CHAPTER VII

GAUSS-SEIDEL LOAD FLOW WITH OPTIMALLY ORDERED NODES BY DYNAMIC PROGRAMMING ALGORITHM

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7.0 Introduction

It is desired that transmission system should be able to transmit electric energy economically and reliably from generation centres to all load centres at a generally acceptable voltage level. This necessiates the study of the load flow in a power system to determine steady operating states. Results of the load flow analysis are used for stability analysis and for power system planning, operation and control. A large number of numerical algorithms have been developed over the last 25 years. The most of the algorithms are variations of two numerical technique such as (i) Gauss-Seidel method and (ii) Newton Raphson method. The present effort is an exposure of the Gauss-Seidel method under different bus conditions with optimal ordering of buses by *Dynamic* programming algorithm. The algorithms are developed in easily understandable manner and illustrated on IEEE 14 bus system.

7.1 BUS Type

Power System Buses are characterised as follows.

(i) P - Q Bus : A P - Q Bus is one where total bus power in complex form is specified. At such a p-th bus the complex power is

$$E_p^* I_p = P_p - jQ_p$$

$$= (P_{Gp} - P_{Lp}) - j(Q_{Gp} - Q_{Lp}) \qquad (7.1.1)$$

where $E_p = e_p + j f_p$ and the subscripts G_p and L_p refer to the generation and load respectively at the p-th bus.

(ii) P - V Bus : A P - V Bus is one where real power P_p is specified and the voltage magnitude is maintained at a constant value. At such a bus the characteristics are

$$Re \left[E_p^* I_p \right] = P_{Gp} - P_{Lp} \qquad (7.1.2)$$

with

$$\left[E_p \right] = (e_p^2 + f_p^2)^{\frac{1}{2}} \qquad (7.1.3)$$

(iii) Swing Bus or Slack Bus : Swing Bus or Slack Bus is a Bus where the complex voltage is specified. The concept of a swing bus is necessary because in the system the losses are not known in advance, and hence it is not possible to fix injected real power at all the buses. It is the standard practice to designate one of the voltage controlled buses having the largest generation as the swing bus. At this bus the complex power is not specified and is calculated at the end when the load flow calculations are converged. The phase angle at the swing bus is specified and is taken as zero. Hence the swing bus is considered as the reference bus.

7.2 Power System Equation

Bus frame of reference of the line parameters in the admittance form has gained widespread application because of the simplicity of data preparation and the ease with which the bus admittance matrix can be formulated and modified for any subsequent network changes. The method using the bus admittance matrix remains the most economical from the point of view of computer time and memory requirements. The solutions of the aljebraic equations describing the load flow process are based on iterative technique because of the non-linearity in the power equations. The present investigation deals with the Gauss-Seidel iterative technique using Y bus and optimally ordered nodes by Dynamic programming algorithm.

The network equation is written as

$$I_{BUS} = Y_{BUS} \; E_{BUS} \tag{7.2.1}$$

Y BUS includes line admittance and the effects of shunt elements to ground such as static capacitors and reactors, line charging, shunt elements of transformer equivalents.

Algorithms for calculation of Y_{BUS} is stated below :

(1) Read bus code p - q , impedance z_{pq} , line charging $y'_{pq/2}$ transformer tap 'a' ;

(2) Obtain reciprocal of transmission line impedance z_{pq} to get admittance y_{pq} ;

(3) Obtain total line charging and shunt capacitor at each bus ;

(4) Obtain self admittance at bus p as

$$Y_{pp} = \sum_{q=1}^{n} y_{pq}$$

$$= y_{p1} + y_{p2} + \ldots + y_{pn} \qquad (7.2.2)$$

and mutual admittance from p to q as

$$Y_{pq} = - y_{pq}$$

(5) When the off-nominal turns ratio 'a' is represented at bus p for a transformer connecting p and q , the self admittance at bus p is

$$Y_{pp} = y_{p1} + y_{p2} + \ldots + y_{pq/a} + \ldