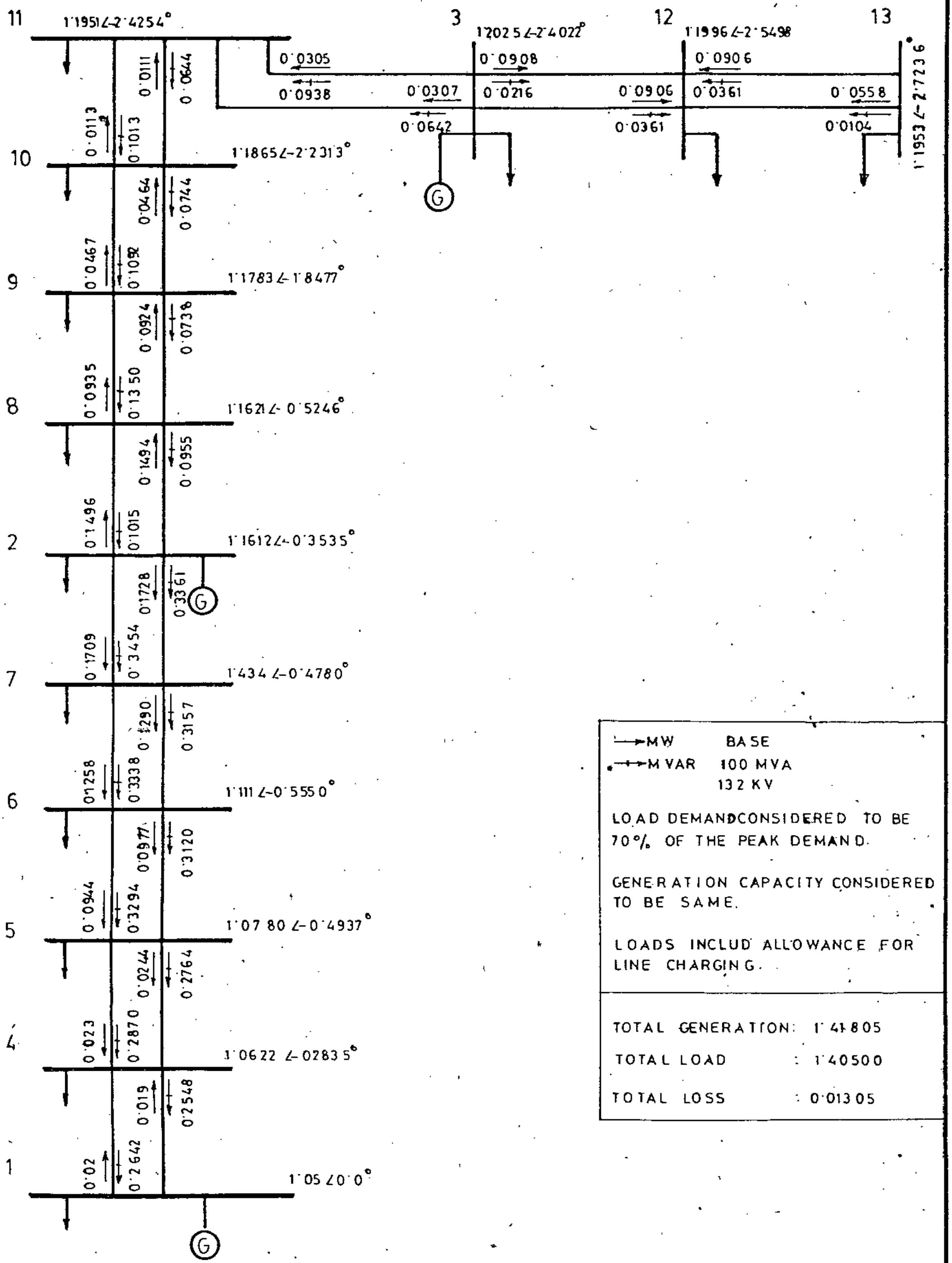


FIG.2.3B: BASE OFF-PEAK LOAD-FLOW, WESTERN GRID, BPDB (1980)

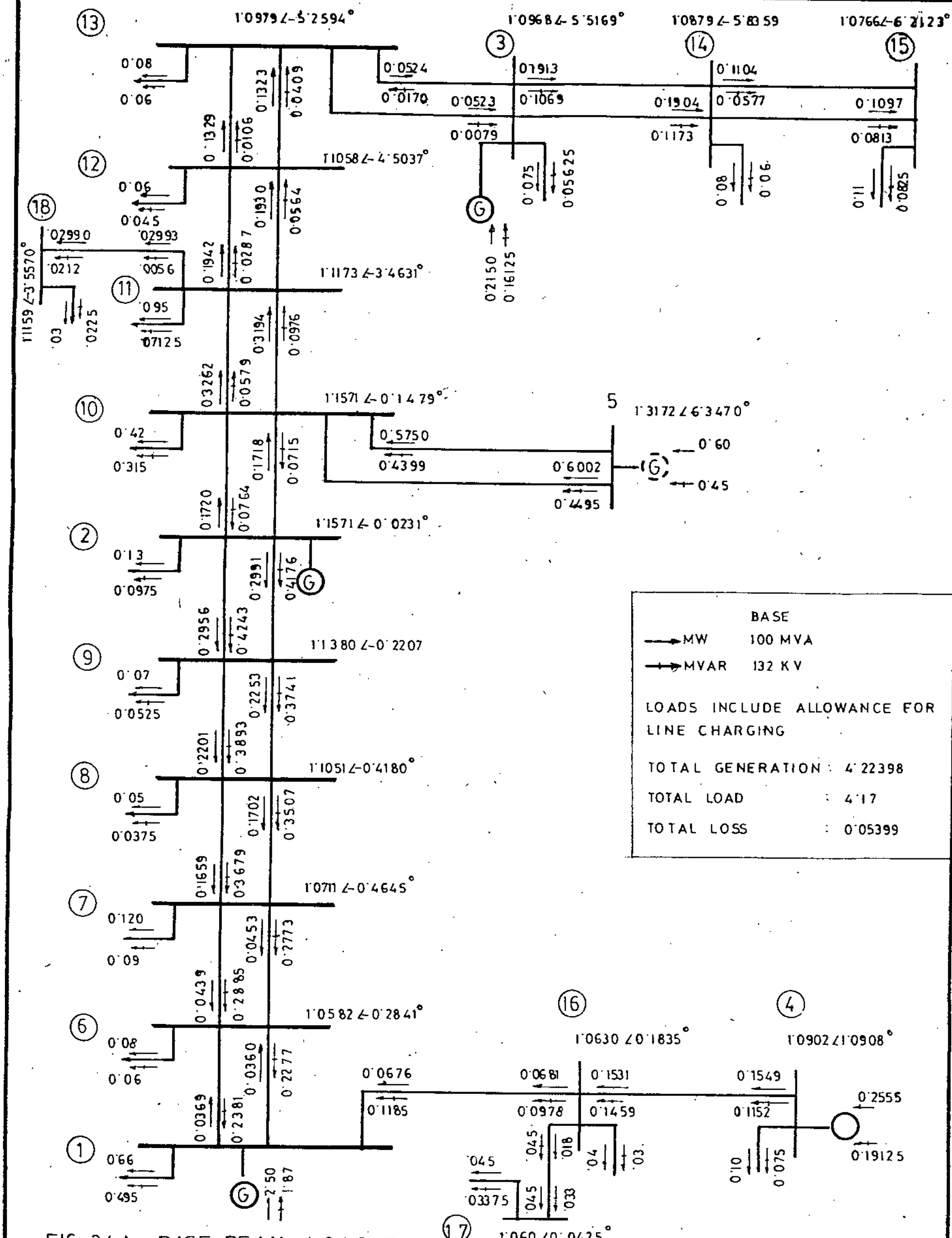


FIG. 24A. BASE PEAK LOAD FLOW (W.G) BPDB (1982-83)

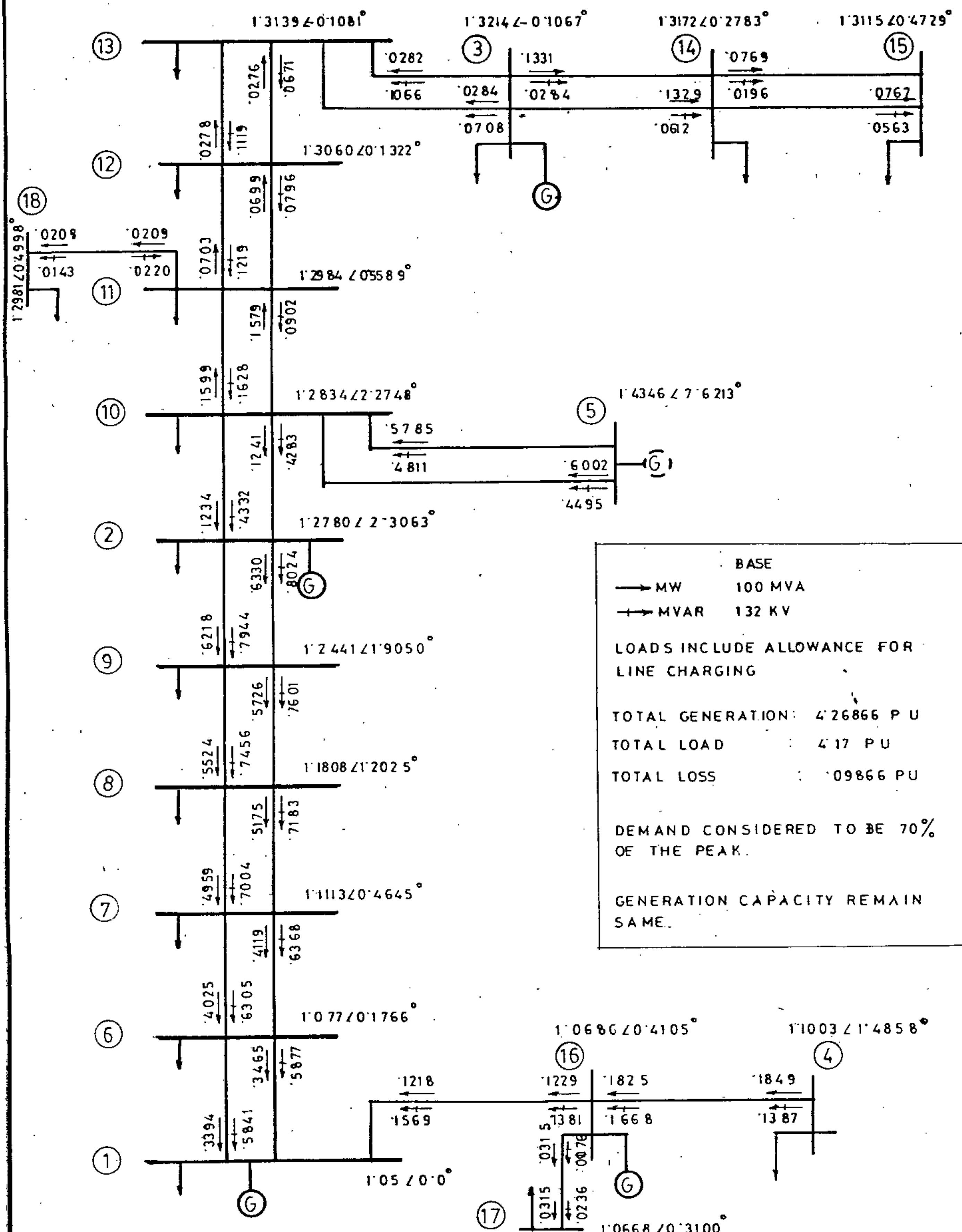


FIG. 2.4 B. BASE OFF-PEAK LOAD-FLOW (WESTERN GRID) BPDB (1982-83)

CHAPTER-3

TRANSMISSION LINE LOSS CO-EFFICIENTS

3.1 INTRODUCTION

For optimum scheduling of generation of an integrated power system, the basic problem involved is the determination of an expression for the transmission losses in terms of source loadings. For this purpose, it is described to proceed from a circuit in which the various sources are connected by an arbitrary transmission network to the individual loads, as shown in Fig. 3.1, to an equivalent circuit, as suggested in Fig. 3.2.

Transmission losses (4) of Figs. 3.1 and 3.2 are to be identical and may be expressed in the following manner:

For Fig. 3.1

$$P_L = \sum_k I_k^2 R_k \text{ (transmission losses in terms of line parameters)} \quad \ldots \quad (3.1)$$

where, P_L = transmission loss

I_k = scalar line current in line k.

R_k = Resistance of line k

For Fig. 3.2.

$$P_L = \sum_m \sum_n P_m B_{mn} P_n \text{ (transmission losses in terms of source power)} \quad \ldots \quad (3.2)$$

where, P_m, P_n = source loadings

B_{mn} = Constants to be determined (Loss-formula co-efficient matrix)

In all our deductions which follow, it is to be noted that whenever a repeated index appears, a summation on that index is indicated.

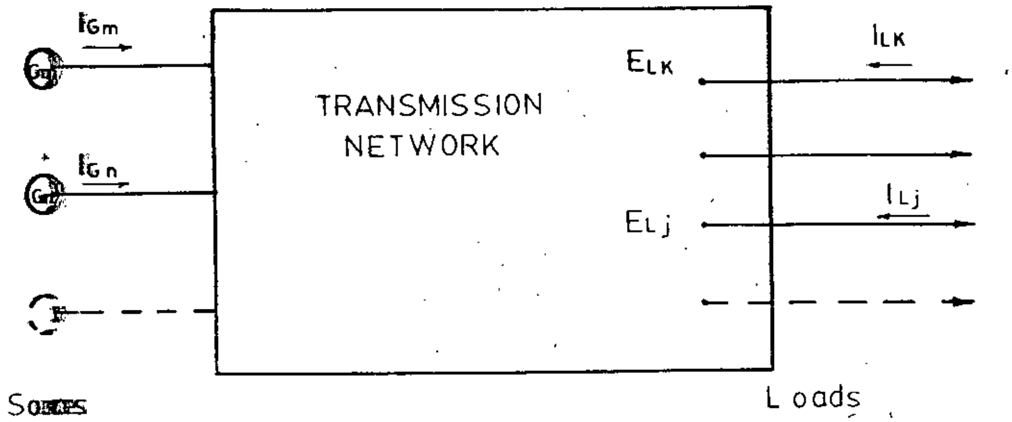


FIG.3.1 SCHEMATIC DIAGRAM OF POWER SYSTEM-CONNECTING SOURCES AND LOADS BY ARBITRARY TRANSMISSION NETWORK.

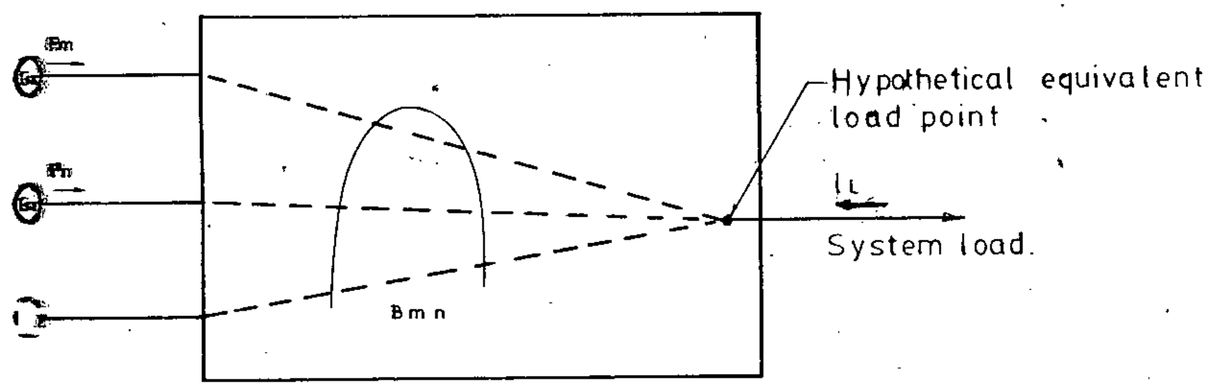


FIG. 3.2 EQUIVALENT CIRCUIT REPRESENTATION OF FIG.3.1 WITH IMPRESSED GENERATOR POWERS SUPPLYING A SINGLE HYPOTHETICAL LOAD.

Thus $E_m = Z_{mn} I_n$

Means $E_m = \sum_{k=1}^{n} Z_{mk} I_k$ .. (3.3)

The various steps involved in the derivation of loss formulae will be noted by reference frame numbers used by G.Kron (5). The method of transformation of Fig. 3.1 to 3.2, i.e. reference frame 1 to 3 developed by Kron (5), is shown in Appendix-B(1). In general, a reference frame denotes a given step in the network analysis when the variables are changed from one set to another. This change may be thought of as a change in reference frame. We shall proceed directly from reference frame 3 to calculation of losses and transformation of generator currents to generator powers.

3.2 DEVELOPMENT OF TRANSMISSION LOSS FORMULAE

3.2.1 Calculation of Losses

The real losses in the equivalent circuit of Fig.3.8B and equation (B-17) (shown in Appendix-B(1)) may be calculated as follows:

P_L = Real $(I_3^*) (E_3)$

= Real $(I_3^*) (Z_3)(I_3)$ .. (3.4)

where, E_3, I_3, and Z_3 denote reference frame 3 quantities.

Let us define the real and imaginary components of I_{Gn} by I_{dn} and I_{qn} respectively (21).

Thus $I_{Gn} = I_{dn} + jI_{qn}$ .. (3.5)

Returning to the general case in which the number of sources = m, n we have

$$Z_3 I_3 = Z_{m-n} (I_{dn} + jI_{qn})$$

$$= (R_{m-n} + jX_{m-n})(I_{dn} + jI_{qn}) \qquad .. \qquad (3.6)$$

Using equations (3.5) and (3.6) in equation (3.4) we have

$$P_L = \text{Real } (I_{dm} - jI_{qm})(R_{m-n} + jX_{m-n})(I_{dn} + jI_{qn})$$

$$= \text{Real } (I_{dm} - jI_{qm})(R_{m-n} I_{dn} - X_{m-n} I_{qn}$$

$$+ j(R_{m-n} I_{qn} + X_{m-n} I_{dn}))$$

$$= I_{dm} R_{m-n} I_{dn} - I_{dm} X_{m-n} I_{qn} + I_{qm} R_{m-n} I_{qn} + I_{qm} X_{m-n} I_{dn}$$

$$= I_{dm} R_{m-n} I_{dn} + I_{qm} R_{m-n} I_{qn} - I_{dm} X_{m-n} I_{qn} + I_{dm} X_{n-m} I_{qn}$$

$$= I_{dm} R_{m-n} I_{dn} + I_{qm} R_{m-n} I_{qn} - 2I_{dm} \frac{X_{m-n} - X_{n-m}}{2} I_{qn} \qquad (3.7)$$

In case of quadratic form such as PAP or $P_j A_{jk} P_k$ in which the elements of P and A are real numbers, the matrix A may be replaced by its symmetric part $(A + A_t)/2$, since the components resulting from the skew-symmetric part reduce to zero (21).

That is $\quad P \dfrac{(A - A_t)}{2} P = 0 \qquad (3.7a)$

Hence we can write equation (3.7) as

$$P_L = I_{dm} \frac{R_{m-n} + R_{n-m}}{2} I_{dn} - 2I_{dm} \frac{X_{m-n} - X_{n-m}}{2} I_{dn}$$

$$+ I_{qm} \frac{R_{m-n} + R_{n-m}}{2} I_{qn} \qquad ... \qquad (3.8)$$

3.2.2 Transformation of Generator Currents to Generator Powers

Equation (3.8) expresses the transmission losses in terms of generator currents, but the load dispatcher customarily works in terms of powers. Hence it is necessary for us to transform equation (3.8) to generator powers so that our expression for losses will be most useful. The steps involved in proceeding from generator currents to generator powers are described as reference frames 4, 5 and 6 by Kron (5). In this section we shall proceed directly from reference frame 3 to reference frame 6.

We denote θ_m as the angle of the voltage of generator m with respect to the reference axis as shown in Fig. 3.3. The reference axis is the common axis upon which all voltages and currents have been projected in our work.

Let P_m = real power output of generator m

Q_m = reactive power output of generator m

V_m = absolute value of the voltage of generator m

From Fig. 3.3, it will be seen that

$$I_{dm} = \frac{1}{V_m} (P_m \operatorname{Cos}\theta_m + Q_m \operatorname{Sin}\theta_m) \quad .. \quad (3.9)$$

$$I_{qm} = - \frac{1}{V_m} (-P_m \operatorname{Sin}\theta_m + Q_m \operatorname{Cos}\theta_m) \quad .. \quad (3.10)$$

To eliminate Q_m as variable, it is assumed that the ratio of $\frac{Q_m}{P_m}$ will remain a constant value S_m.

That is $\frac{Q_m}{P_m}$ = constant = S_m

Therefore, $Q_m = S_m P_m \quad .... \quad (3.11)$

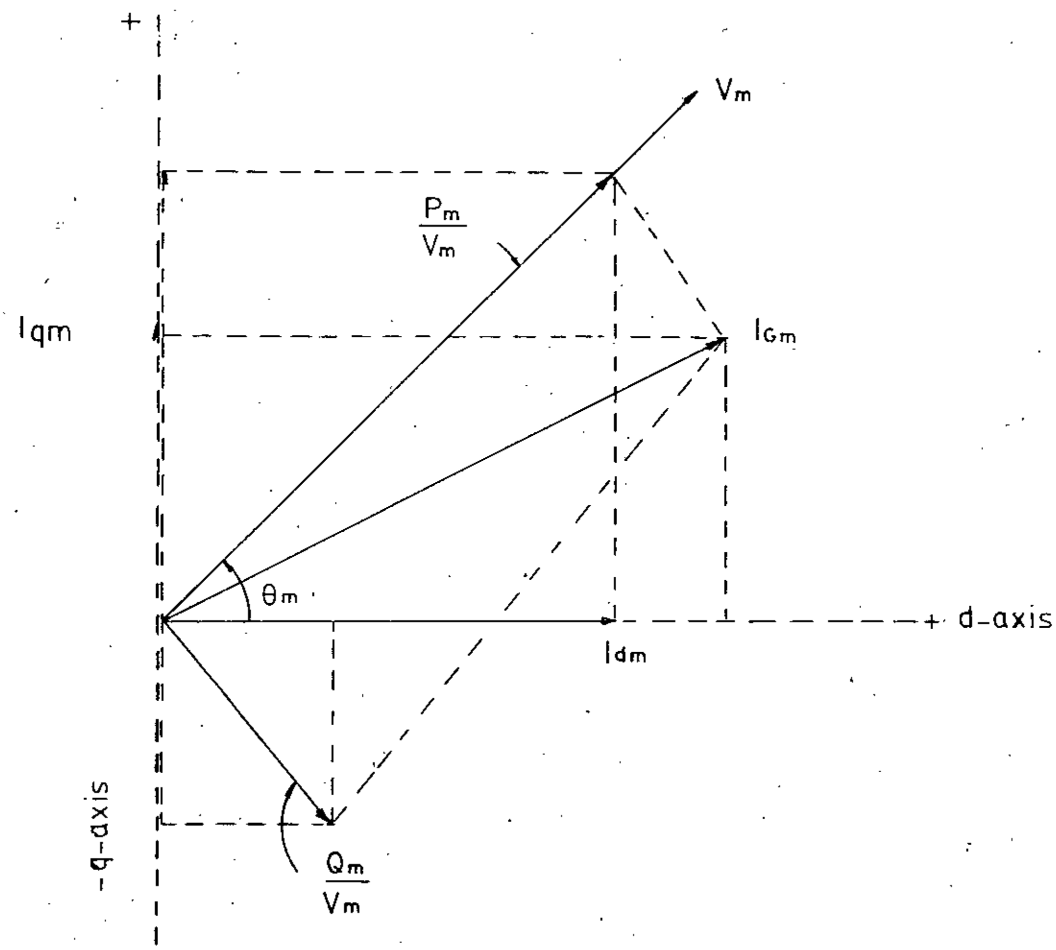


FIG. 3.3 VECTOR DIAGRAM FOR TRIGONOMETRIC PROJECTIONS.

Thus, equations (3.9) and (3.10) may be written as

$$I_{dm} = \frac{1}{V_m} (Cos\theta_m + S_m \; Sin\theta_m) P_m \quad .. \quad (3.12)$$

$$I_{qm} = - \frac{1}{V_m} (- \; Sin\theta_m + S_m \; Cos\theta_m) P_m \quad .. \quad (3.13)$$

Substituting equations (3.12) and (3.13) into equation (3.8), we have

$$P_L = P_m . \frac{1}{V_m} (Cos\theta_m + S_m \; Sin\theta_m) \frac{R_{m-n} + R_{n-m}}{2} \frac{1}{V_n} (Cos\theta_n + S_n Sin\theta_n) P_n$$

$$+ P_m \frac{1}{V_m} (-Sin\theta_m + S_m Cos\theta_m) \frac{R_{m-n} + R_{n-m}}{2} \frac{1}{V_n} (-Sin\theta_n + S_n Cos\theta_n) P_n$$

$$+ 2P_m \frac{1}{V_m} (Cos\theta_m + S_m Sin\theta_m) \frac{X_{m-n} - X_{n-m}}{2} \cdot \frac{1}{V_n} (-Sin\theta_n + S_n Cos\theta_n) P_n$$

or $$P_L = P_m \frac{1}{V_m V_n} (Cos\theta_m Cos\theta_n + S_n Cos\theta_m Sin\theta_n + S_m Sin\theta_m Cos\theta_n + S_m S_n Sin\theta_m Sin\theta_n)$$

$$\left(\frac{R_{m-n} + R_{n-m}}{2}\right) P_n + P_m \frac{1}{V_m V_n} (Sin\theta_m Sin\theta_n - S_n Sin\theta_m Cos\theta_n - S_m Cos\theta_m .$$

$$Sin\theta_n + S_m S_n \; Cos\theta_m Cos\theta_n) \; \left(\frac{R_{m-n} + R_{n-m}}{2} \right) \; P_n$$

$$+ \; 2P_m \frac{1}{V_m V_n} (-Cos\theta_m \; Sin\theta_n + S_n Cos\theta_m Cos\theta_n \; - \; S_m Sin\theta_m Sin\theta_n$$

$$+ \; S_m S_n \; Sin\theta_m \; Cos\theta_n) \; \left(\frac{X_{m-n} - X_{n-m}}{2} \right) P_n \quad ... \quad (3.14)$$

Remembering that $Cos\theta_{mn} = Cos(\theta_m - \theta_n) = Cos\theta_m Cos\theta_n + Sin\theta_m Sin\theta_n$ (3.15)

and, $Sin\theta_{mn} = Sin(\theta_m - \theta_n) = Sin\theta_m Cos\theta_n - Sin\theta_n Cos\theta_m$ ... (3.16)

and substituting equations (3.15) and (3.16) into (3.14), we have:

$$P_L = P_m \; A_{mn} \frac{R_{m-n} + R_{n-m}}{2} P_n + 2P_m F_{mn} P_n \quad ... \quad (3.17)$$

where, $$A_{mn} = \frac{1}{V_m V_n}((1 + S_m S_n)\cos\theta_{mn} + (S_m - S_n)\sin\theta_{mn}) \qquad (3.18)$$

$$F_{mn} = \frac{1}{V_m V_n}(-\cos\theta_m \sin\theta_n + S_n \cos\theta_m \cos\theta_n - S_m \sin\theta_m \sin\theta_n$$

$$+ S_m S_n \sin\theta_m \cos\theta_n)\left(\frac{X_{m-n} - X_{n-m}}{2}\right) \quad \ldots \quad (3.19)$$

$P_m F_{mn} P_n$ being in quadratic form we can further simplify equation (3.17) by substituting F_{mn} by $\frac{F_{mn}+F_{nm}}{2}$

Then from equation (3.19) we have

$$\frac{F_{mn} + F_{nm}}{2} = \frac{1}{2} H_{mn} \frac{X_{m-n} - X_{n-m}}{2}$$

where $$H_{mn} = \frac{1}{V_m V_n}((1 + S_m S_n)\sin\theta_{mn} + S_n - S_m)\cos\theta_{mn}) \qquad (3.20)$$

Therefore, equation (3.17) can be written as

$$P_L = P_m A_{mn} \frac{R_{m-n} + R_{n-m}}{2} P_n + P_m H_{mn} \frac{X_{m-n} - X_{n-m}}{2} P_n \qquad (3.21)$$

$$= P_m \left(A_{mn} \frac{R_{m-n} + R_{n-m}}{2} + H_{mn} \frac{X_{m-n} - X_{n-m}}{2}\right) P_n \qquad (3.22)$$

$$= P_m B_{mn} P_n \qquad (3.23)$$

where $$B_{mn} = A_{mn} \frac{R_{m-n} + R_{n-m}}{2} + H_{mn} \frac{X_{m-n} - X_{n-m}}{2} \qquad (3.24)$$

The equivalent circuit corresponding to equation (3.24) is given in Fig. 3.2. It is the circuit which we derived and which we have developed from our basic circuit of Fig.3.1. We now have impressed generator powers insteac of generator currents, but the losses given by the two circuits must be identical. Mathematically we can write this identity in usual notations as

$$P_L = \sum_m \sum_n P_m B_{mn} P_n = \sum I_k^2 R_k \quad \ldots \quad (3.25)$$

We recall that the B_{mn} represent an equivalent loss network through which the generator powers flow in supplying the overall system load. Since $B_{mn} = B_{nm}$, as it is evident from equations (3.19), (3-20) and (3.24), the number of loss-coefficients to be calculated for a loss formula with n sources is n(n + 1)/2.

3.2.3 Assumptions

In deriving the loss formulae, we have assumed that

1) The equivalent load current at a bus, that is sum of load current, line charging current and synchronous condenser current (if any) at that bus maintains a constant complex ratio with total current. This assumption is more flexible in the sense that we did not assume the ratio to be a real constant.

2) The voltage magnitudes at generator buses remain constant.

3) The voltage phase angle at each generator bus remains constant. This is equivalent to saying that the source currents maintain constant phase angles with respect to a common reference.

4) The source reactive characteristic is linear. In other words S-value of a generator is constant.

All the above assumptions are not true for large variations in loads. The assumption that each load current is a constant fraction of total load is valid for most of the loads. The voltage phase angle definitely deviates larger for large variation of loads. The reactive characteristics of generators may not be linear for all range of generators. However the above assumptions do not introduce any appreciable error in the usual case where the variations in loads are not abrupt with respect to a base case.

3.3 DERIVATION OF OPERATING EQUATION

We rewrite the reference frame 3 equation (5.21) (shown in Appendix-B(1) as

$$\begin{bmatrix} E_{Gm} - E_L \end{bmatrix} = \begin{bmatrix} Z_{m-n} \end{bmatrix} \begin{bmatrix} I_{Gn} \end{bmatrix} \qquad \dots \qquad (3.26)$$

where E_{Gm} = voltage of source m

E_L = voltage of hypethetical load

Z_{m-n} = self and mutual impedance between sources and hypothetical load.

I_{Gn} = source current n

we also recall that

$$E_L = \sum_j l_j^* E_{Lj} \qquad \dots \qquad (3.27)$$

and $I_{Lj} = l_j \, I_L$

$$\text{or } l_j = I_{Lj}/I_L \qquad \dots \qquad (3.28)$$

where E_{Lj} = voltage at load bus j

I_{Lj} = equivalent load current at bus j

$$I_L = \sum_j I_{Lj} \qquad \dots \qquad (3.29)$$

For a three-source system the frame-3 equation (3.26) can be written as

$$\begin{bmatrix} E_{G1} - E_L \\ E_{G2} - E_L \\ E_{G3} - E_L \end{bmatrix} = \begin{bmatrix} Z_{1-1} & Z_{1-2} & Z_{1-3} \\ Z_{2-1} & Z_{2-2} & Z_{2-3} \\ Z_{3-1} & Z_{3-2} & Z_{3-3} \end{bmatrix} \begin{bmatrix} I_{G1} \\ I_{G2} \\ I_{G3} \end{bmatrix} \qquad (3.30)$$

If the load current for the base case is supplied by one generator at a time as may be simulated readily by digital computer methods, these reference frame 3 impedances can be determined one column at a time. For example source-1 supplying all load currents, maintaining $l_j = I_{Lj}/I_L$, we get

$$\begin{bmatrix} E_{G1} - E_L \\ E_{G2} - E_L \\ E_{G3} - E_L \end{bmatrix} = \begin{bmatrix} Z_{1-1}\, I_{G1} \\ Z_{2-1}\, I_{G1} \\ Z_{3-1}\, I_{G1} \end{bmatrix}$$

So that

$$\begin{bmatrix} Z_{1-1} \\ Z_{2-1} \\ Z_{3-1} \end{bmatrix} = \begin{bmatrix} (E_{G1} - E_L)/I_{G1} \\ (E_{G2} - E_L)/I_{G1} \\ (E_{G3} - E_L)/I_{G1} \end{bmatrix} \quad \ldots \quad (3.31)$$

In more general terms for the case of source 1 energized we would have

$$Z_{m-1} = (E_{Gm} - E_L)/I_{G1} \quad \ldots \quad (3.32)$$

and with source 2 supplying the total load current we obtain

$$Z_{m-2} = (E_{Gm} - E_L)/I_{G2} \quad \ldots \quad (3.33)$$

Similarly for source n taking all loads

$$Z_{m-n} = (E_{Gm} - E_L)/I_{Gn} \quad \ldots \quad (3.34)$$

The values of E_{Gm}, E_{Lj} and hence E_L can be calculated by an iterative circuit solution as shown in Appendix-B(2).

Thus we may obtain the complex reference frame 3 impedances (shown in Appendix-B(1)). Only the real symmetric part and imaginary skew-symmetric part of this impedance matrix are required for determination of the real losses. Similarly on the imaginary symmetric part and real skew-symmetric part of this matrix are required to determine the reactive losses. However, the full matrix is required for accurate treatment of losses for interconnected systems (22,23).

The loss formulae co-efficients then may be calculated as

$$B_{mn} = A_{mn} \frac{R_{m-n} + R_{n-m}}{2} + H_{mn} \frac{X_{m-n} - X_{n-m}}{2} \quad \ldots \quad (3.35)$$

where $\frac{R_{m-n} + R_{n-m}}{2}$ = real symmetric part of frame 3 impedances ... (3.36)

$\frac{X_{m-n} - X_{n-m}}{2}$ = imaginary skew symmetric part of frame 3 impedances ... (3.37)

$$A_{mn} = \frac{1}{V_m V_n} ((1 + S_m S_n) \cos\theta_{mn} + (S_m - S_n) \sin\theta_{mn}) \quad (3.38)$$

$$H_{mn} = \frac{1}{V_m V_n} ((1 + S_m S_n) \sin\theta_{mn} + (S_n - S_m) \cos\theta_{mn}) \quad (3.39)$$

Recall that V_m = voltage magnitude of generator m

and $S_m = \frac{\Delta Q_m}{\Delta P_m}$ ... (3.40)

3.4 DETERMINATION OF SOURCE-REACTIVE CHARACTERISTICS(S_m)

The values of source reactive characteristics (S_m) of the generating plants are determined (21) from a knowledge of impedances between each source and the hypothetical load point (Appendix-B(1).

The value of S_m can be taken as

$$S_m = - \frac{R_{m-m}}{X_{m-m}} \quad \ldots \quad (3.41)$$

where, R_{m-m} = self resistance of source m to hypothetical load.

X_{m-m} = self reactance of source m to hypothetical load.

In Section 3.2.2, equation (3.11), Q_m was eliminated as a variable by assuming

$$Q_m/P_m = \text{constant} = S_m$$

or $$Q_m = S_m P_m \quad \ldots \quad (3.42)$$

In many cases, particularly when S_m is small, this assumption results in satisfactory answers. But when it is determined by the total system load level, it would be appropriate to include the plant reactive component as part of the load of that bus. It is seen (21) that as the system load increases Q_m increases. Similarly, when the system load decreases, Q_m decreases. By denoting Q_{Lm} that part of reactive power of plant m which is included as part of the load at that bus.

Then $$Q_m = Q_{Lm} + S_m P_m \quad \ldots \quad (3.43)$$

or $$Q_{Lm} = Q_m - S_m P_m \quad \ldots \quad (3.44)$$

Mathematically Q_{Lm} is the intercept of P_m Vs. Q_m characteristic. Q_{Lm} is considered to be part of the load at load bus m. Thus if Q_{Lom} is the equivalent reactive load at bus m, then total reactive load at that bus $Q_{L'm}$ is given (20) by

$$Q_{L'm} = Q_{Lom} + Q_{Lm} \quad \ldots \quad (3.45)$$

$$= Q_{Lom} + Q_m - S_m P_m \quad \ldots \quad (3.46)$$

3.5 DATA REQUIRED FOR CALCULATING B-COEFFICIENTS

Input data describing the system for the loss formulae programme is identical to that required for a digital load-flow programme and includes:

1. Per unit values of transmission line and transformer impedances and line charging susceptance together with bus code numbers.
2. Estimate of per unit bus voltages and their phase angles in degrees.
3. Per unit values of the plant generations.
4. Per unit values of the system loads.
5. Per unit admittances of static capacitors and shunt reactors (if any).
6. Transformer tap settings.
7. Estimated values of S-constants for generating plants.
8. Acceleration factor and tolerance limit for real and imaginary components of frame 3 voltages.
9. Acceleration factor and tolerance limit for reactive characteristics (S-values).

3.6 FEATURES OF THE COMPUTER PROGRAMME

The programme was developed in FORTRAN IV language (24,29), incorporating the theory developed in the previous sections, for running on the IBM-370 computer at the Computer Centre, BUET, Dacca. The programme provides a means for proceeding automatically from one step to the next in the calculation of loss-formulae co-efficients thus greatly simplifying the preparation of necessary data.

In describing the programme we start with a very compact flow chart as shown in Fig. 3.4. Step I provides complete load flow results for peak and off-peak load conditions. During the calculation, data requiried in the suceeding steps are stored automatically. This step can be executed separately with the required output punched on cards (diskette), as has been done in this study (see Chapter 2).

In step II, based on estimated values of S_m, reference frame 3 voltages and hence impednances are calculated one column at a time by an iterative circuit solution similar to nodal load-flow studies (24,25,26,27). The diagonal Z is used to calculate improved values of S_m. These values are written (printed)immediately after the calculation together with changes in S. If the maximum change in S from the previous value is not within a desired tolerance a new calculation is done and the process is iterated until the precision index is reached. Final S-values are printed and stored for Step III.

Input for the calculation of B-matrix in Step III includes frame 3 resistance and reactance values which were stored in Step II, generator angles and voltages from Step I and final S-values just calculated (Step II).

In Step IV the B-matrix of Step III is used to calculate PBP (transmission) losses.

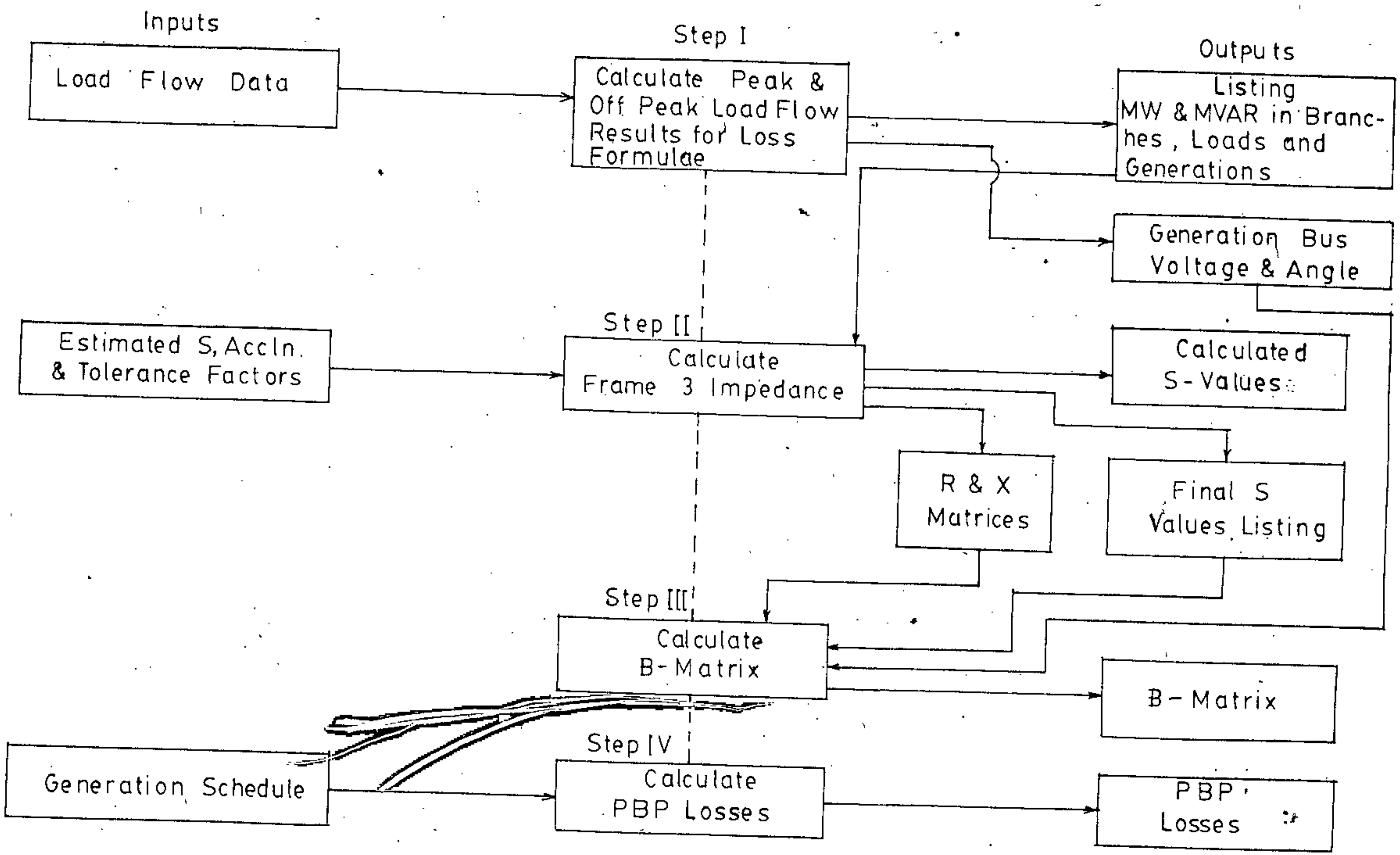


FIG. 3.4 COMPACT FLOW CHART FOR CALCULATING B-COEFFICIENTS

The development of the load-flow programme was described in Chapter-2. The detail flow-chart for Step II, Step III and Step IV is given in Fig. 3.5 and the programme in FORTRAN IV is listed in Appendix-B(3).

The programme starts with the reading-in of input data such as total number of buses (N), number of generator buses (M), acceleration factor(C1) and tolerance limit (TOLER) for real and reactive part of frame 3 voltages; maximum number of iterations allowable (ITMAX) for calculating these voltages; and acceleration factor (A1), tolerance limit (TOL) and maximum number of iterations (ITM) permitted for calculation of S. It then reads-in, for each bus: voltage magnitude, angle, real and reactive load (with allowance for line charging) obtained from load flow studies in Step 1 and real and reactive power input to the generator buses. Number of connections with each generator bus is read-in next as well as for buses where no generator is connected. The equivalent reactive power is equated to the load reactive power.

Line connection matrix is read-in next. It is an NXN matrix having as elements either zero or 1. Zero represents no connection whereas 1 represents a connecting line between the relative buses. At every calculation step, the computer compares each pair of buses against this matrix and if there is no connection between the buses the calculation proceeds to the next bus, thus saving an enormous amount of time as most of the elements of the line-connection matrix is zero. Whenever there is a connection, the computer reads the line parameters, i.e resistance and reactance,

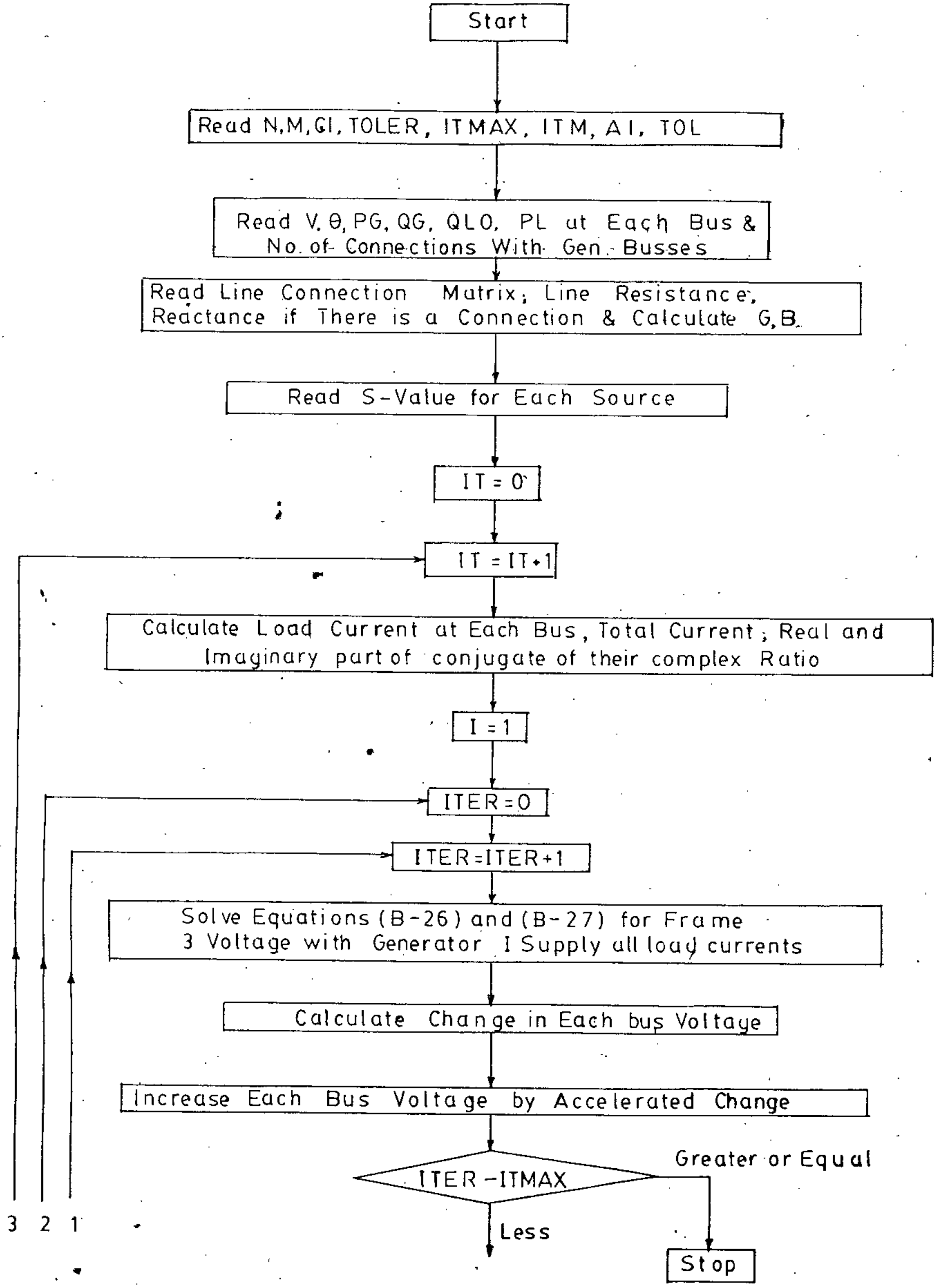


FIG. 3.5 DETAIL FLOW CHART FOR CALCULATION OF B-COEFFICIENTS

Contd.

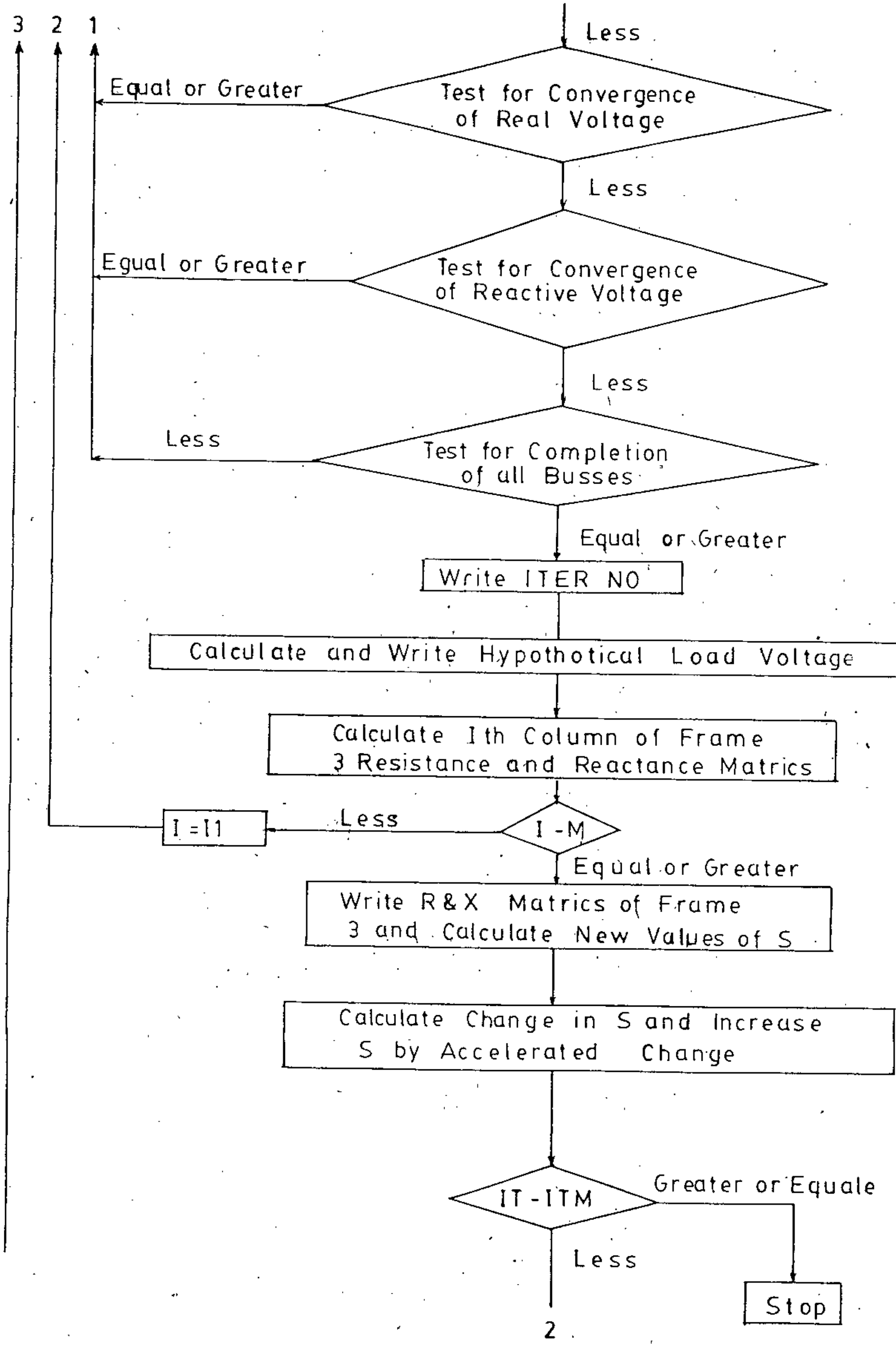


FIG. 3.5 DETAIL FLOW CHART FOR CALCULATION OF B-COEFFICIENTS

Contd.

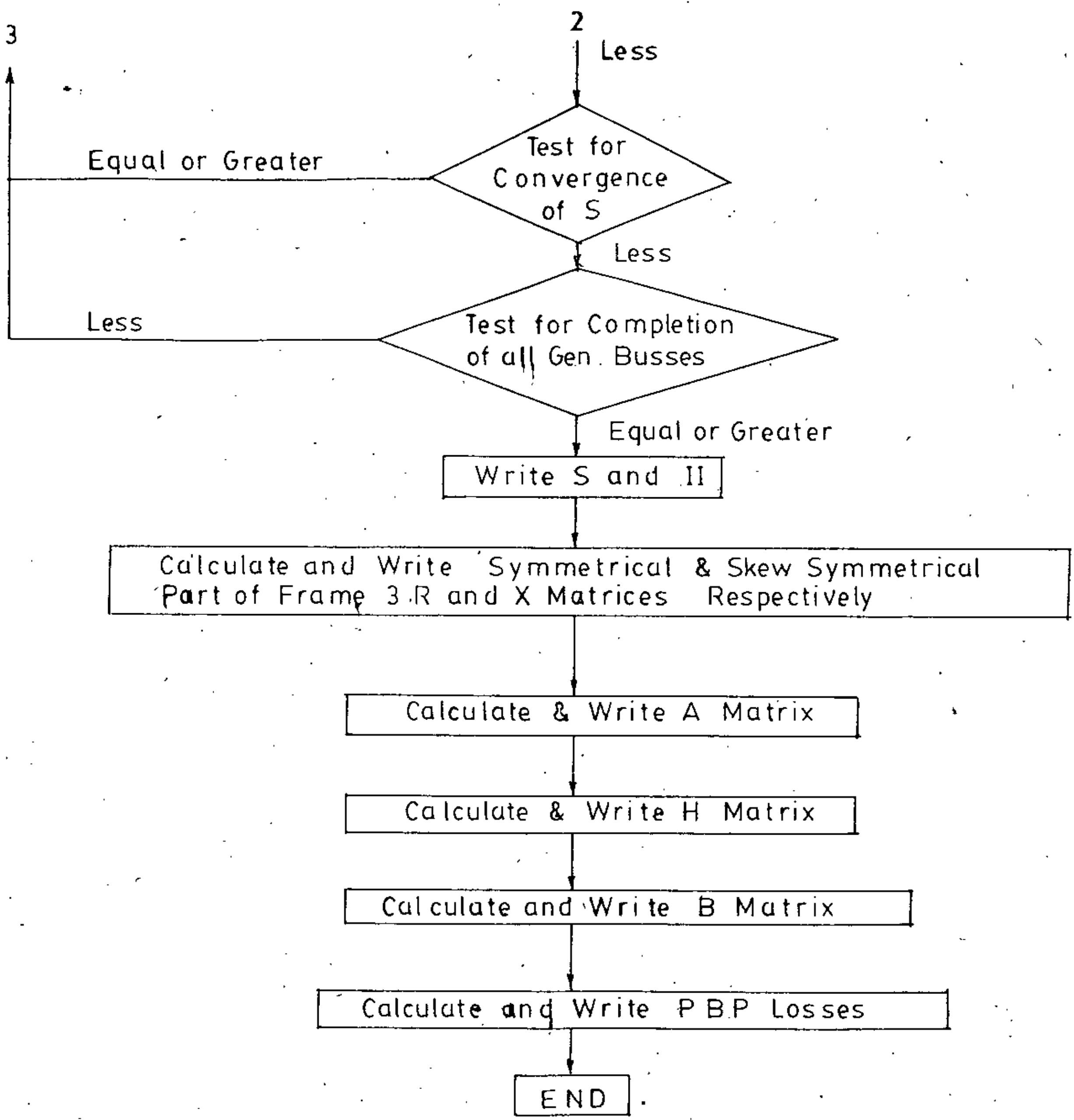


FIG.3.5 DETAIL FLOW CHART FOR CALCULATION OF B-COEFFICIENTS

and calculates conductances and susceptances, both the mutual and self terms.

Estimated S-values are read-in next and, based on these estimations, the equivalent reactive load at the generator buses are calculated according to equation (3.46).

The computer then calculates the real and reactive parts of the load currents at each bus, total load current and the complex conjugate of the ratio of load current to total current. The frame 3 voltages are calculated next by an iterative process (Appendix-B(2))with the first generator supplying all the loads. The voltages at the hypothetical load are calculated in accordance with equation (3-27) and the first column of frame 3 impedances (resistances and reactances) are then computed following equations (3.32). The whole process is repeated with the second generator supplying all loads, thus computing the second column of frame 3 impedances (resistances and reactances) using equation (3.33) and so on. Obviously the number of load-flow steps required for calculating the whole frame of impedances is equal to the number of sources. Once the complete frame 3 impedances are obtained the diagonal resistance and reactance terms are used for calculating new values of S using equation (3.41) and if the change in S from the previous calculation or estimation is not within the desired tolerance, the whole frame 3 impedances are calculated once again with the values of S just calculated. The process is repeated until the desired tolerance is reached. The final values of frame 3 resistance and reactance matrices are converted to their symmetrical and skew-symmetrical compounts respectively according to equations

(3.36) and (3.37). A-matrix and H-matrix are calculated next as given by equations (3.38) and (3.39) respectively. Finally the computer calculates the B-matrix according to equation (3.24).

3.7 OUTPUT FORMAT

Printed results of the calculations are: number of voltage iterations required for calculation of each column of the frame 3 impedance matrix; whole frame 3 resistance and reactance matrices, list of S-values and correction to S-values with respect to previous values for each S-iteration and finally the list of converged S-values as well as the number of S-iterations of Step II.

The printed output of Step III are the symmetric and skew-symmetric parts of frame 3 resistance and reactance matrices respectively and symmetric and skew-symmetric parts of the A-matrix and the H-matrix respectively. The entire B-matrix, that will again be used in the programme of generation scheduling (next Chapter), is also printed out. The transmission loss (PBP) computed is printed finally.

3.8 RESULTS

The systems chosen for the study are the present (1980) and projected (1982-83) Western-Grid of Bangladesh Power Development Board, shown in Fig. 2.1 and Fig. 2.2 respectively (Chapter-2). For our purpose, the systems were simplified by considering only 3 generating plants and 13 buses for the present network and 5 generating plants and 18 buses for the projected network.

For convenience of the programme, the generator buses were coded as bus number 1 to 3 and 1 to 5 respectively. The peak/off-peak load-flow studies of Step 1, executed separately, are shown in Fig. 2.3A/2.3B and 2.4A/2.4B for present and future systems respectively.

The maximum number of iterations were set at 400 for frame 3 voltage calculations. A number of acceleration factors e.g. 1.4, 1.5, 1.6, 1.7, 1.75, 1.8 were used in both the cases. But 22 to 83/21 to 80 and 24 to 128 voltage iterations were required for one complete set of frame 3 impedances for the present (peak/off peak) and projected (peak) systems respectively.

S-values of generators were estimated as -0.30 and -0.33 which are approximately equal to the system-R/X ratios respectively. With such estimation it took only 6 (both peak and off-peak) and 8(peak) iterations for reaching the desired tolerance of 0.001 with an acceleration factor of 1.5. (Total CPU times taken by the computer to run the complete loss formulae programmes were 3-22/3-21 and 7-55 seconds respectively).

The results of the calculations are shown below:

BASE PEAK LOAD-FLOW CASE (1980)

FRAME 3 RESISTANCE MATRIX

0.048309	-0.036206	-0.081924
-0.006253	0.032187	-0.013624
-0.041386	-0.003102	0.148366

FRAME 3 REACTANCE MATRIX

0.014353	-0.055707	-0.181778
-0.065636	0.096532	-0.029998
-0.195161	-0.033439	0.465323

SYMMETRICAL PART OF FRAME-3 RESISTANCE

0.048309	-0.021230	-0.061655
-0.021230	0.032187	-0.008363
-0.061655	-0.008363	0.148366

SKEW SYMMETRICAL PART OF FRAME 3 REACTANCE

0.0	0.004965	0.006691
-0.004965	0.0	0.001720
-0.006691	-0.001720	0.0

SYMMETRICAL A-MATRIX

1.009827	0.982926	0.999349
0.982926	0.959105	0.979476
0.999349	0.979476	1.008245

SKEW SYMMETRICAL H-MATRIX

0.0	0.048856	0.139476
-0.048856	0.0	0.087412
-0.139476	-0.087412	0.0

CONVERGED REACTIVE CHARACTERISTICS OF GENERATORS

S(1)	S(2)	S(3)
-0.336644	-0.333536	-0.319171

B-MATRIX

0.048783	-0.020625	-0.060682
-0.020625	0.030871	-0.008041
-0.060682	-0.008041	0.149589

PBP LOSSES

PBP = 0.01169 P.U.

OFF-PEAK (MINIMUM) LOAD FLOW CASE (1980)

FRAME-3 RESISTANCE MATRIX

0.052806	-0.055259	-0.112637
0.014512	0.029508	-0.027994
-0.005876	0.008958	0.148732

FRAME-3 REACTANCE MATRIX

0.156523	-0.046356	-0.163273
-0.069808	0.088526	-0.0289936
-0.198543	-0.040762	0.466787

SYMMETRICAL PART OF FRAME-3 RESISTANCE

0.052806	-0.020374	-0.059256
-0.020374	0.029508	-0.009518
-0.059256	-0.009518	0.148732

SKEW SYMMETRICAL PART OF FRAME-3 REACTANCE

0.0	0.011726	0.017635
-0.011726	0.0	0.005913
-0.017635	-0.005913	0.0

SYMMETRICAL A-MATRIX

1.010273	0.912365	0.875811
0.912365	0.824025	0.791386
0.875811	0.791386	0.761856

SKEW SYMMETRICAL H-MATRIX

0.0	0.008867	0.051345
-0.008867	0.0	0.038683
-0.051345	-0.038683	0.0

CONVERGED REACTIVE CHARACTERISTICS OF GENERATORS

S(1)	S(2)	S(3)
-0.337380	-0.333433	-0.318959

B-MATRIX

0.053349	-0.018484	-0.050992
-0.018484	0.024315	-0.007304
-0.050992	-0.007304	0.113312

PBP LOSSES

PBP = 0.01710 P.U.

Arithmatic mean$((B_{peak} + B_{off-peak})/2)$of B-matrics obtained from.

PEAK AND OFF-PEAK LOAD-FLOW DATA (OF 1980)

0.0510660	-0.0195545	-0.0558370
-0.0195545	0.0275930	-0.0076725
-0.0558370	-0.0076725	0.1314505

BASE PEAK LOAD FLOW CASE (1982-83)

FRAME-3 RESISTANCE MATTRIX

0.040902	-0.040564	-0.065682	0.034049	-0.061372
-0.010432	0.033367	0.008257	-0.017326	0.012704
-0.032361	0.011310	0.182355	-0.039293	-0.003181
0.036113	-0.045353	-0.070472	0.113905	-0.066178
-0.015325	0.028472	0.009563	-0.022221	0.084463

FRAME 3 REACTANCE MATRIX

0.100804	-0.045079	-0.117290	0.082581	-0.100890
-0.058077	0.083516	0.011017	-0.076196	0.027475
-0.131489	0.009941	0.555163	-0.149564	-0.031692
0.081953	-0.063928	-0.136110	0.332012	-0.119716
-0.117515	0.024061	-0.034151	-0.135628	0.329008

CONVERGED REACTIVE CHARACTERISTICS OF GENERATORS

S(1)	S(2)	S(3)	S(4)	S(5)
-0.405487	-0.399400	-0.328463	-0.342983	-0.257091

SYMMETRICAL PART OF FRAME 3 RESISTANCE

0.040902	-0.025498	-0.049021	0.035081	-0.038348
-0.025498	0.033367	0.009783	-0.031339	0.020588
-0.049021	0.009783	0.182335	-0.054883	0.003191
0.035081	-0.031339	-0.054883	0.113905	-0.044200
-0.038348	0.020588	0.003191	-0.044200	0.084463

SKEW SYMMETRICAL PART OF FRAME-3 REACTANCE

0.0	0.006499	0.007099	0.000314	0.008313
-0.006499	0.0	0.000538	-0.006134	0.001707
-0.007099	-0.000538	0.0	-0.006727	0.001229
-0.000314	0.006134	0.006727	0.0	0.007956
-0.008313	-0.001707	-0.001229	-0.007956	0.0

SYMMETRICAL A-MATRIX

1.056168	0.956306	0.972932	0.995911	0.805336
0.956306	0.865917	0.881764	0.901930	0.729286
0.972932	0.881764	0.920849	0.922863	0.744671
0.995911	0.901930	0.922863	0.940297	0.760010
0.805336	0.729286	0.744671	0.760010	0.614395

SKEW SYMMETRICAL H-MATRIX

0.0	0.005396	0.161163	0.035648	0.018372
-0.005396	0.0	0.140954	0.027189	0.012520
-0.161163	-0.140954	0.0	-0.119129	-0.105964
-0.035648	-0.027189	0.119129	0.0	-0.009858
-0.018372	-0.012520	0.105964	0.009858	0.0

B-MATRIX

0.043199	-0.024348	-0.046550	0.034949	-0.030731
-0.024348	0.028893	0.008702	-0.028433	0.015036
-0.046550	0.008702	0.167903	-0.049848	0.002246
0.034949	-0.028433	-0.049848	0.107105	-0.033670
-0.030731	0.015036	0.002246	-0.033670	0.051894

PBP LOSSES

PBP = 0.13227 P.U.

3.9 INTERPRETATION OF RESULTS

A close study of the relative magnitude of B-coefficients help us to arrive at some interesting conclusion. From arithmatic mean of B-matrices(1980), we note that at Saidpur (source No.3), the most distant one from the system load has the highest self-term 0.1314505, whereas the self-term of Goalpara (source No.1) is 0.0510660 and the self-term of Bheramara (source No.2), which is the nearest to the system load is 0.0275930 and is the lowest. From the B-matrics obtained from peak-load of 1982-83, we also note that at Saidpur (source No.3), the most distant one from the system load has the highest self-term 0.167903, whereas the self-term of Barisal (source No.4) is 0.107105 and self-term of Tongi(source No.5) and Goalpara (source No.1) are 0.051894 and 0.043199 respectively. But the self-terms of Bheramara (source No.2) which is again the nearest to the system load is 0.028893 and is the lowest. This is quite reasonable because the contribution to loss from the distant sources are higher in supplying the system load.

CHAPTER-4

SCHEDULING OF GENERATION

4.1 INTRODUCTION

In an integrated system where electrical power is supplied from more than one generating plant, the plant with minimum fuel cost is normally chosen to supply the part or full base load of the system. First, hydrostations, next nuclear plants, with high 'plant factor' are normally chosen to do so. The rest of the system load is shared by the remaining generating stations. The problem at hand is to decide on the sharing of the total demand between individual generators so that maximum overall economy is achieved.

The generating plants are normally situated according to the availability of fuel sources such as water, diesel, gas etc. and may not necessarily be located adjacent to the load centre. The transmission of power from the generating plants to the load centre thus becomes necessary.

The bulk power generated in a given area has to be transmitted to another area when the generating power becomes excess with respect to the consumption capacity of the generating area.

Even if the generating area has the capacity of consuming the total generated power, power systems of the different areas have to be interconnected for the purposes of economy, interchange and spinning reserve capacity.

The economic distribution of loads among different plants is thus an important problem to the load dispatch and scheduling egnineer.

In the past much effort has been expended in the analysis of fuel costs and the thermal performance of generating units at equal incremental fuel costs. However, in an integrated power system it is necessary to consider not only the incremental fuel cost but also the transmission loss cost for optimum economy. This chapter discusses the use of loss formula (see Chapter-3) in coordinating incremental production costs and incremental transmission losses.

4.2 DEVELOPMENT OF SCHEDULING EQUATION

In Chapter-3 we have developed a method of expressing transmission loss in terms of plant output which will enable us to co-ordinate transmission loss in scheduling output of each plant for optimum economy for a given system load (3,18). The derivation of co-ordinating equations follows directly from the method of Lagrangian multipliers described by Courant (37).

Let

F_t = total cost of fuel input to system in takas per hour

$$= F_1 + F_2 + \ldots\ldots + F_M = \sum_{n=1}^{M} F_n \qquad (4.1)$$

where, $F_1, F_2, \ldots\ldots F_M$ are the fuel cost of individual plants and are functions of the respective plant outputs.

The total power input to the network from all the plants is

$$P_T = P_1 + P_2 + \ldots\ldots P_M = \sum_{n=1}^{M} P_n \qquad (4.2)$$

where, $P_1, P_2 \ldots\ldots P_M$ are the individual plant outputs.

Our objective is to minimize the total input F_T in takas per hour for a given received load P_R. Let

P_R = given received load

By application of the method of Lagrangian multipliers (37) the equation of constraint is given by

$$\Upsilon(P_1, P_2, P_3 \ldots P_n) = \sum P_n - P_L - P_R = 0 \qquad (4.3)$$

Then minimum cost of fuel input for a given received load is obtained (21,32) when

$$\frac{\partial \mathcal{F}}{\partial P_n} = 0 \qquad (4.4)$$

where $\mathcal{F} = F_t - \lambda \Upsilon$

λ = Lagrangian type of multiplier

$$\frac{\partial \mathcal{F}}{\partial P_n} = \frac{\partial F_t}{\partial P_n} - \lambda \frac{\partial \Upsilon}{\partial P_n} = 0 \qquad \ldots \qquad (4.5)$$

Then

$$\frac{\partial F_t}{\partial P_n} - \lambda \frac{\partial}{\partial P_n} \left(\sum_n P_n - P_L - P_R \right) = 0$$

or

$$\frac{\partial F_t}{\partial P_n} - \lambda \left(1 - \frac{\partial P_L}{\partial P_n}\right) = 0$$

or

$$\frac{\partial F_t}{\partial P_n} + \lambda \frac{\partial P_L}{\partial P_n} = \lambda \qquad \ldots \qquad (4.6)$$

But

$$\frac{\partial F_t}{\partial P_n} = \frac{\partial (\sum_n P_n)}{\partial P_n} = \frac{\partial F_n}{\partial P_n} = \frac{dF_n}{dP_n}$$

Then equation (4.6) becomes

$$\frac{dF_n}{dP_n} + \lambda \frac{\partial P_L}{\partial P_n} = \lambda \qquad \ldots \qquad (4.7)$$

The terms involved in equation (4.7) are identified as

$\frac{dF_n}{dP_n}$ = incremental production cost of plant n in takas per MW hr.

λ = incremental cost of received power in takas per MW hr.

$\frac{\partial P_L}{\partial P_n}$ = incremental transmission loss at plant n in megawatts per megawatt.

From Chapter-3 (equation 3.23) we can write

$$P_L = \sum_m \sum_n P_m B_{mn} P_n$$

So that
$$\frac{\partial P_L}{\partial P_n} = \frac{\partial}{\partial P_n} \left(\sum_m \sum_n P_m B_{mn} P_n \right)$$

$$= 2 \sum_m P_m B_{mn} \quad \ldots \quad (4.8)$$

The incremental production cost of a given plant over a limited range may be represented by (21)

$$\frac{dF_n}{dP_n} = F_{nn} P_n + f_n \quad \ldots \quad (4.9)$$

where

F_{nn} = slope of incremental production cost curve.

f_n = intercept of incremental production cost curve

Equation (4.7) then reduces to a set of simulataneous equations as below:

$$F_{nn} P_n + f_n + \lambda \left(\sum_m 2B_{mn} P_n \right) = \lambda \quad \ldots \quad (4.10)$$

The set of simultaneous equations thus obtained may be solved for different total loads by varying the magnitude of λ.

Equation (4.7) can be rearranged as

$$\frac{dF_n}{dP_n}\left(\frac{1}{\left(1-\frac{\partial P_L}{\partial P_n}\right)}\right) = \lambda$$

or $$\frac{dF_n}{dP_n} L_n = \lambda \qquad \ldots \qquad (4.11)$$

Where

L_n = penalty factor of plant n = $\frac{1}{\left(1-\frac{\partial P_L}{\partial P_n}\right)}$

From equation (4.11) we can say that the most economic scheduling of generation is obtained for the condition when the incremental production cost of each plant multiplied by its penalty factor is constant.

Again if we neglect transmission loss in equation (4.7) we get

$$\frac{dF_n}{dP_n} = \lambda \qquad \ldots \qquad (4.12)$$

or $$F_{nn} P_n + f_n = \lambda \qquad \ldots \qquad (4.13)$$

From equation (4.12) we conclude that economic scheduling of generation neglecting transmission losses is obtained, when all plants operate at the same incremental production cost.

4.3 INCREMENTAL PRODUCTION COST

The incremental production cost of a given plant is composed of incremental fuel cost plus the incremental cost of such items as labour, supplies, maintenance and water. For accurate analysis it is necessary to express these items as a function of plant output. However no method is presently available to include them as functions of plant loadings. It is usual practice to include them as a certain percentage of incremental fuel cost. In many systems, for the purpose of economic scheduling, the incremental production cost is taken to be equal to incremental fuel cost (21) and this applied in our case, too.

4.4 PHYSICAL INTERPRETATION OF SCHEDULING EQUATION

The scheduling equation can be interpreted physically by inspecting figure 4.1 . The incremental production cost of a given plant n is measured at the plant bus and is denoted by dF_n/dP_n. A given plant n incurs an incremental transmission loss $dP_L/\partial P_n$ in supplying the next increment of system load. It is desired that the next incremental cost of power received from each plant be the same at the receiving point L.

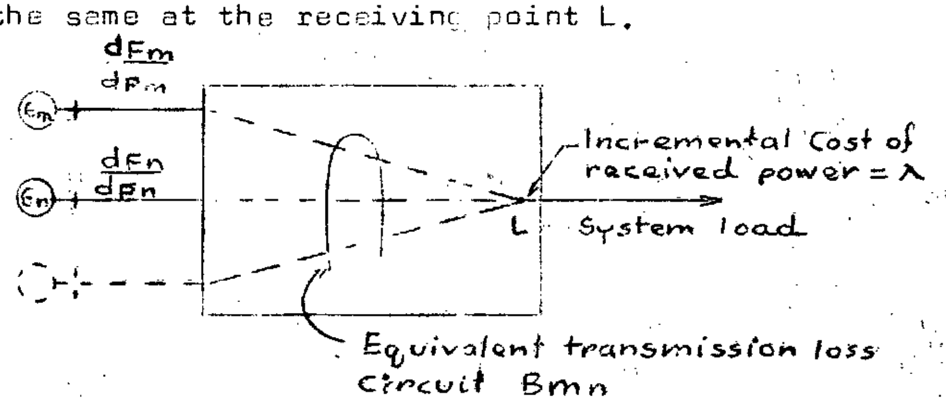


Fig. 4.1 Schematic representation of cost relations.

For example, suppose that the load increases by an amount ΔP_R. Assume that this load change is first taken up by plant 1 only by increasing the output of plant 1 by ΔP_1. Then the cost of this increment of power at the receiver is given by

$$\lambda = \frac{dF_1}{dP_1} \frac{\Delta P_1}{\Delta P_R} \quad \ldots \quad (4.14)$$

The expression $\frac{\Delta P_1}{\Delta P_R}$ may be thought of as the reciprocal of incremental efficiency of the transmission system. The foregoing equation may be rewritten as

$$\lambda = \frac{dF_1}{dP_1} \quad \frac{\Delta P_1}{\Delta P_1 - \Delta P_L}$$

or $$\lambda = \frac{dF_1}{dP_1} \quad \frac{1}{1 - (\Delta P_L / \Delta P_1)} \qquad \ldots \qquad (4.15)$$

As P_1 becomes progressively smaller, we have

$$\lambda = \frac{dF_1}{dP_1} \left(\frac{1}{1 - (\partial P_L / \partial P_1)} \right) \qquad \ldots \qquad (4.16)$$

$$\lambda = \frac{dF_1}{dP_1} \; L_1 \qquad \ldots \qquad (4.17)$$

For plant n we can rewrite the above equations as

$$\lambda = \frac{dF_n}{dP_n} \left(\frac{1}{1 - \partial P_L / \partial P_n} \right) \qquad \ldots \qquad (4.18)$$

$$\lambda = \frac{dF_n}{dP_n} \, L_n \qquad \ldots \qquad (4.19)$$

the equation 4.19 is the same as equation 4.11 (comparing equation 4.15) and we conclude that the penalty factor of plant n is the ratio of the small change in power at plant n to the small change in received power when only plant n supplies this small change in received power. For practical example please see Appendix-C(1).

4.5 CHARACTERISTIC CURVES OF THE PLANTS OF WESTERN GRID, BPDB, '80

The system under investigation, i.e the Western Grid of BPDB shown in Fig. 2.1 and described in Sec. 2.3, has three generating plants (excluding some small capacity isolated plants) at Goalpara (plant No.1), Bheramara (plant No.2), and Saidpur (plant No.3)** to supply the system load. The three plants have different characteristics. Table 4.1, 4.2 and 4.3* give the fuel cost data for Goalpara, Bheramara and Saidpur power plants respectively.

Based on the data of 1980, a plot of fuel input (Taka/hr.) Vs. power output (MW) is shown in Fig. 4.2 for the different plants. The slopes of these curves at different outputs give the incremental production cost at these outputs. The incremental production cost (Taka/MW-hr) is plotted against output (MW) in Fig. 4.3. The latter curve can be approximated by a straight line as shown by the dotted lines in the figure. The slope and intercept of the incremental production cost curve can then be easily determined.

4.6 GENERATION SCHEDULE

For the system under investigation (see Fig. 2.1), the generator at Goalpara has been marked as plant No.1, that at Bheramara as plant No.2 and that at Saidpur as plant No.3.

From the incremental production cost curves of Fig. 4.3, the values of the coefficients of Eqns. (4.9) i.e the intercept(f_n)

** The plant capacity of Thakurgaon (3x2MW) is small and it is not considered as an individual plant for economic scheduling. Moreover same type of generators and fuel are used as used at Saidpur. It is also within a short distance of 40 miles from Saidpur. So the plant capacity of Thakurgaon is included with Saidpur (10.5MW + 6MW = 16.5MW).

* Obtained by the courtesy of System Planning Directorate, BPDB.

TABLE 4.1

Fuel Cost Data of Goalpara Power Station.

Power output (MW)	Specific fuel cost (Tk./KWhr)	Fuel input (Gallon/KWhr)	Fuel input (Tk./hr.)	Fuel Cost in (Tk./Gallon)
5	0.850	0.0963	4250.00	8.82
10	0.767	0.0869	7664.58	"
20	0.672	0.0762	13441.68	"
30	0.610	0.0690	18257.40	"
40	0.635	0.072	25401.60	"
50	0.672	0.0762	33604.20	"
60	0.709	0.0804	42550.00	"
70	0.709	0.0804	49640.00	
80	0.709	0.0804	56730.00	"

TABLE 4.2

Fuel Cost Data of Bheramara (G.T)Power Station

4	1.53	0.1115	6132.50	13.75
8	1.41	0.1025	11275.00	"
10	1.364	0.0990	13612.50	"
15	1.30	0.0948	19552.50	"
20	1.258	0.0915	25162.50	"
25	1.30	0.0948	32587.50	"
30	1.33	0.0967	39888.75	"
35	1.41	0.1025	49328.125	"
40	1.474	0.1072	58960.00	"

TABLE 4.3

Fuel Cost Data of Saidpur (Thakurgaon)Deisel Power Station

1	1.447	0.10507	1444.70	13.75
3	1.377	0.10016	4130.00	"
5	1.362	0.09907	6811.06	"
9	1.190	0.0867	10729.00	"
10	1.340	0.0976	13420.00	"
12	1.340	0.0976	16100.00	"
13	1.362	0.09907	17710.00	"
15	1.440	0.10476	21610.00	"
16	1.440	0.10476	23047.20	"

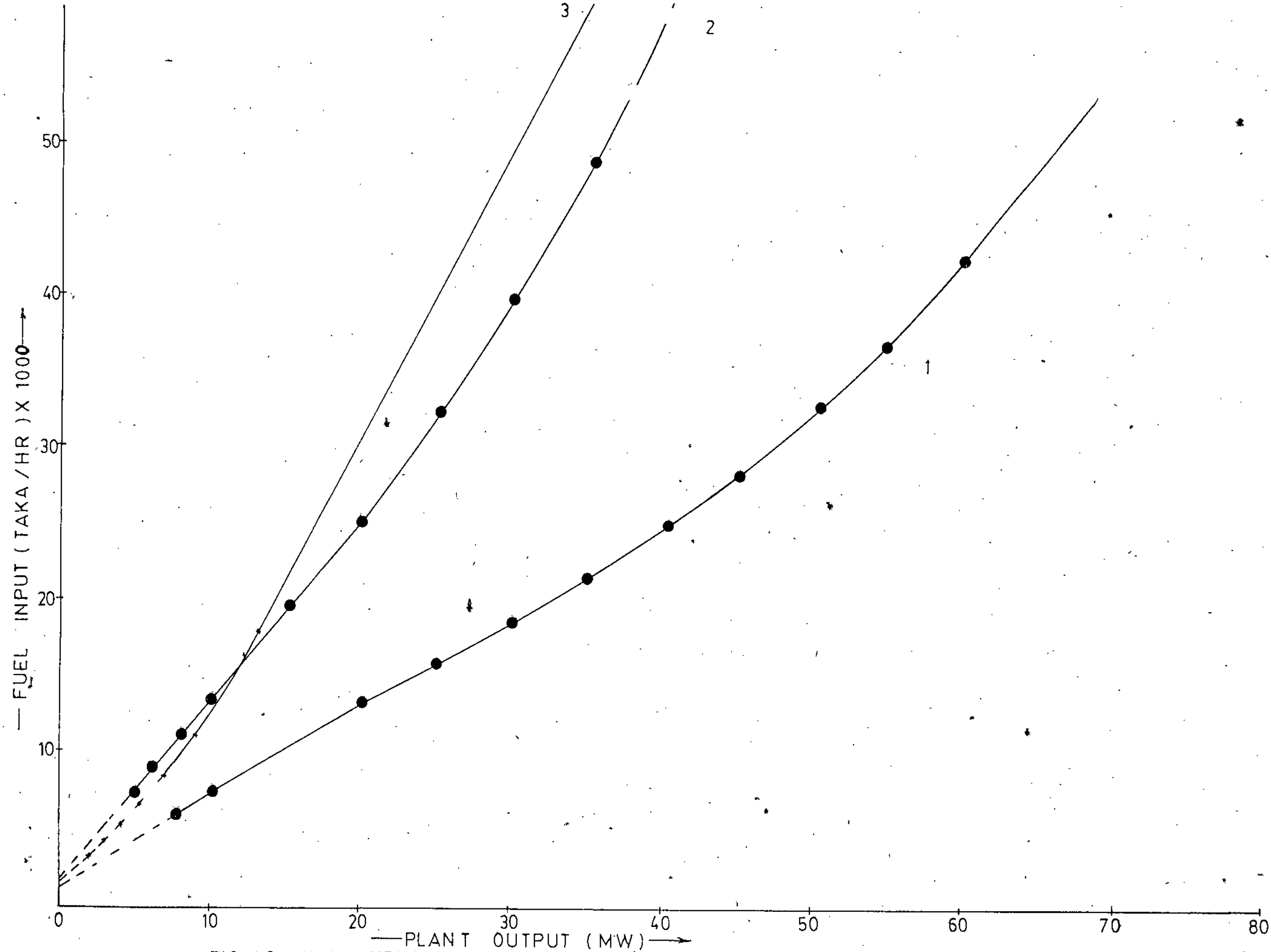


FIG. 4.2 FUEL INPUT Vs POWER OUTPUT CURVES FOR VARIOUS PLANTS.

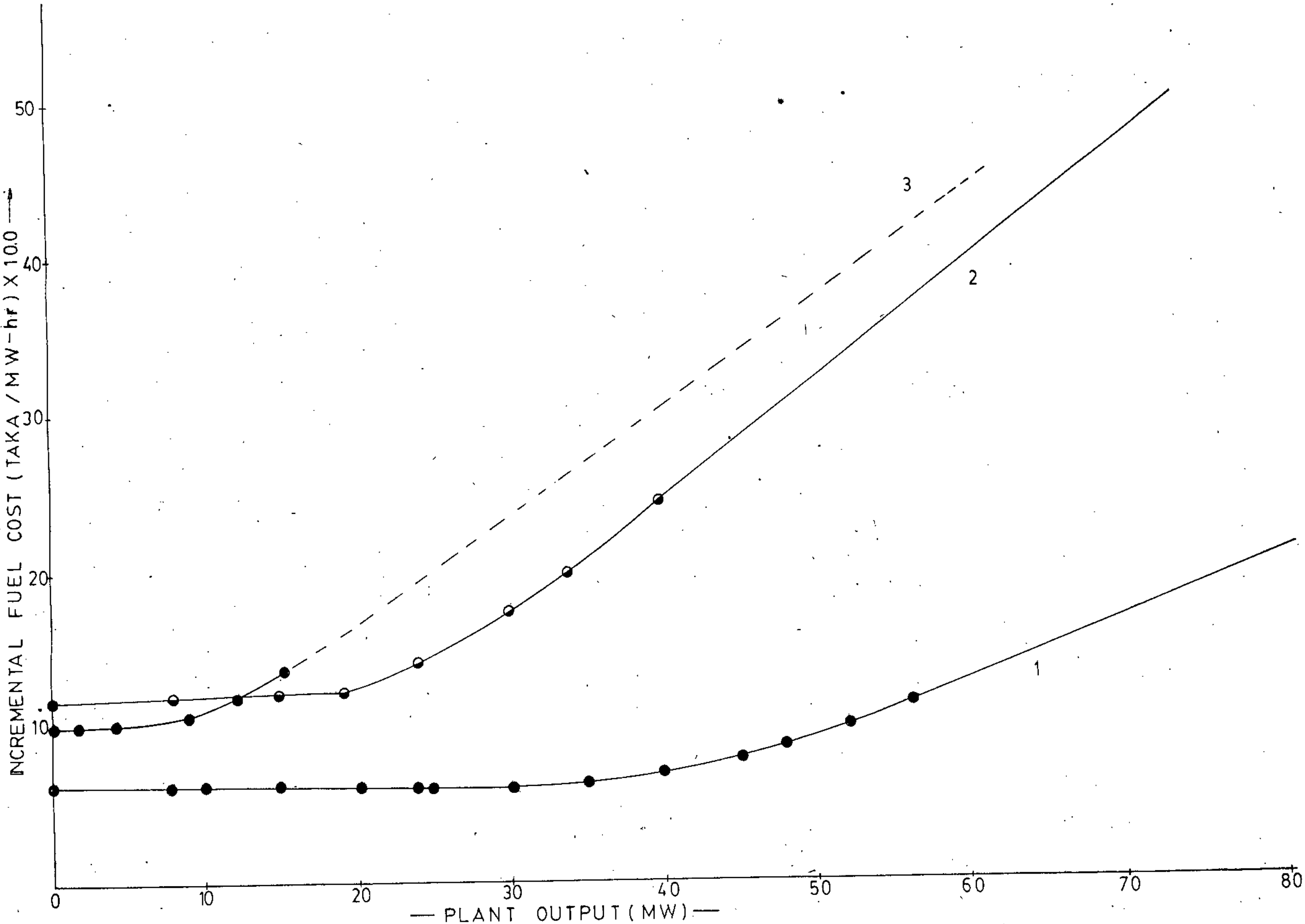


FIG. 4.3 INCREMENTAL FUEL COST Vs POWER OUTPUT CURVES.

and slope (F_{nn}) extended to 40 MW, where necessary, for different plants, are obtained and shown in Table 4.4.

TABLE 4.4

Values of F_{nn} and f_n

Palnt n	F_{nn} (slope)	f_n (intercept)
1	20	625
2	66.67	1175
3	66.67	1000

The B-matrix obtained in Chapter-3 is in per unit and it is to be converted into actual units (1/MW). This requires division of per unit values by the base MVA (100) which gives the B-matrix in units of (1/MW) as

B-Matrix

(Mean (B_{peak}+ $B_{off-peak}$)/2) values of peak and off-peak load-flow,'80)

0.000510660	-0.000195545	-0.000558370
-0.000195545	0.000275930	-0.000076725
-0.000558370	-0.000076725	0.001314505

The equations for optimum scheduling of generation, neglecting transmission losses, may be written from Eqns. (4.12) and (4.13) as

$$\begin{aligned} F_{11}P_1 + f_1 &= \lambda \\ F_{22}P_2 + f_2 &= \lambda \qquad \ldots \qquad (4.20) \\ F_{33}P_3 + f_3 &= \lambda \end{aligned}$$

The exact co-ordination simultaneous equations for optimum scheduling of generation may be written from Eqns. (4.7) and (4.10) as

$$F_{11}P_1 + 2B_{11}P_1 + 2B_{12}P_2 + 2B_{13}P_3 = \lambda - f_1$$
$$2B_{21}P_1 + F_{22}P_2 + 2B_{22}P_2 + 2B_{23}P_3 = \lambda - f_2 \quad (4.21)$$
$$2B_{31}P_1 + 2B_{32}P_2 + F_{33}P_3 + 2B_{33}P_3 = \lambda - f_3$$

The above equations can be rewritten as

$$(F_{11} + 2B_{11})P_1 + 2B_{12}P_2 + 2B_{13}P_3 = \lambda - f_1$$
$$(F_{22} + 2B_{22})P_2 + 2B_{21}P_2 + 2B_{23}P_3 = \lambda - f_2 \quad (4.22)$$
$$(F_{33} + 2B_{33})P_3 + 2B_{31}P_1 + 2B_{32}P_2 = \lambda - f_3$$

Using numerical values of B_{ij}, f_{nn} and f_n, the above set of equations have been solved on an IBM 370/115 computer for different values of λ giving different received load. Total generation and total transmission loss have also been computed for each value of λ. The iterative procedure and the programme are shown in Appendix-C(2), C(4) and C(5).

4.7 GRAPHS AND RESULTS

Fig. 4.4 gives a plot of generation schedules with individual plant generation plotted against the total generation. The calculation of generation schedules for various values of λ are given in Appendix-C(4). Fig. 4.5 gives a plot of individual plant generation against the total received load. The abscissa of this graph is obtained by subtracting the transmission losses from the corresponding total generation of Fig. 4.4 for different

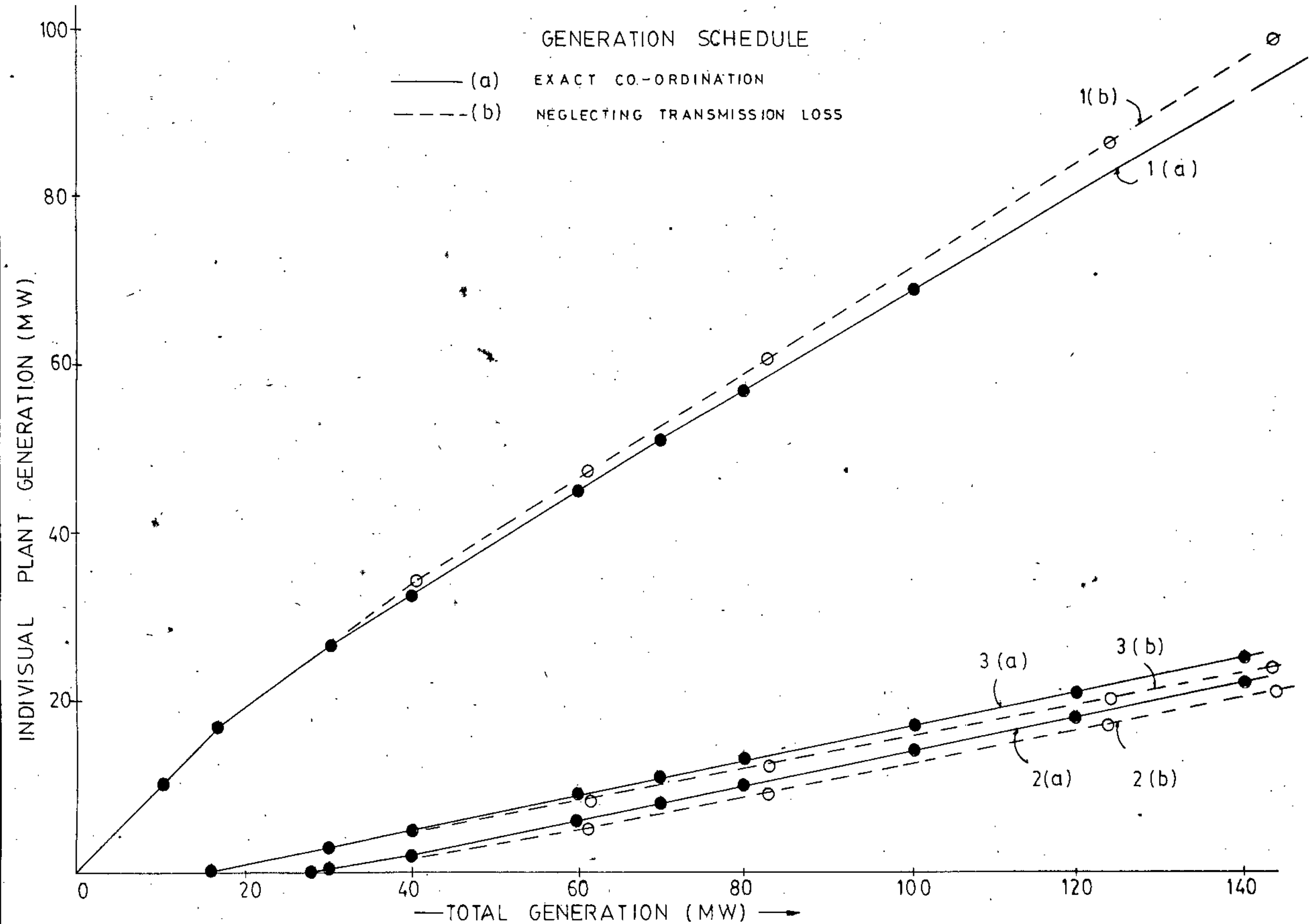


FIG.4.4 PLOT OF INDIVISUAL GENERATION Vs TOTAL GENERATION

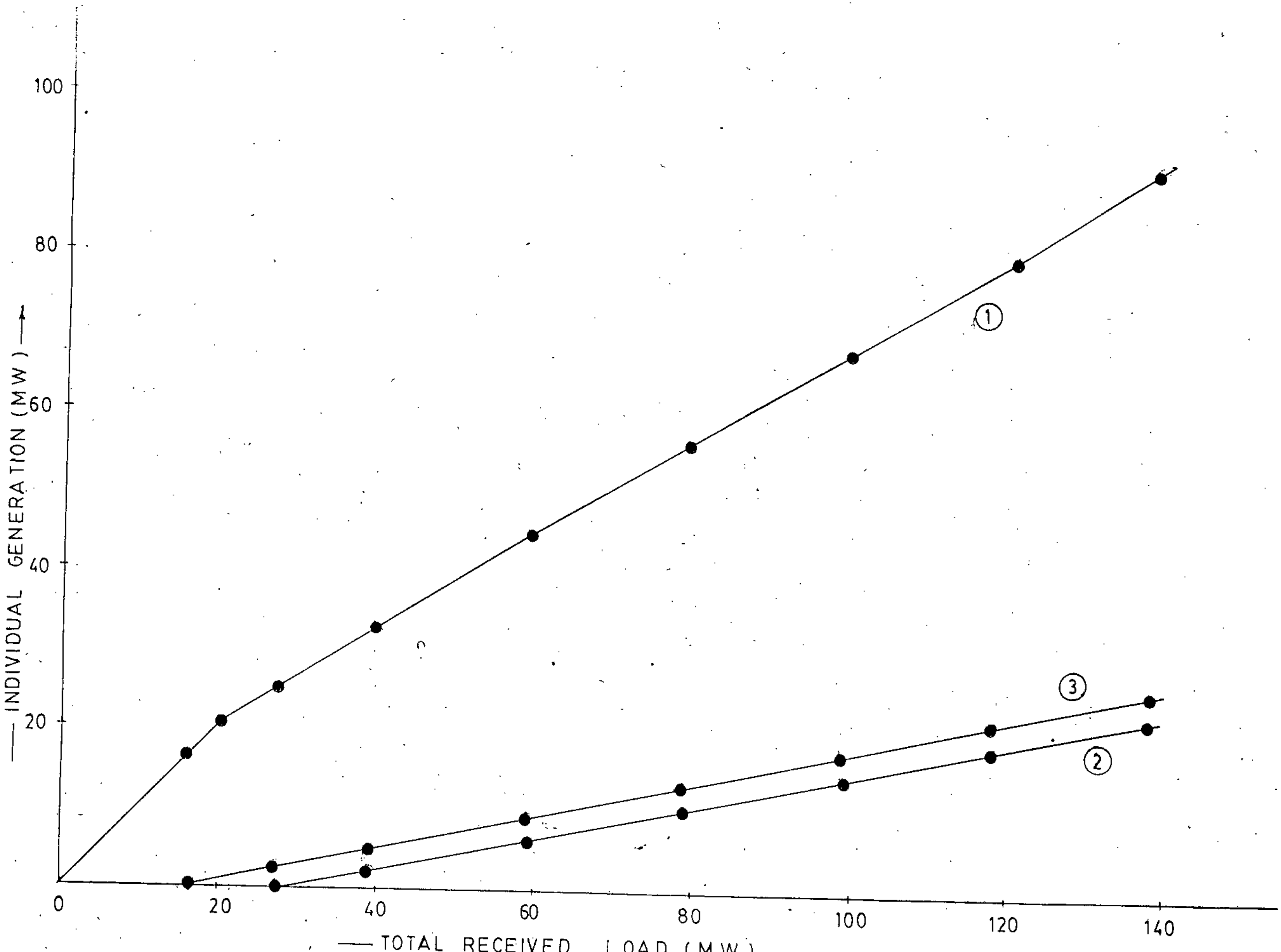
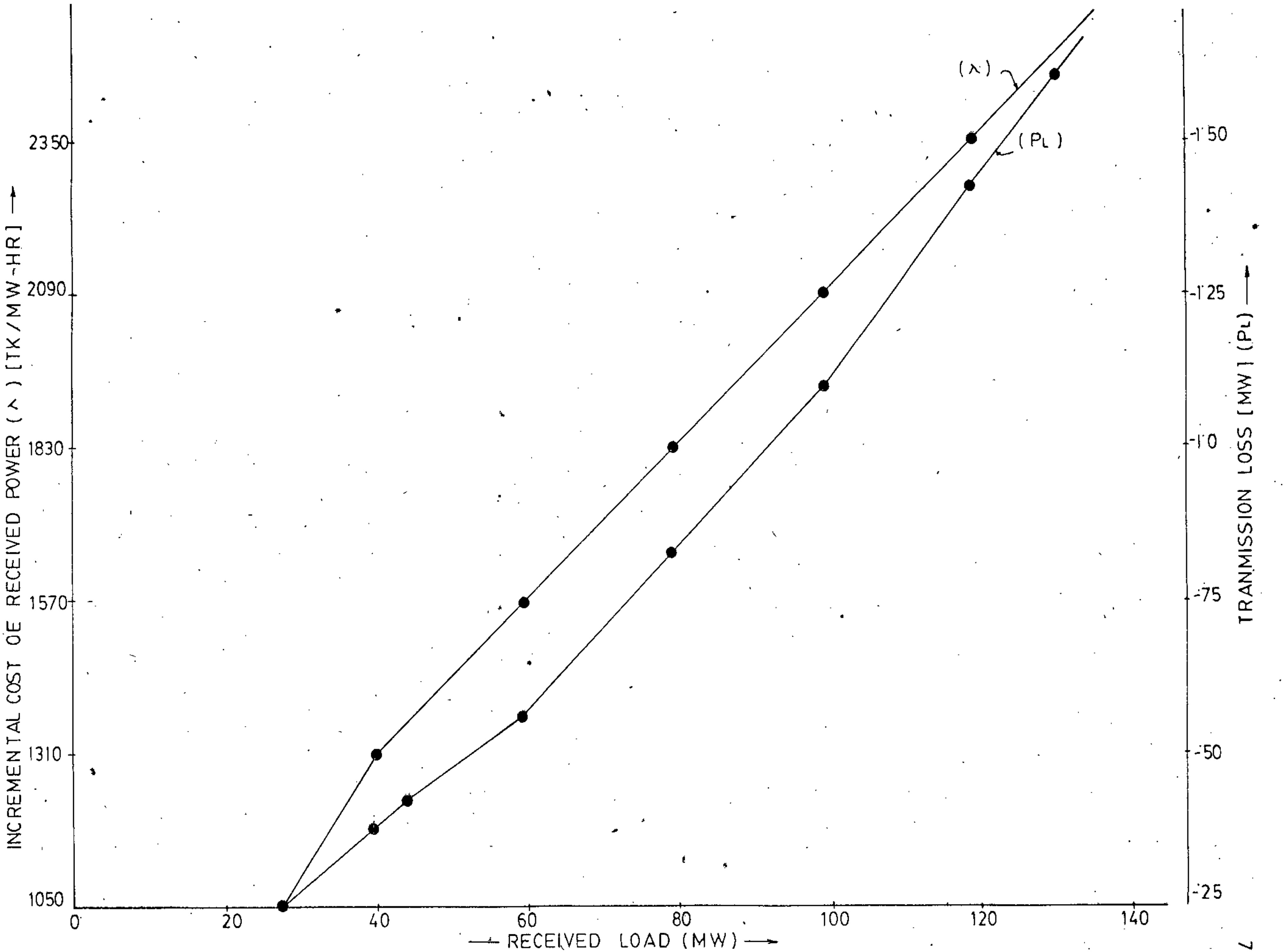


FIG. 4.5 PLOT OF RECEIVED LOAD Vs. INDIVIDUAL GENERATION (MW.)



FIG·4·6. PLOT OF RECEIVED LOAD Vs. INCREMENTAL COST OF RECEIVED POWER & TRANSMISSION values of λ . A plot of transmission loss Vs. received load has been given in Fig. 4.6. Variation of λ , (the incremental cost of received power) with the received load is important for a knowledge of how the cost of received power increases with increments of load. This is also plotted in Fig. 4.6. In Fig.4.4 the dotted curves are the schedule of generation considering only the incremental fuel cost as per equation (4.13).

A tabulation of results from the curves plotted are given in Table 4.5 and Table 4.6.

4.8 DIFFERENT CONSIDERATIONS AND LIMITATIONS TO SCHEDULING

Although the criterion of incremental production cost and penalty factor determines the optimum scheduling of generation, the following methods of scheduling are some times still found in use (38,39);

1. Base Loading to most Efficient Load

In a power plant with several units, most of the units need be in operation only when the peak demand occurs. To establish a basis for reasonable continuity of service, sufficient capacity should be operative at all time so that in case of failure of the largest in-service unit, the remaining active units are capable of maintaining supply without interruption. If the minimum (base) load is equal to or less than the capacity of a single unit, two units will have to be placed in operation to profect continuity of service. The order in which the units are placed in service depends upon their relative efficiencies.

The most efficient machine is placed in service first, followed by machines in descending order of efficiency as needed. The load is divided among the units in operation on the basis of equal incremental rates.

2. Proportional to Capacity

The loads on the units or plants are scheduled in proportion of their rated capacities.

The question as to the maximum capacity to which a plant can be operated for a given total load is not ans-wered in the scheduling equation. Determination of this capacity is based on such considerations as:

a) Economic evaluation

b) Reserve requirements

c) Stability limitations

d) Voltage limitations

e) Ability to pick up load quickly

Thus the above criterions put a limitation on scheduling and hence should be taken into consideration while scheduling for optimum economy. Usually in large integrated systems conditions 2 to 5 overrule condition 1.

TABLE 4.5

Generation Schedule Co-ordinating Transmission Losses

Value of Tk/MWhr	Individual Generation of Plants P_1(MW)	P_2(MW)	P_3(MW)	Total Generation P_T(MW)	Total Loss PBP(MW)	Total Received Load P_R(MW)
975	16.61230	0.0	0.0	16.61230	0.14092	16.4713
1050	20.19337	0.0	1.05710	21.25047	0.18586	21.0646
1310	32.50687	2.26564	5.10625	39.87877	0.35935	39.5194
1570	44.66644	6.28764	9.17882	60.13289	0.56390	59.56895
1830	56.67899	10.332	13.272	80.284	0.811	79.472
2090	68.550	14.399	17.385	100.335	1.098	99.236
2350	80.287	18.487	21.515	120.290	1.423	118.866
2610	91.894	22.596	25.661	140.152	1.784	138.368
3130	114.740	30.875	33.991	179.606	2.602	177.003
3650	137.125	39.229	42.363	218.718	3.539	215.179
4170	159.081	47.656	50.768	257.506	4.582	252.923
4820	185.96	58.285	61.305	305.560	6.019	299.540
5340	207.064	66.860	69.751	343.676	7.264	336.411
5860	227.816	75.495	78.204	381.516	8.587	372.929
6120	238.070	79.834	82.432	400.337	9.275	391.062

TABLE 4.6

Generation Schedule Neglecting Transmission Losses

1050	21.249	-1.874	0.749	21.999
1310	34.250	2.025	4.649	40.925
1570	47.25	5.9248	8.549	61.7249
1830	60.25	9.8246	12.449	82.524
2090	73.250	13.7244	16.349	103.324
2350	86.25	17.624	20.249	124.123
2610	99.250	21.524	24.148	144.923
3130	125.25	29.323	31.948	186.522
3650	151.250	37.12325	39.748	228.121
4170	177.25	44.922	47.547	269.72
4820	209.75	54.672	57.297	321.719
5340	235.75	62.471	65.096	363.318
5860	261.75	70.271	72.896	404.917

CHAPTER-5

EVALUATION OF SAVINGS

5.1 INTRODUCTION

The technique of including transmission losses in generation scheduling must have certain outstanding effects in the field of economic study of power generation. The ultimate aim of our analysis is to investigate what savings in terms of money could be achieved by scheduling the generations according to the preceeding mathematical analysis. The two types of scheduling curves (neglecting and including the transmission losses) for each plant have distinctly different positions causing significant differences in total fuel consumption costs. The difference is the amount of saving (Taka per hour) that is obtained for a particular value of received load. The savings, however, may seem to be small when computed on per hour basis, but they accumulate to a huge amount when calculated for the whole year.

5.2 CALCULATION OF FUEL INPUT FOR VARIOUS GENERATORS

The fuel input (Taka/hr.) versus output (MW) of various plants are plotted in Fig. 4.2. For any given value of total generation the individual plant generations can be found from Fig. 4.4. The combination of the two plots gives full cost (and hence production cost) for each plant at a particular total generation. The accumulation of the cost of all plants gives the total cost. A comparative study of the fuel costs for various schedules is given in the section 5.3.

5.3 COMPARATIVE STUDY

The comparison is made at a total generation of 140 MW. The total fuel inputs for various cases and the annual losses incurred for the different cases as compared to the reference case are given in Table 5.1. It is assumed that all the plants run 24 hours a day, that is 8760 hours annually.

5.4 REMARKS

Table 5.1 reveals a considerable amount of loss in crores of taka per annum for scheduling the generation arbitrarily. The loss is considerable (9.37 crores of taka per annum) for the existing generating scheduling practises by authority concerned (BPDB) i.e the plant at Goalpara carries 84 MW, and Bheramara and Saidpur carry 40 MW and 16 MW respectively. The loss is also prominent (6.84 crores of taka per annum), considering the Goalpara plant at a constant generation of 84 MW and the capacity of the plant at Saidpur increases to 20 MW and the plant at Bheramara decreases to 36 MW. The loss is maximum (31.27 crores of taka per annum), if each of the plants carries equal (44.667 MW) share of the total (140 MW) system load. The scheduling of generation neglecting transmission losses for a total generation of 140 MW caused an annual saving of 1.4 crores of taka assuming that the plants operate 24 hours a day continuously (hypothetical saving due to comparatively good scheduling only, but there will always be some transmission losses). Even if we consider that the plants operate 18 hrs or 12 hrs a day still the losses involved in arbitrary generation is high when accumulated for the whole year.

TABLE 5.1

COMPARATIVE STUDY OF FUEL INPUTS AND LOSSES INCURRED AT DIFFERENT CASES (FOR TOTAL GENERATION OF 140 MW)

Type of Scheduling	Total Fuel Input (Tk/hr)	Difference of fuel inputs as compared to the reference case (Tk/hr)	Annual Loss* compared to the reference case (Tk.in crores)
Generation schedule co-ordinating transmission loss (Reference case) (Goalpara = 92 MW, Bherampara = 22.5 MW Saidpur = 25.5 MW)	1,31,300.00	-	-
Goalpara = 84 MW Bheramara =40 MW Saidpur = 16 MW	1,42,000.00	10,700.00	9.3732
Schedule to supply loads equally (46.667 MW)	1,67,000.00	35,700.00	31,2732
Goalpara = 84 MW, Bheramara= 36 MW Saidpur = 20 MW	1,39,113.00	7,813.00	6.8444
Schedule, Neglecting transmission loss (Goalpara = 95.88 MW, Bheramara = 20.79 MW Saidpur = 23.33 MW)	1,29,700.00	1,600.00	1.4016 (saving)**

* Considering 24 hours of operation of plants

** Hypothetical saving due to comparatively good scheduling <u>only</u>, but there will always be some transmission losses.

CHAPTER-6

DISCUSSION AND CONCLUSION

6.1 DISCUSSION

In the present world, because of the continuously rising cost of fuel, labour, supplies and maintenance in any system, much efforts are expended to have more return from less capital investment. Economic operation of power stations in an integrated system is a complex problem to the power system engineer. One of the aspects of economic operation is scheduling of generation. Several methods are available (1) for the economic scheduling of generating plants, such as, (i) economic scheduling by neglecting transmission losses, (ii) economic scheduling by co-ordinating transmission losses in the scheduling equation, (iii) economic scheduling by penalty factor method.

Method (i) is an approximate method and may introduce appreciable loss in terms of money as is evident from the evaluation of savings done in the previous chapter. Methods (ii) and (iii) are accurate, and require expression of transmission losses in terms of source loadings. The constants involved in such expression are called B-coefficients which need to be determined accurately. Previously, B-coefficients were determined by network analyser measurements and the results were of questionable accuracy. But with the advent of high speed digital computers, the B-coefficients can be determined accurately and in a much shorter time. Computer methods are cheaper too. As the system grows the B-matrix is to be calculated for the changed system every time and once the programme for calculation of B-coefficients is developed, it requires only a few minutes to calculate the B-coefficients.

In our calculations of B-matrix with 13 buses and 3-generators it took only 3 minutes 21 seconds with binary deck to get B-matrix, using an IBM 370/115 computer.

In this endeavour, economic secheduling of generations for the Western-Grid of BPDB has been obtained with method (ii) quoted earlier.

6.2 CONCLUSION

The aim of the research work undertaken here was to present a digital computer method of calculating the transmission line loss co-efficients and coordinating the loss in the problem of determining the optimum scheduling of generation. The achievement of the desired objectives involved the following steps:

(1) The development of an efficient load-flow (Gauss-Seidel iterative method) programme for determining unknown voltages and phase angles at different buses and real and reactive power flows in various lines of the system.

(2) The development of an efficient programme for calculating the transmission line loss coefficients (B-coefficients) automatically without intermediate data handling and for the determination of reactive characteristics of the various plants during the course of calculating the B-coefficients.

(3) Drawing up an optimum generation schedule for the present (1980) Western-Grid of BPDB.

(4) Evaluation of the amount of annual savings under the most desirable scheduling of generation.

The results obtained from the investigation of the problems undertaken, if utilised by the authority concerned, can save a huge amount of money annually which is being lost at present because of arbitrary scheduling.

6.3 SUGGESTIONS FOR FUTURE WORK

Future research work in the field of economic operation and control of power systems could concentrate on the following:

(1) Penalty factor approach of co-ordinating the transmission loss in the digital method of determining the optimum scheduling of generation.

(2) A digital method of calculating coefficients for systems involving non-conforming loads, i.e the loads which do not vary over the daily load cycle in the same manner as the system loads and which do not maintain a constant ratio with the total load. They can be handled by splitting them into two parts (i) a constant part which do not vary within the range of variation of load, (ii) a variable part which varies with the total load. The constant components are treated as negative generators in the loss formula. The loss formula (21) then takes the form:

$$P_L = P_m B_{mn} P_n + B_{no} P_n + B_{oo} \quad \ldots \quad (6.1)$$

where

$$B_{no} = 2P_j \; B_{nj} \qquad \ldots \qquad (6.2)$$

$$B_{oo} = P_j B_{jk} P_k \qquad \ldots \qquad (6.3)$$

P_j, P_k = constant MW components of loads

B_{nj} = mutual loss-formula co-efficients between constant components of loads and generators

B_{jk} = self and mutual loss-formula co-efficients for constant components of loads.

(3) Calculation of B-matrix for systems involving auto-transformers taking into account their off-nominal turns ratios.

APPENDIX-A(1)

THE GAUSS-SEIDEL ITERATIVE METHOD OF SOLUTION

In general, there are two types of numerical techniques for solving simultaneous equations:

1. The direct methods, which are finite, would in principle (neglecting round-off errors) produce an exact solution, if there is one, in a finite number of arithmatic operations. But this method is not of help in solving large system of equations due to accumulation of round-off errors, limitations of the high-speed computer storage, and the programming complexity.

The limitations of the finite methods could be overcome to a great extent with the help of an infinite method the iterative technique.

2. The indirect methods, which are infinite, would in principle require an infinite number of arithmatic operations to produce an exact solution, that is an indirect method has a truncation error.

The best known and most widely used finite technique for the solution of simultaneous linear equations is generally referred to as the method of Gaussian Elimination. This method expresses every variable interms of the other variables. Taking any first approximation to the solution, the expression for each variable is solved for a new approximation. The process is repeated till the values attain the required precision. A numerical method in which a succession of approximation is made is called an iterative technique. Each step, or approximation, is called an iteration.

Of all the iterative techniques, the most common one, marked by its simplicity and the case with which it may be programmed for a high-speed computer, is the Gauss-Seidel iterative method. Though its round-off error is small, the method converges only under certain conditions. Luckily the conditions for convergence are often satisfied when partial differential equations are solved (35) numerically by certain techniques. The power network equations fall in this group.

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

$$a_{11} x_1 + a_{12} x_2 + a_{13} x_3 = b_1 \quad \ldots \quad (A-1)$$

$$a_{21} x_1 + a_{22} x_2 + a_{23} x_3 = b_2 \quad \ldots \quad (A-2)$$

$$a_{31} x_1 + a_{32} x_2 + a_{33} x_3 = b_3 \quad \ldots \quad (A-3)$$

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

$$x_1 = \frac{1}{a_{11}} (b_1 - a_{12} x_2 - a_{13} x_3) \quad \ldots \quad (A-4)$$

$$x_2 = \frac{1}{a_{22}} (b_2 - a_{21} x_1 - a_{23} x_3) \quad \ldots \quad (A-5)$$

$$x_3 = \frac{1}{a_{33}} (b_3 - a_{31} x_1 - a_{32} x_2) \quad \ldots \quad (A-6)$$

We now take any first approximation to the solution; call it $x_1^{(o)}$, $x_2^{(o)}$ and $x_3^{(o)}$. We solve (A-1) for a new approximation to x_1:

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

Using the new value of x_1, together with $x_3^{(o)}$, we solve the eqn. (A.5) for x_2:

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

Finally we use the newly computed values of x_1 and x_2 in (A.6) to find a new value of x_3:

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

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

$$x_1^{(k)} = \frac{1}{a_{11}} (b_1 - a_{12}x_2^{(k-1)} - a_{13}x_3^{(k-1)}) \qquad (A-7)$$

$$x_2^{(k)} = \frac{1}{a_{22}} (b_2 - a_{21}x_1^{(k)} - a_{23}x_3^{(k-1)}) \qquad (A-8)$$

$$x_3^{(k)} = \frac{1}{a_{33}} (b_3 - a_{31}x_1^{(k)} - a_{32}x_2^{(k)}) \qquad (A-9)$$

It may be noted that the most recently computed values for each x are always used and that we cannot calculate $x_2^{(k)}$ until $x_1^{(k)}$ has been computed. Similarly, the calculation of $x_3^{(k)}$ requires the prior calculation of $x_1^{(k)}$ and $x_2^{(k)}$.

Extending now equations (A-7) to (A-9) to n equations in n unknowns, the Kth approximation to x_i is:

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

$$- \ldots - a_{in}x_n^{(k-1)}) \quad i = 1, 2, \ldots, n \qquad (A-10)$$

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

$$M^{(k)} = \max \left| x_i^{(k)} - x_i^{(k-1)} \right| \qquad \ldots \qquad (A\text{-}11)$$

where the maximum is taken over all i. Then if:

$$M^{(k)} \leq \epsilon \qquad \ldots \qquad (A\text{-}12)$$

where ϵ is some predetermined small positive number usually called the tolerance limit, the iteration process is stopped.

APPENDIX-A(2)

ACCELERATED CONVERGENCE OF THE G.S. ITERATIVE METHOD

In any iterative process if the iterations produce approximations that approach the solution more and more closely, the iterative method is said to converge. If, on the other hand, the iterations produce approximations that are more and more further away from the solution, the iterative method is said to diverge.

Experience (27,32,35) with the Gauss-Seidel method of solutions has shown that an excessive number of iterations are required before the final values are within an acceptable precision index (tolerance) if the corrected value at one iteration merely replaces the best previous value as the computations proceeds from one iteration to another iteration. The number of iterations required is reduced considerably if the correction in each value is multiplied by some constant that increases the amount of correction to bring the final value closer to the value it is approaching. The multipliers that accomplish this improved convergence are called acceleration factors. The difference between the newly calculated value and the best previous value is multiplied by an appropriate acceleration factor to obtain a better correction to be added to the previous value.

To explain this, the value obtained from equation (A-7) may be modified in the following way:

$$x_{1(accelerated)} = x_1^{(k-1)} + \alpha \left| x_1^{(k)} - x_1^{(k-1)} \right| \qquad (A-13)$$

where, the parameter α is called the relaxation parameter or more commonly acceleration factor.

The acceleration factor for the real component of the correction may differ from that for the imaginary component. For any system, optimum values for acceleration factors exist, and poor choice of acceleration factors may result in less rapid convergence or make convergence impossible. In general (27,28,31,32) the value of α lies between one and two i.e $1 < \alpha \leq 2$. An acceleration factor of 1.6 for both real and imaginary components is usually a good choice.

APPENDIX-B(1)

SUMMARY OF TRANSFORMATION

In the following analysis, the lower case indices m, n, j and k are tensor indices, and the capitals G and L are identification indices referring to generator and load respectively. Whenever a repeated tensor index appears in a product a summation on that index is identified.

Transformation to Reference Frame 1

Let us consider Fig. 3.1(B), if any point R in this

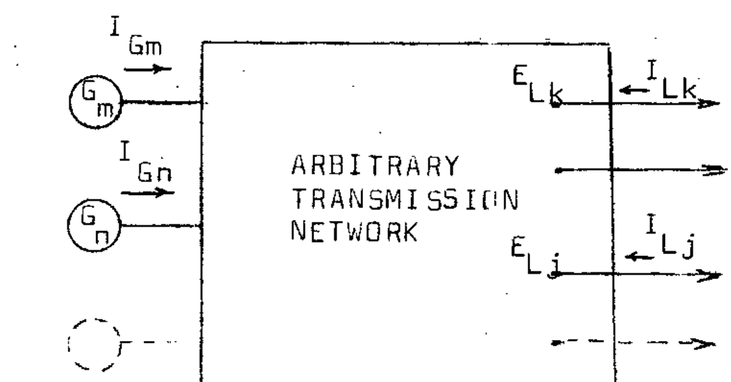


Fig. 3.1(B) Schematic diagram of a system connecting sources and loads by an arbitrary transmission network.

transmission system is chosen as reference point as shown in Fig. 3.5(B). Then the following set of equations may be written in terms of all the generators and load self and mutual impedances with respect to the reference point.

$$\begin{bmatrix} E_{Gm} - E_R \\ E_{Lj} - E_R \end{bmatrix} = \begin{bmatrix} Z_{Gm-Gn} & Z_{Gm-Lk} \\ Z_{Lj-Gn} & Z_{Lj-Lk} \end{bmatrix} \begin{bmatrix} I_{Gn} \\ I_{Lk} \end{bmatrix} \qquad (B.1)$$

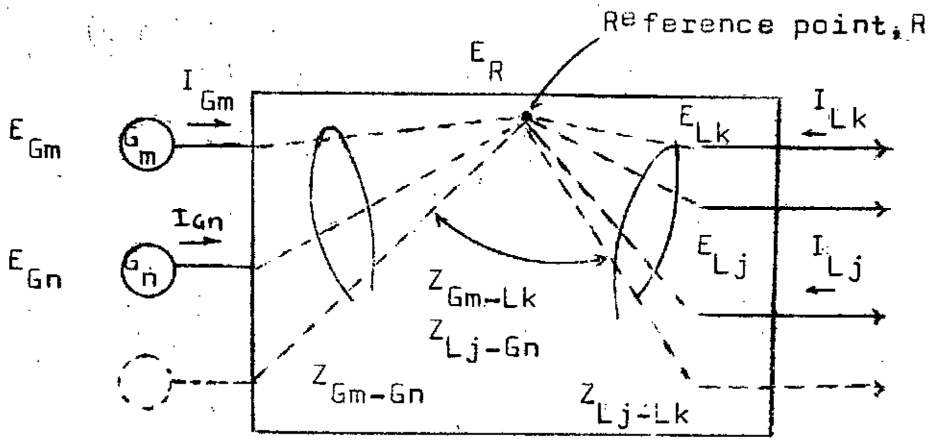


Fig. 3.5(B) Self and mutual impedances for transmission network (reference frame 1).

where

m, n = number of sources

j, k = number of loads

G, L = identification indices refering to generator and load respectively.

Z_{Gm-Gn} = self and mutual impedances between the generators

$\left.\begin{matrix} Z_{Lj-Gn} \\ Z_{Gm-Lk} \end{matrix}\right\}$ = self and mutual impedances between the generators and the loads

Z_{Lj-Lk} = self and mutual impedance between the loads

For example, let us consider a simple system with three generators and two loads as shown in Fig. 3.6(B). Equation (B.1) would then be written as

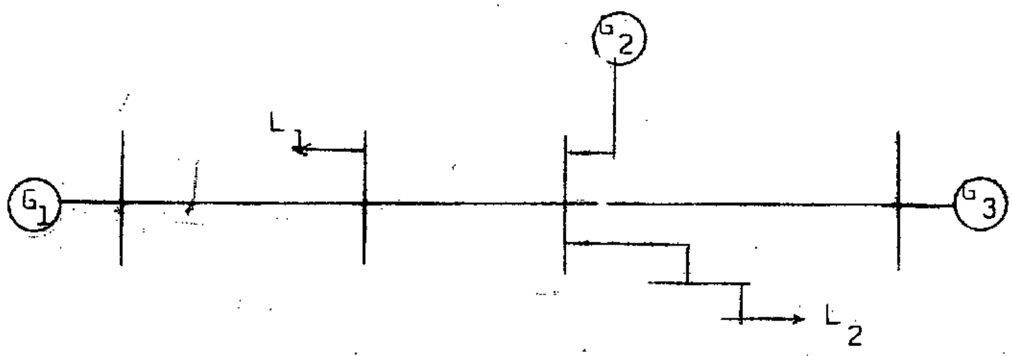


Fig. 3.6(B): Simple system with 3 generators and 2 loads.

$$\begin{bmatrix} E_{G1} - E_R \\ E_{G2} - E_R \\ E_{G3} - E_R \\ E_{L1} - E_R \\ E_{L2} - E_R \end{bmatrix} = \begin{bmatrix} Z_{G1-G1} & Z_{G1-G2} & Z_{G1-G3} & Z_{G1-L1} & Z_{G1-L2} \\ Z_{G2-G1} & Z_{G2-G2} & Z_{G2-G3} & Z_{G2-L1} & Z_{G2-L2} \\ Z_{G3-G1} & Z_{G3-G2} & Z_{G3-G3} & Z_{G3-L1} & Z_{G3-L2} \\ Z_{L1-G1} & Z_{L1-G2} & Z_{L1-G3} & Z_{L1-L1} & Z_{L1-L2} \\ Z_{L2-G1} & Z_{L2-G2} & Z_{L2-G3} & Z_{L2-L1} & Z_{L2-L2} \end{bmatrix} \begin{bmatrix} I_{G1} \\ I_{G2} \\ I_{G3} \\ I_{L1} \\ I_{L2} \end{bmatrix} \qquad (B.2)$$

Transformation to Reference Frame 2:

In this step, it is desired to eliminate the individual load currents as variable, since the final result involved only the generator powers. It is to be noted that the equivalent load current at a bus is defined as the sum of the line charging, synchronous condenser and load current at that bus.

Let us assume that each equivalent load current remains a constant complex fraction of the total equivalent load current. Such an assumption is reasonably valid for most of the loads.

Now we define (21) $I_L = \sum_j I_{Lj}$ .. (B.3)

By the above assumption $I_{Lj} = l_j I_L$ ... (B.4)

Then for the system given by the Fig. 3.6(B) and equation (B.2), we may write

$$I_{G1} = I_{G1}$$

$$I_{G2} = I_{G2}$$

$$I_{G_3} = I_{G3} \qquad \text{...} \qquad \text{(B.5)}$$

$$I_{L1} = l_1 I_L$$

$$I_{L2} = l_2 I_L$$

The preceeding relation may be written in terms of a matrix of transformation;

$$\begin{bmatrix} I_{G1} \\ I_{G2} \\ I_{G3} \\ I_{L1} \\ I_{L2} \end{bmatrix} = \begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & l_1 \\ & & & l_2 \end{bmatrix} \begin{bmatrix} I_{G1} \\ I_{G2} \\ I_{G3} \\ I_L \end{bmatrix} \qquad \text{(B.6)}$$

Thus the currents of reference frame $1(I_1)$ are related to the currents of reference frame $2(I_2)$ by a matrix of transformation $C_2^{\ 1}$

where

$$C_2^{\ 1} = \begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & l_1 \\ & & & l_2 \end{bmatrix} \qquad \text{...} \qquad \text{(B.7)}$$

The concept of the transformation matrix C allows a given circuit to be modified to a new circuit in such a manner that the power input remains invariant. By denoting the quantities pertaining to the original circuit by the subscript old and the quantities pertaining to the desired new circuit by the subscript new . In general, it has been shown by G. Kron (30) that if the set of currents I_{old} pertaining to the old circuit is related to the new currents I_{new} by a transformation matrix C such that

$$I_{old} = C\, I_{new} \qquad \ldots \qquad (B.7)$$

and if the power is to remain invariant the new set of voltages is given by

$$E_{new} = C_t^{*}\, E_{old} \qquad \ldots \qquad (B.8)$$

and the new set of impedances is given by

$$Z_{new} = C_t^{*}\, Z_{old}\, C \qquad \ldots \qquad (B.9)$$

The matrix C_t^{*} is obtained by conjugating the elements of the matrix C_t. Here our transformation matrix is C_2^{1} as given by equation (B.7). The symbol C_k^{j} is used to indicate the transformation from set or reference frame j to set a reference frame k.

Using equation (B.9) for the system illustrated we get reference frame 2 impedance (21) as

$$\left[Z_2 \right] = \begin{bmatrix} Z_{G1-G1} & Z_{G1-G2} & Z_{G1-G3} \\ Z_{G2-G1} & Z_{G2-G2} & Z_{G2-G3} \\ Z_{G3-G1} & Z_{G3-G2} & Z_{G3-G3} \\ c_1 & c_2 & c_3 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ w \end{bmatrix} \tag{B.10}$$

where,

$$\begin{aligned} a_1 &= Z_{G1-L1}\, I_1 + Z_{G1-L2}\, I_2 \\ a_2 &= Z_{G2-L1}\, I_1 + Z_{G2-L2}\, I_2 \\ a_3 &= Z_{G3-L1}\, I_1 + Z_{G3-L2}\, I_2 \\ c_1 &= Z_{L1-G1}\, I_1^* + Z_{L2-G1}\, I_2^* \\ c_2 &= Z_{L1-G2}\, I_1^* + Z_{L2-G2}\, I_2^* \\ c_3 &= Z_{L1-G3}\, I_1^* + Z_{L2-G3}\, I_2^* \\ w &= I_1^*\, Z_{L1-L1}\, I_1 + I_1^* Z_{L1-L2}\, I_2 + I_2^* Z_{L2-L1} I_1 \\ &\quad + I_2^*\, Z_{L2-L2}\, I_2 \end{aligned} \tag{B.11}$$

From equation (B.8) it is seen that our new voltages of reference frame 2 are given by $C_t^* E_{old}$ as indicated by

$$\begin{bmatrix} 1 & & & & \\ & 1 & & & \\ & & 1 & & \\ & & & I_1^* & I_2^* \\ & & & & \end{bmatrix} \begin{bmatrix} E_{G1} - E_R \\ E_{G2} - E_R \\ E_{G3} - E_R \\ E_{L1} - E_R \\ E_{L2} - E_R \end{bmatrix} = \begin{bmatrix} E_{G1} - E_R \\ E_{G2} - E_R \\ E_{G3} - E_R \\ E_L - E_R \\ \end{bmatrix} \tag{B.12}$$

$$C_t^* \qquad E_{old} \qquad = \qquad E_{new}$$

The calculation of $E_L - E_R$ is indicated in detail below.

$$l_1^*(E_{L1} - E_R) + l_2^*(E_{L2} - E_R) = l_1^* E_{L1} + l_2^* E_{L2} - (l_1^* + l_2^*) E_R$$

By defining $E_L = l_1^* E_{L1} + l_2^* E_{L2}$

Since

$$(l_1^* + l_2^*) = 1$$

we have

$$l_1^*(E_{L1} - E_R) + l_2^*(E_{L2} - E_R) = E_L - E_R$$

From equation (B.6), (B.10) and (B.12) we have the reference frame equation for the system illustrated.

$$\begin{bmatrix} E_{G1} - E_R \\ E_{G2} - E_R \\ E_{G3} - E_R \\ E_L - E_R \end{bmatrix} = \begin{bmatrix} Z_{G1-G1} & Z_{G1-G2} & Z_{G1-G3} & a_1 \\ Z_{G2-G1} & Z_{G2-G2} & Z_{G2-G3} & a_2 \\ Z_{G3-G1} & Z_{G3-G2} & Z_{G3-G3} & a_3 \\ c_1 & c_2 & c_3 & w \end{bmatrix} \begin{bmatrix} I_{G1} \\ I_{G2} \\ I_{G3} \\ I_L \end{bmatrix} \qquad (B.13)$$

It will be noted that the effect of each load current has been replaced by a single total load current (I_L). And is general we write equation (B-13) as

$$\begin{bmatrix} E_{Gm} - E_R \\ E_L - E_R \end{bmatrix} = \begin{bmatrix} Z_{Gm-Gn} & a_m \\ c_n & w \end{bmatrix} \begin{bmatrix} I_{Gn} \\ I_L \end{bmatrix} \qquad (B.14)$$

where

$$a_m = Z_{Gm-Lk}\, l_k$$

$$c_n = l_j^* Z_{Lj-Gn}$$

$$w = l_j^* Z_{Lj-Lk}\, l_k$$

$$E_L = l_j^* E_{Lj}$$

By means of above transformation the circuit of Fig. 3.1(B) has been changed to the circuit given in Fig. 3.7(B).

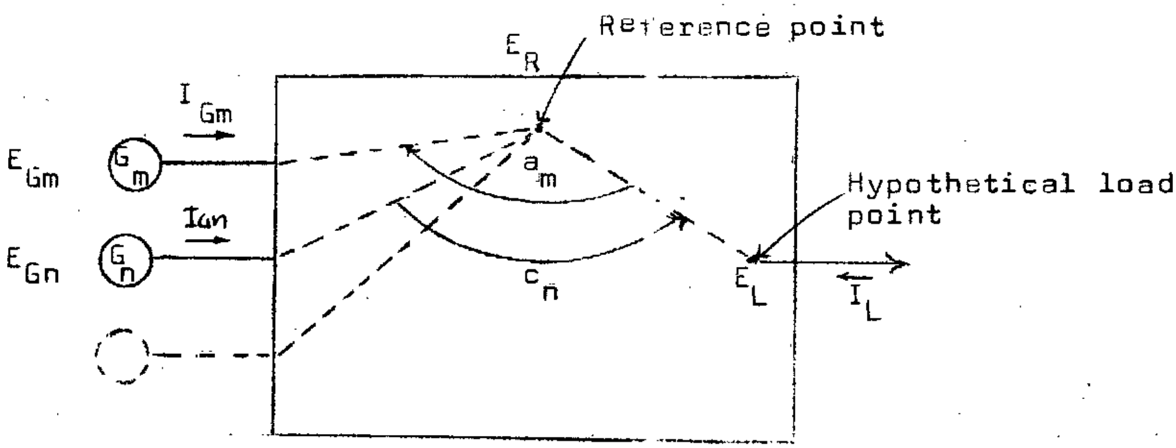


Fig. 3.7(B) Equivalent circuit with respect to Reference Frame 2.

The load point L does not exist in actual network. So it can be visualised as a hypothetical load point. It is evident from equation (B.14) that the component of the voltage drop $E_{Gm} - E_R$ due to load current I_L is given by $a_m I_L$. Similarly the component of the voltage drop $E_L - E_R$ due to generator current I_{Gn} is given by $c_n I_{Gn}$. The impedance w is the self impedance between the hypothetical load point and the reference bus. The next step in next step in our analysis will be the elimination of total load current (I_L) as a variable.

Transformation to Reference Frame 3

Since the load current is supplied by the generators, we may accomplish this by the relationship that the summation of the generator currents must be equal and opposite to the summation of the load currents.

Thus

$$\sum_n I_{Gn} = I_L$$

So for the system illustrated in Fig. 3.6(B) and equation (B.13), we may write

$$\begin{aligned} I_{G1} &= I_{G1} \\ I_{G2} &= I_{G2} \\ I_{G3} &= I_{G3} \\ I_L &= -(I_{G1} + I_{G2} + I_{G3}) \end{aligned} \qquad (B.15)$$

The above relation may be written in terms of a matrix of transformation as indicated below:

$$\begin{bmatrix} I_{G1} \\ I_{G2} \\ I_{G3} \\ I_L \end{bmatrix} = \begin{bmatrix} 1 & & \\ & 1 & \\ & & 1 \\ -1 & -1 & -1 \end{bmatrix} \begin{bmatrix} I_{G1} \\ I_{G2} \\ I_{G3} \end{bmatrix} \quad \ldots \qquad (B.16)$$

Thus the currents of reference frame $2(I_2)$ are related to the currents of reference frame $3(I_3)$ by a matrix of transformation $C_3^{\,2}$, where

$$C_3^{\,2} = \begin{bmatrix} 1 & & \\ & 1 & \\ & & 1 \\ -1 & -1 & -1 \end{bmatrix} \qquad (B.17)$$

The new voltages of reference frame 3 are then given by the equation (B.8).

$$E_3 = \begin{bmatrix} 1 & & & -1 \\ & 1 & & -1 \\ & & 1 & -1 \\ & & & \end{bmatrix} \begin{bmatrix} E_{G1} - E_R \\ E_{G2} - E_R \\ E_{G3} - E_R \\ E_L - E_R \end{bmatrix} = \begin{bmatrix} E_{G1} - E_L \\ E_{G2} - E_L \\ E_{G3} - E_L \\ \end{bmatrix} \qquad (B.18)$$

$$C_t^{*} \qquad E_{old} \quad = \quad E_{new}$$

The new impedance matrix, as indicated by the equation (B.9) will be (21) as

$$\begin{bmatrix} Z_3 \end{bmatrix} = \begin{bmatrix} Z_{1-1} & Z_{1-2} & Z_{1-3} \\ Z_{2-1} & Z_{2-2} & Z_{2-3} \\ Z_{3-1} & Z_{3-2} & Z_{3-3} \end{bmatrix} \qquad (B.19)$$

where, $Z_{m-n} = Z_{Gm-Gn}\ a_m - c_n + w$ (B.20)

So that the reference frame 3 equation reduces to

$$\begin{bmatrix} E_{G1} - E_L \\ E_{G2} - E_L \\ E_{G3} - E_L \end{bmatrix} = \begin{bmatrix} Z_{1-1} & Z_{1-2} & Z_{1-3} \\ Z_{2-1} & Z_{2-2} & Z_{2-3} \\ Z_{3-1} & Z_{3-2} & Z_{3-3} \end{bmatrix} \begin{bmatrix} I_{G1} \\ I_{G2} \\ I_{G3} \end{bmatrix} \qquad (B.21)$$

And in general

$$\begin{bmatrix} E_{Gm} - E_L \end{bmatrix} = \begin{bmatrix} Z_{Gm-Gn} - a_m - c_n + w \end{bmatrix} \begin{bmatrix} I_{Gn} \end{bmatrix} \qquad (B.22)$$

$$= \begin{bmatrix} Z_{m-n} \end{bmatrix} \begin{bmatrix} I_{Gn} \end{bmatrix}$$

The circuit of reference frame 2, given by Fig. 3.7(B), has been modified as indicated by equation (B.22) to that given in Fig, 3.8(B).

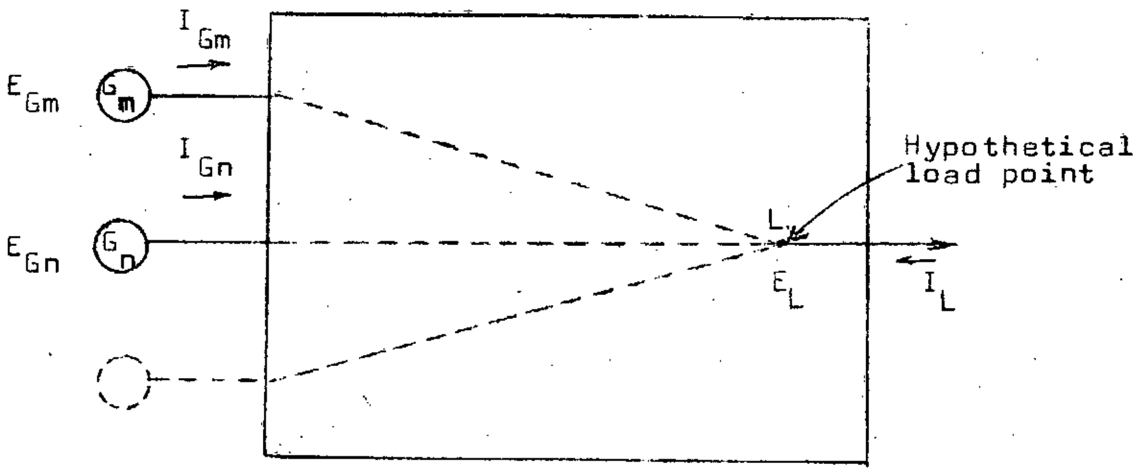


Fig. 3.8(B) Equivalent Circuit with respect to Reference Frame 3.

Obviously frame 3 impedance are not symmetrical. Hence it is not possible to represent the above circuit on the analyser through the use of static circuit elements. Thus direct measurement of these impedances is not feasible. But they can be calculated directly by the use of digital computers as demostrated in Chapter-3.

APPENDIX-B(2)

Nodal load flow method of determining reference frame 3 voltages

(Iterative circuit solution)

We have established that total load current is to be supplied by one generator at a time to get the corresponding column of frame 3 impedances. We assume that the bus connected to the generator which takes all the load current in turn, is the swing bus and we arbitrarily specify a voltage magnitude and angle for that bus. All other buses are then load buses.

Let I(k) be the current entering at some load bus k. Then from node equation at that bus we can write

$$I(k) = Y(k1)E(1) + Y(k2)E(2) + \dots + Y(kN)E(N) \qquad (B.23)$$

Where the admittances are the self and mutual admittances at the nodes as usual. E(k) is the frame 3 voltage at bus k and N is the total number of buses.

Rearranging the above equation we (20) can write

$$E(k) = \frac{1}{Y(kk)} \left(I(k) - Y(kn)E(n) \right) \quad \dots \qquad (B.24)$$

Let

$$Y(kn) = G(kn) + jB(kn)$$

$$I(k) = IR(k) + jII(k) \quad \dots \qquad (B.25)$$

$$E(k) = ER(k) + jEI(k)$$

Then from equation (B.24), solving real and imaginary terms, we (20) get

$$ER(k) = IR(k)G1(k) + II(k)B1(k) - YL1(k,n)ER(n) - YL2(k,n)EI(n)$$

$$(B.26)$$

$$EI(k) = II(k)G1(k) - IR(k)B1(k) - YL2(k,n)ER(n) + YL1(k,n)EI(n) \quad (B.27)$$

Where,

$$YL1(k,n) = G(kn)G1(k) + B(kn)B1(k)$$

$$YL2(k,n) = B(kn)G1(k) - G(kn)B1(k) \quad (B.28)$$

$$G1(k) = G(kk)/(G^2(kk) + B^2(kk))$$

$$B1(k) = B(kk)/(G^2(kk) + B^2(kk))$$

Equations (B.26) and (B.27) can be solved by Gauss-Seidal iterative method (27) to find frame 3 voltages.

APPENDIX-C(1)

CO-ORDINATION OF INCREMENTAL COST

Consider the simple system of Fig. 5.1(C) in which we have a single plant supplying a single load. It is desired to know the incremental cost of

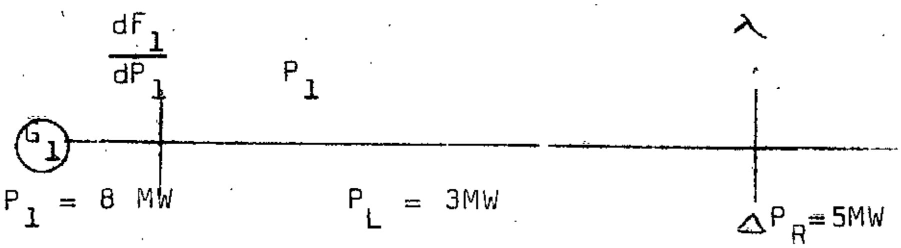


Fig. 5.1(C) Simple one-plant system.

received power. Let $\Delta P_R = 5$ MW. Assume that to supply this increase in received power it is necessary to increase P_1 by 8 MW. Then $\Delta P_L = 8 \text{ MW} - 5 \text{ MW} = 3$ MW. If the cost at the plant bus bar is assumed to be three takas per MWhr, then the cost at the receiver is given by

$$\lambda = 3 \times \frac{\Delta P_1}{\Delta P_R} = 3 \times \frac{8}{5} = 4.8 \text{ takas per MWhr.}$$

or

$$\lambda = 3 \times \frac{1}{1 - (\Delta P_L / \Delta P_1)} = 3 \times \frac{1}{1 - \frac{3}{8}}$$

$$= 3 \times \frac{1}{\frac{5}{8}} = 4.8 \text{ takas per MWhr.}$$

APPENDIX-C(2)

ITERATIVE PROCEDURE FOR SCHEDULING OF GENERATION

The iterative procedure involves a method of successive approximations(1) which rapidly converge to the correct solution. From equation (4.7) of the Chapter-4, the exact co-ordination equations are given by

$$\frac{dF_n}{dP_n} + \lambda \frac{\partial P_L}{\partial P_n} = \lambda \quad \ldots \qquad (C.1)$$

or

$$F_{nn} P_n + f_n + \lambda \sum_m 2B_{mn} P_m = \lambda \quad \ldots \qquad (C.2)$$

collecting all coefficients of P_n, we obtain

$$P_n(F_{nn} + \lambda\, 2B_{nn}) = -\lambda \Big(\sum_{m \neq n} 2B_{mn} P_m \Big) - f_n + \lambda \qquad (C.3)$$

Solving for P_n, we obtain

$$P_n = \frac{1 - \frac{f_n}{\lambda} - 2B_{mn} P_m}{\frac{F_{nn}}{\lambda} + 2B_{nn}} \qquad (C.4)$$

This iterative procedure is programmed and shown in Appendix-C(4).

APPENDIX-C(3)

Calculation of Generation Schedules for the Case of Neglecting Transmission Losses:

From eqn. (4.13) we have,

$$P_n F_{nn} + f_n (= \frac{dF_n}{dP_n}) = \lambda \quad \ldots \quad (C.5)$$

or

$$P_n = \frac{\lambda - f_n}{F_{nn}} \quad \ldots \quad (C.6)$$

From Table 4.4 we have

Values of F_{nn} and f_n

Plant n	F_{nn} (slope)	f_n (intercept)
1	20	625
2	66.67	1175
3	66.67	1003

Case: (i) $\lambda = 1050$

$20P_1 = 1050 - 625 = 425$ i.e $P_1 = 21.25$

$66.67P_2 = 1050 - 1175 = -125$ i.e $P_2 = -1.875$

$66.67P_2 = 1050 - 1000 = 50$ i.e. $P_3 = 0.749962$

Total generation(P_T)= 21.99960 MW

Case (ii) $\lambda = 1310$

$20P_1 = 1310-625 = 685$ i.e $P_1 = 34.25$

$66.67P_2 = 1310-1175=135$ i.e $P_2 = 2.02$

$66.67P_3 = 1310-1000=310$ i.e $P_3 = 4.65$

Total generation (P_T) = 40.92 MW

Case (iii) $\lambda = 1570$

$20P_1 = 1570 - 625 = 945$ i.e $P_1 = 47.25$

$66.67P_2 = 1570 - 1175 = 395$ i.e $P_2 = 5.92$

$66.67P_3 = 1570-1000 = 570$ i.e $P_2 = 8.55$

Total generation (P_T)= 61.72MW

Case (iv) $\lambda = 1830$

$20P_1 = 1830 - 625 = 1205$ i.e $P_1 = 60.25$

$66.67P_2 = 1830 - 1175 = 655$ i.e $P_2 = 9.82$

$66.67P_3 = 1830 - 1000 = 830$ i.e $P_3 = 12.449$

Total generation (P_T) = 82.50 MW

Case (v) $\lambda = 2090$

$20P_1 = 2090 - 625 = 1465$ i.e $P_1 = 73.25$

$66.67P_2 = 2090 - 1175 = 915$ i.e $P_2 = 13.724$

$66.67P_3 = 2090 - 1000 = 1090$ i.e $P_3 = 16.349$

Total generation(P_T)=103.32MW

Case (vi) $\lambda = 2350$

$20P_1 = 2350 - 625 = 1725$ i.e $P_1 = 86.25$

$66.67P_2 = 2350 - 1175 = 1175$ i.e $P_2 = 17.624$

$66.67P_3 = 2350 - 1000 = 1350$ i.e $P_3 = 20.249$

Total generation(P_T)= 124.125MW

Case (vii) $\lambda = 2610$

$20P_1 = 2610 - 625 = 1985$ i.e $P_1 = 99.25$

$66.67P_2 = 2610 - 1175 = 1435$ i.e $P_2 = 21.5239$

$66.67P_3 = 2610 - 1000 = 1610$ i.e $P_3 = 24.1487$

Total generation(P_T)= 144.92 MW

```
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  OPTIONS IN EFFECT
  -----------------

  LOAD   =4

  DECK   NO

  LIST   YES

  LISTX  NO

  EBCDIC
```

APPENDIX-A(3)

```
C       AMINUL HOQUE/ BUET /MARCH,1980
C       LOAD FLOW STUDIES BY DIGITAL COMPUTER
C       GAUSS SEIDEL ITERATIVE METHOD OF SOLUTION
        DIMENSION LINE(18,18),G(100),B(100),BS(100),YL1(100),YL2(100),V(99
       1),PD(99),QD(99),ANGLE(99),EER(18),EEI(18),RL1(18),RL2(18),STER(18)
       2,STEI(18),CORR(18),CORI(18),PG(18),QG(18),PL(18),QLO(18),P(99),
       4Q(99)
        WRITE(3,91)
     91 FORMAT (51X,'AMINUL HOQUE / BUET / MARCH,1980'//)
        READ (1,11) N,C1,TOLER,ITMAX
        WRITE (3,90)
        WRITE (3,112)
    112 FORMAT(30X,'TOTAL BUS'10X,'ACCL FACTOR' 16X,'TOLER'16X,'ITMAX'/)
        WRITE(3,12) N,C1,TOLER,ITMAX
     12 FORMAT (32X,I4,15X,F6.2,15X,F10.5,15X,I4)
     11 FORMAT (I4,F6.2,F10.5,I4)
        I=1
        READ (1,18) ((LINE(K,L),L=1,N),K=1,N)
        WRITE (3,90)
        WRITE (3,119)
    119 FORMAT (58X,'DATA OF LINE MATRIX'/)
        WRITE (3,19) ((LINE(K,L),L=1,N),K=1,N)
     18 FORMAT (26I2)
     19 FORMAT (41X,26I2)
        WRITE (3,90)
        WRITE (3,1222)
   1222 FORMAT(/47X,'RESISTANCE'6X,'REACTANCE'3X,'SHUNT SUSCEPTANCE'/)
        J=N
        DO 20 K=1,N
        G(K)=0.0
     20 B(K)=0.0
        DO 24 K=1,N
        DO 24 L=1,N
        IF(LINE(K,L))21,24,21
     21 J=J+1
        READ(1,22) R1,X1,XS
        WRITE (3,222)R1,X1,XS
     22 FORMAT (3F10.5)
    222 FORMAT (41X,3F15.5)
     23 TERM=R1**2+X1**2
        G(J)=-R1/TERM
        B(J)=X1/TERM
        BS(J)=XS*0.5
        G(K)=G(K)-G(J)
        B(K)=B(K)-B(J)+BS(J)
C       WRITE (3,115) K,G(K),K,B(K)
C   115 FORMAT (30X,'G(' I2, ')=' E15.7,10X, 'B('I2, ')=' E15.7)
     24 CONTINUE
        WRITE (3,90)
        WRITE (3,999)
    999 FORMAT (/32X,'PG'19X,'QG'19X,'PD'18X,'QD'/)
        DO 102 K=1,N
        READ (1,179) PG(K),QG(K),PD(K),QD(K)
        WRITE (3,9999)PG(K),QG(K),PD(K),QD(K)
```

```
   25 P(K)=(PG(K)-PD(K)*0.7)
      Q(K)=(QG(K)-QD(K)*0.7)
  101 EER(K)=1.0
      EEI(K)=0.0
  102 CONTINUE
      P(1)=0.0
      Q(1)=0.0
      EER(1)=1.05
  179 FORMAT (4F10.6)
 9999 FORMAT(16X,4F21.6)
   99 J=N
      WRITE (3,90)
      DO 35 K=1,N
      G1=G(K)/(G(K)**2+B(K)**2)
      B1=B(K)/(G(K)**2+B(K)**2)
C     WRITE (3,114) K, G1, B1
C 114 FORMAT (10X, 'K=' I2, 10X, 'G1=' E15.7, 10X,'B1=' E15.7)
   26 RL1(K)=P(K)*G1-Q(K)*B1
      RL2(K)=-Q(K)*G1-P(K)*B1
C     WRITE (3,113) K, RL1(K), K, RL2(K)
C 113 FORMAT (10X, 'RL1(' I2, ')='E15.7,10X, 'RL2(' I2, ')='E15.7)
      DO 35 L=1,N
      IF (LINE(K,L)) 34,35,34
   34 J=J+1
      YL1(J)=G(J)*G1+B(J)*B1
      YL2(J)=B(J)*G1-G(J)*B1
C     WRITE (3,85) J,YL1(J),YL2(J),G(J),B(J),G(K),B(K),K,L
C  85 FORMAT (20X,I5,5X,6F10.5,I6,5X,I2)
   35 CONTINUE
C     WRITE (3,90)
   36 ITER=0
   38 ITER=ITER+1
      J=N+1
      DO 46 K=2,N
      STER(K)=0.0
      STEI(K)=0.0
   39 DO 42 L=1,N
      IF(LINE(K,L)) 100,42,100
  100 J=J+1
   41 STER(K)=STER(K)+YL1(J)*EER(L)-YL2(J)*EEI(L)
      STEI(K)=STEI(K)+YL2(J)*EER(L)+YL1(J)*EEI(L)
   42 CONTINUE
C     AMINUL HOQUE/ENGG COLLEGE/CTG
C     AMINUL HOQUE/MATLAB/COMILLA
      DIVIDE=EER(K)**2+EEI(K)**2
      ER=(RL1(K)*EER(K)-RL2(K)*EEI(K))/DIVIDE-STER(K)
      EI=(RL2(K)*EER(K)+RL1(K)*EEI(K))/DIVIDE-STEI(K)
   43 CORR(K)=(ER-EER(K))
      CORI(K)=(EI-EEI(K))
C     AMINUL HOQUE/NORTH BARI BHANGA/COMILLA
C     AMINUL HOQUE/COMILLA
   44 EER(K)=EER(K)+CORR(K)*C1
      EEI(K)=EEI(K)+CORI(K)*C1
C     AMINUL HOQUE
```

```
   46 CONTINUE
      IF(ITER-ITMAX) 48,54,54
   48 DO 52 K=1,N
      IF(K-I) 49,52,49
   49 IF(ABS(CORR(K))-TOLER)50,53,53
   50 IF(ABS(CORI(K))-TOLER) 51,53,53
   51 IF(K-N) 52,54,54
   52 CONTINUE
   53 GO TO 38
  177 FORMAT(2F10.5)
  175 FORMAT (/37X, 'EER(',I2, ')=',E15.7, 11X,'EEI(',I2,')=',E15.7/)
   54 WRITE(3,55)    ITER
   55 FORMAT(64X,'ITER=' I4)
      WRITE (3,90)
      WRITE (3,1175)
 1175 FORMAT (/41X, 'REAL VOLTAGE'18X,'REACTIVE VOLTAGE'/)
      DO 176 K=1,N
  174 WRITE (3,175) K,EER(K) ,K,EEI(K)
  176 CONTINUE
      WRITE (3,90)
      WRITE (3,2200)
 2200 FORMAT (/36X,'VOLTAGE MAGNITUDE'16X,'ANGLE IN DEG.'/)
      DO  56 K=1,N
      V(K)=SQRT (EER(K)**2+EEI(K)**2)
      ANGLE (K)=ATAN(EEI(K)/EER(K))*180./3.1415926
  200 WRITE (3,181) K,V(K),K,ANGLE(K)
   56 CONTINUE
  181 FORMAT(/37X,'V(',I2,')=',F10.6,16X,'ANGLE(',I2,')=',F10.6/)
      WRITE (3,90)
      WRITE (3,1178)
 1178 FORMAT(/46X,'BUS TO BUS'6X,'REAL POWER'9X,'REACTIVE POWER'/)
      J=N
      DO 60 K=1,N
      PL(K)=PG(K)
      QLO(K)=QG(K)
      DO 60 L=1,N
      IF(LINE(K,L)) 59,60,59
   59 J=J+1
      SUBR=EER(K)-EER(L)
      SUBI=EEI(K)-EEI(L)
      SU1=EER(K)*SUBR+EEI(K)*SUBI
      SU2=EER(K)*SUBI-EEI(K)*SUBR
      P(J)=(SU2*B(J)-SU1*G(J))
      Q(J)=-((EER(K)**2+EEI(K)**2)*BS(J)-SU1*B(J)-SU2*G(J))
      PL(K)=PL(K)+P(J)
      QLO(K)=QLO(K)+Q(J)
      WRITE (3,178) K,L,P(J),Q(J)
  178 FORMAT (45X,I4,2X,I3,5X,F14.9,5X,F14.9)
   60 CONTINUE
      TGEN=0.0
      TLOAD=0.0
      WRITE (3,90)
      WRITE (3,1180)
 1180 FORMAT(/26X,'K'15X,'V'11X,'ANG'12X,'PL'11X,'QLO'12X,'QG'11X,'PG'/)
```

```
      DO 61 K=1,N
      TGEN=TGEN+PL(K)
      TLOAD=TLOAD+PG(K)
      QG(K)=-QG(K)
      WRITE(3,180)K,V(K),ANGLE(K),PL(K),QLO(K),QG(K),PG(K)
  180 FORMAT(25X,I2,5X,6F14.6)
   61 CONTINUE
      WRITE (3,90)
   90 FORMAT(25X'-----------------------------------------------------
     2------------------------------')
      TLOSS=TGEN-TLOAD
      WRITE(3,222)TGEN,TLOAD,TLOSS
      WRITE (3,909)
  909 FORMAT (//60X, 'END OF JOB' )
   83 CALL  EXIT
      END
```

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OPTIONS IN EFFECT

LOAD =4

DECK NO

LIST YES

LISTX NO

EBCDIC

APPENDIX- B(3)

```
C     AMINUL HOQUE / BUET / MARCH,1980
C     DETERMINATION OF TRANSMISSION LION LOSS COEFFICIENTS(B-COFFS)
      DIMENSION LINE(18,18),B(100),YL1(100),YL2(100),V(18),PL(18),QLO(18
     1),ANGLE(18),EER(18),EEI(18),RL1(18),RL2(18),STER(18),STEI(18),CORR
     2(18),BS(100),PG(18),QG(18),AL1(18),AL2(18),QL(18),AILR(18),AIL(18)
     3,ANGLD(18),R(5,5),X(5,5),A(5,5),H(5,5),BC(5,5),S(5),CORS(5),NCON(5
     4),PB(5),RR(5,5),     G(100),AILI(18),CORI(18),XX(5,5)
      WRITE (3,91)
   91 FORMAT (47X, 'AMINUL HOQUE / BUET / MARCH,1980'//)               BCO 011
      READ (1,11) N,M,C1,TOLER,ITM,A1,TOL,ITMAX                         BCO 012
      WRITE(3,90)                                                       BCO 013
      WRITE(3,911) N,M,C1,TOLER,ITM, A1,TOL,ITMAX
  911 FORMAT(/23X,I4,7X,I4,5X,F6.2,5X,F10.5,5X,I4,5X,F6.2,5X,F8.5,3X,I4)
      WRITE (3,90)
      WRITE (3,1915)
      DO 16 K=1,N
      READ (1,15) V(K),ANGLE(K),PL(K),QLO(K),QG(K),PG(K)
 1915 FORMAT(/28X,'V'    11X,'ANGLE'10X,'PL'   11X,'QLO'12X,'QG'12X'PG'/)
      WRITE(3,915) V(K),ANGLE(K),PL(K),QLO(K),QG(K),PG(K)
   15 FORMAT (6F10.6)
  915 FORMAT(19X,6F14.6)
   16 CONTINUE
      READ (1,200) (NCON(I),I=1,M)
      WRITE(3,90)
      WRITE(3,1202)
 1202 FORMAT(/45X,'NO. OF CONNECTIONS TO GENERATOR BUSES'/)             BCO 014
      WRITE(3,202) (NCON(I),I=1,M)                                      BCO 015
  200 FORMAT(3I4)                                                       BCO 016
  202 FORMAT(36X,3I14)                                                  BCO 017
      DO 17 K=4,13                                                      BCO 018
   17 QL(K)=QLO(K)                                                      BCO 019
      READ (1,18) ((LINE(K,L),L=1,N),K=1,N)                             BCO 020
      WRITE(3,90)                                                       BCO 021
      WRITE (3,119)                                                     BCO 022
  119 FORMAT (/53X,'DATA OF LINE MATRIX'/)                              BCO 023
      WRITE(3,19) ((LINE(K,L),L=1,N),K=1,N)                             BCO 024
   18 FORMAT (26I2)                                                     BCO 025
   19 FORMAT(37X,26I2)                                                  BCO 026
      J=N                                                               BCO 027
      DO 20 K=1,N                                                       BCO 028
      G(K)=0.0                                                          BCO 029
   20 B(K)=0.0                                                          BCO 030
      WRITE (3,90)                                                      BCO 031
      WRITE (3,9222)                                                    BCO 032
      DO 24 K=1,N                                                       BCO 033
      DO 24 L=1,N                                                       BCO 034
      IF (LINE (K,L)) 21,24,21                                          BCO 035
   21 J=J+1                                                             BCO 036
      READ (1,22) R1,X1,XS                                              BCO 037
 9222 FORMAT(/43X,'RESISTANCE'6X,'REACTANCE'3X,'SHUNT SUSCEPTANCE'/)    BCO 038
      WRITE (3,222) R1,X1,XS                                            BCO 039
   22 FORMAT (3F10.5)                                                   BCO 040
  222 FORMAT ( 37X,3F15.5)                                              BCO 041
   11 FORMAT (2I4,F6.2,F10.5,I4,F6.2,F8.5,I4)                           BCO 042
```

```
   23 TERM = R1**2+X1**2                                           BCO 043
      G(J)=-R1/TERM                                                BCO 044
      B(J) = X1/TERM                                               BCO 045
C     BS(J)=XS*0.5
      G(K) = G(K)-G(J)                                             BCO 046
      B(K) = B(K)-B(J)                                             BCO 047
   24 CONTINUE                                                     BCO 048
      READ (1,25) (S(K), K=1,M)                                    BCO 049
   25 FORMAT (3F10.5)                                              BCO 050
C     WRITE ( 3,500 )
C 500 FORMAT ( ' AA ' )
      IT = 0                                                       BCO 051
   36 IT = IT+1                                                    BCO 052
   27 DO 30 K=1,M                                                  BCO 053
   30 QL(K) = QLO(K)+QG(K)-S(K)*PG(K)                              BCO 054
      AILTR = 0.0                                                  BCO 055
      AILTI = 0.0                                                  BCO 056
   31 DO 32 K=1,N                                                  BCO 057
      Z=ANGLE(K)*3.14159/180.                                      BCO 058
      Q=ATAN(QL(K)/PL(K))                                          BCO 059
      Y=SQRT(PL(K)*PL(K)+QL(K)*QL(K))/V(K)                         BCO 060
C     WRITE ( 3,501 )
C 501 FORMAT ( ' A ' )
      AILR(K)=Y*COS(Q+Z)                                           BCO 061
      AILI(K)=Y*SIN(Q+Z)                                           BCO 062
      AIL(K)=SQRT(AILR(K)**2+AILI(K)**2)                           BCO 063
      ANGLD(K)=ATAN(AILI(K)/AILR(K))                               BCO 064
      AILTR=AILTR+AILR(K)                                          BCO 065
      AILTI=AILTI+AILI(K)                                          BCO 066
   32 CONTINUE                                                     BCO 067
      AILT=SQRT(AILTR**2+AILTI**2)                                 BCO 068
      THETA=ATAN(AILTI/AILTR)                                      BCO 069
      DO 33 K=1,N                                                  BCO 070
      D=THETA-ANGLD(K)                                             BCO 071
      AL1(K)=(AIL(K)/AILT)*COS(D)                                  BCO 072
      AL2(K)=(AIL(K)/AILT)*SIN(D)                                  BCO 073
C     WRITE ( 3,502 )
   33 CONTINUE
      WRITE(3,90)                                                  BCO 074
   99 J=N                                                          BCO 075
      DO 35 K=1,N                                                  BCO 076
      G1=G(K)/(G(K)**2+B(K)**2)                                    BCO 077
      B1=B(K)/(G(K)**2+B(K)**2)                                    BCO 078
      RL1(K)=(-AILR(K)*G1-AILI(K)*B1)                              BCO 079
      RL2(K)=(AILR(K)*B1-AILI(K)*G1)                               BCO 080
C     WRITE ( 3,90 )
C 503 FORMAT ( ' C ' )
      DO 35 L=1,N                                                  BCO 081
      IF (LINE (K,L)) 34,35,34                                     BCO 082
   34 J=J+1                                                        BCO 083
      YL1(J)=G(J)*G1+B(J)*B1                                       BCO 084
      YL2(J)=B(J)*G1-G(J)*B1                                       BCO 085
   35 CONTINUE                                                     BCO 086
      DO 59 I=1,M                                                  BCO 087
```

```
      DO 102 K=1,N                                                      BCO 088
      IF (K-I) 101,102,101                                              BCO 089
  101 EER(K)=1.0                                                        BCO 090
      EEI(K)=0.0                                                        BCO 091
  102 CONTINUE                                                          BCO 092
      EER(I)=1.05                                                       BCO 093
      EEI(I)=0.0                                                        BCO 094
      ITER=0                                                            BCO 095
   38 ITER=ITER+1                                                       BCO 096
      J=N                                                               BCO 097
      DO 46 K=1,N                                                       BCO 098
      STER(K)=0.0                                                       BCO 099
      STEI(K)=0.0                                                       BCO 100
      IF(K-I) 39,37,39                                                  BCO 101
   37 J=J+NCON(I)                                                       BCO 102
      GO TO 46                                                          BCO 103
   39 DO 42 L=1,N                                                       BCO 104
      IF (LINE(K,L)) 100,42,100                                         BCO 105
  100 J=J+1                                                             BCO 106
   41 STER(K)=STER(K)+YL1(J)*EER(L)-YL2(J)*EEI(L)                       BCO 107
      STEI(K)=STEI(K)+YL2(J)*EER(L)+YL1(J)*EEI(L)                       BCO 108
   42 CONTINUE                                                          BCO 109
      ER=RL1(K)-STER(K)                                                 BCO 110
      EI=RL2(K)-STEI(K)                                                 BCO 111
   43 CORR(K)=(ER-EER(K))                                               BCO 112
      CORI(K)=(EI-EEI(K))                                               BCO 113
   44 EER(K)=EER(K)+CORR(K)*C1                                          BCO 114
      EEI(K)=EEI(K)+CORI(K)*C1                                          BCO 115
   46 CONTINUE                                                          BCO 116
      IF (ITER-ITMAX) 48,54,54                                          BCO 117
   48 DO 52 K=1,N                                                       BCO 118
      IF(K-I) 49,52,49                                                  BCO 119
   49 IF(ABS(CORR(K))-TOLER) 50,53,53                                   BCO 120
   50 IF (ABS(CORI(K))-TOLER) 51,53,53                                  BCO 121
   51 IF (K-N) 52,54,54                                                 BCO 122
   52 CONTINUE                                                          BCO 123
   53 GO TO 38                                                          BCO 124
   54 WRITE(3,55)    ITER                                               BCO 125
   55 FORMAT (60X,'ITER=' I4 )                                          BCO 126
      ELR=0.0                                                           BCO 127
      ELI=0.0                                                           BCO 128
      DO 56 K=1,N                                                       BCO 129
      ELR=ELR+AL1(K)*EER(K)-AL2(K)*EEI(K)                               BCO 130
      ELI=ELI+AL1(K)*EEI(K)+AL2(K)*EER(K)                               BCO 131
   56 CONTINUE                                                          BCO 132
C     WRITE (3,221)ELR,ELI                                              BCO 133
C 221 FORMAT ( 5X, 2E20.7 )
      DO 59 K=1,M                                                       BCO 134
      DIV=(AILTR**2+AILTI**2)                                           BCO 135
      RR(K,I)=((EER(K)-ELR)*AILTR+(EEI(K)-ELI)*AILTI)/DIV               BCO 136
      XX(K,I)=((EEI(K)-ELI)*AILTR-(EER(K)-ELR)*AILTI)/DIV               BCO 137
   59 CONTINUE                                                          BCO 138
      WRITE (3,90)                                                      BCO 139
   90 FORMAT (25X,'---------------------------------------------------- BCO 140
```

```
     5----------------------')                                          BCO 141
      DO 60 K=1,M
      SS=-RR(K,K)/XX(K,K)
      CORS(K)=SS-S(K)
   60 S(K)=S(K)+CORS(K)*A1
      DO 62 K=1,M
      IF (ABS(CORS(K))-TOL) 61,900,900
   61 IF (K-M) 62,64,64
   62 CONTINUE
  900 IF (IT-ITM) 63,64,64
   63 GO TO 36
   64 WRITE (3,1150)
 1150 FORMAT(/50X,'FRAME-3 RESISTANCE MATRIX'/)                         BCO 142
      WRITE (3,150) ((RR(K,I),I=1,M),K=1,M)                             BCO 143
      WRITE (3,90)                                                      BCO 144
      WRITE (3,2150)                                                    BCO 145
 2150 FORMAT(/50X,'FRAME-3 REACTANCE MATRIX'/)                          BCO 146
      WRITE (3,150) ((XX(K,I),I=1,M),K=1,M)                             BCO 147
  150 FORMAT (43X,3F12.6/)                                              BCO 148
      WRITE (3,90)                                                      BCO 149
      WRITE(3,4150)                                                     BCO 150
 4150 FORMAT (39X,'CONVERGED REACTIVE CHARCTERISTICS OF GENERATORS'/)   BCO 151
      WRITE (3,150) (S(K),K=1,M)                                        BCO 152
      WRITE (3,90)                                                      BCO 153
      WRITE(3,888)                                                      BCO 154
  888 FORMAT (38X,'DIFFERENCE FROM THE PREVIOUS ITERATION  FOR  S-CHS'/) BCO 155
      WRITE (3,150) (CORS(K),K=1,M)                                     BCO 156
      WRITE (3,90)                                                      BCO 157
      WRITE (3,95) IT                                                   BCO 158
   95 FORMAT (60X, 'IT='I3)                                             BCO 159
      WRITE (3,90)                                                      BCO 160
      DO 66 K=1,M                                                       BCO 161
      WRITE (3,65) K,S(K),IT                                            BCO 162
      WRITE (3,90)
   65 FORMAT(45X,I3,10X,F10.5,7X,I4/)                                   BCO 163
   66 CONTINUE                                                          BCO 164
      DO 67 K=1,M                                                       BCO 165
      DO 67 I=1,M                                                       BCO 166
      R(K,I)=(RR(K,I)+RR(I,K))/2.                                       BCO 167
      X(K,I)=(XX(K,I)-XX(I,K))/2.                                       BCO 168
   67 CONTINUE                                                          BCO 169
      WRITE (3,5150)
 5150 FORMAT (/44X,'SYMMETRCAL PART OF FRAME-3 RESISTANCE'/)
      WRITE (3,150) ((R(K,I),I=1,M),K=1,M)
      WRITE (3,90)
      WRITE (3,6150)
 6150 FORMAT (/42X,'SKEW SYMMETRICAL PART OF FRAME-3 REACTANCE'/)
      WRITE (3,150) ((X(K,I),I=1,M),K=1,M)
      DO 72 K=1,M
      DO 72 I=1,M
      P=(ANGLE(K)-ANGLE(I))*3.1415926/180.
      A(K,I)=(1./(V(K)*V(I)))*((1.+S(K)*S(I))*COS(P)+(S(K)-S(I))*SIN(P))
   72 H(K,I)=(1./(V(K)*V(I)))*((1.+S(K)*S(I))*SIN(P)+(S(I)-S(K))*COS(P))
      WRITE (3,90)
```

```
      WRITE (3,7150)
 7150 FORMAT (/52X, 'SYMMETRICAL A- MATRIX'/)                        BCO 170
      WRITE (3,150)  ((A(K,I),I=1,M),K=1,M)
      WRITE (3,90)                                                   BCO 171
      WRITE (3,8150)
 8150 FORMAT (/50X,'SKEW SYMMETRICAL  H- MATRIX'/)                   BCO 172
      WRITE (3,150)((H(K,I),I=1,M),K=1,M)                            BCO 173
      DO 78 K=1,M                                                    BCO 174
      DO 78 L=1,M                                                    BCO 175
      BC(K,L)=A(K,L)*R(K,L)+H(K,L)*X(K,L)                            BCO 176
   78 CONTINUE                                                       BCO 177
      WRITE (3,90)                                                   BCO 178
 9150 FORMAT (/55X,' B-COFF.  MATRIX'/)
      WRITE (3,9150)
C     WRITE (3,90)                                                   BCO 179
C     DO 78 L=1,M                                                    BCO 180
C     BC(K,L)=A(K,L)*R(K,L)+H(K,L)*X(K,L)                            BCO 181
C  78 CONTINUE                                                       BCO 182
      WRITE (3,150) ((BC(K,L),L=1,M),K=1,M)                          BCO 183
      WRITE (3,90)                                                   BCO 184
C     WRITE (3,80)
C     WRITE (3,90)
C 140 FORMAT (25X,5F12.7)                                            BCO 185
      WRITE (3,80)                                                   BCO 186
   80 FORMAT (60X, 'PBP   LOSSES'//)                                 BCO 187
      DO 81 L=1,M                                                    BCO 188
      PB(L)=0.0                                                      BCO 189
      DO 81 K=1,M                                                    BCO 190
      PB(L)=PB(L)+PG(K)*BC(K,L)                                      BCO 191
   81 CONTINUE                                                       BCO 192
      PBP=0.0                                                        BCO 193
      DO 82 L=1,M                                                    BCO 194
      PBP=PBP+PB(L)*PG(L)                                            BCO 195
   82 CONTINUE                                                       BCO 196
      WRITE (3,79) PBP                                               BCO 197
   79 FORMAT (59X, 'PBP='F10.5)                                      BCO 198
      WRITE(3,979)                                                   BCO 199
  979 FORMAT (//60X,'END OF JOB' )                                   BCO 200
   83 CALL EXIT                                                      BCO 201
      END                                                            BCO 202
```

DOS FORTRAN IV 360N-FO-479 3-8

OPTIONS IN EFFECT

LOAD =4

DECK NO

LIST YES

LISTX NO

EBCDIC

APPENDIX-C(4)

```
C     AMINUL HOQUE / BUET / APRIL, 1980
C     OPTIMUM ECONOMIC SCHEDULING OF GENERATION
      DIMENSION B(5,5),P(5),F(4),FF(4),CORP(4),PB(5)
      WRITE (3,91)
   91 FORMAT (47X, 'AMINUL HOQUE / BUET / APRIL, 1980'//)
C     READ (1,6) ((B(K,L),L=1,3),K=1,3)
C     WRITE (3,8)((B(K,L),L=1,3),K=1,3)
      READ (1,7) (F(K),K=1,3),(FF(K),K=1,3)
      WRITE(3,8) (F(K),K=1,3),(FF(K),K=1,3)
      IIT=0
      CRP=1050.0
C     P(4)=80.0
   22 DO 25 K=1,3
   25 P(K)=0.0
   20 DO 11 K=1,3
C     D=0.0
C     DO 10 L=1,3
C     IF (K-L) 9,10,9
C   9 D=D+B(L,K)*P(L)
C  10 CONTINUE
C     PP= (1.0-F(K)/CRP-2.0*D)/(FF(K)/CRP+2.0*B(K,K))
      PP=(CRP-F(K))/FF(K)
      CORP(K)=PP-P(K)
   11 P(K)=P(K)+CORP(K)*1.25
      DO 13 K=1,3
      IF (ABS(CORP(K))-0.002) 12,14,14
   12 IF (K-3) 13,15,15
   13 CONTINUE
   14 GO TO 20
   15 TGEN =00.0
      WRITE (3,21) (P(K),K=1,3)
      DO 26 K=1,3
      IF (P(K)) 24,26,26
   24 P(K)=0.0
   26 CONTINUE
      DO 16 K=1,3
   16 TGEN=TGEN+P(K)
      WRITE (3,21) (P(K),K=1,3),TGEN,CRP
C     DO 30 L=1,3
C     PB(L)=0.0
C     DO 30 K=1,3
C  30 PB(L)=PB(L)+P(K)*B(K,L)
C     PBP=0.0
C     DO 31 L=1,3
C  31 PBP=PBP+PB(L)*P(L)
C     TLOAD=TGEN-PBP
C     WRITE (3,5) PBP,TLOAD
      IIT=IIT+1
      IF(IIT.GE.400) GO TO 18
      IF (TGEN-400.0) 17,17,18
   17 CRP=CRP+130.0
      GO TO 20
C   5 FORMAT (40X, 'PBP='F15.7,5X, 'LOAD=' F15.7/)
C   6 FORMAT (3F15.9)
```

```
            7 FORMAT (6F10.5)
            8 FORMAT (30X, 3F17.9/)
           21 FORMAT (10X,5F12.5/)
           18 WRITE (3,92)
           92 FORMAT (//60X,'END OF JOB' )
              END
```

DOS FORTRAN IV 360N-FO-479 3-8

OPTIONS IN EFFECT

LOAD =4

DECK NO

LIST YES

LISTX NO

EBCDIC

APPENDIX- C(5)

```
C        AMINUL HOQUE
C        AMINUL HOQUE / BUET / JUNE, 1980
C        OPTIMUM SCHEDULING OF GENERATION NEGLECTING TRASMISSION LOSS
         DIMENSION P(3), F(3), FF(3), CORP(3)
         WRITE (3,91)
      91 FORMAT (47X, 'AMINUL HOQUE / BUET / JUNE,1980'//)
         READ (1,7) (F(K),K=1,3), (FF(K),K=1,3)
         WRITE(3,8) (F(K),K=1,3), (FF(K),K=1,3)
         IIT=0
         CRP=1050.0
      22 DO 25 K=1,3
      25 P(K)=0.0
      20 DO 11 K=1,3
         PP= (CRP-F(K))/FF(K)
         CORP(K)=PP-P(K)
      11 P(K)=P(K)+CORP(K)*1.25
         DO 13 K=1,3
         IF (ABS(CORP(K))-0.002) 12, 14, 14
      12 IF (K-3) 13, 15, 15
      13 CONTINUE
      14 GO TO 20
      15 TGEN =0.0
         WRITE (3,21) (P(K), K=1,3)
         DO 26 K=1,3
         IF (P(K))  24, 26, 26
      24 P(K)=0.0
      26 CONTINUE
         DO 16 K=1,3
      16 TGEN=TGEN+P(K)
         WRITE (3,21)(P(K), K=1,3), TGEN, CRP
         IIT=IIT+1
         IF (IIT. GE. 400) GO TO 18
         IF (TGEN-400.0) 17, 17, 18
      17 CRP=CRP+130.0
         GO TO 20
       7 FORMAT (6F10.5)
       8 FORMAT (36X, 3F17.9//)
      21 FORMAT (30X, 5F12.5 /)
      18 WRITE (3,92)
      92 FORMAT (// 60X, 'END OF JOB ')
         END
```

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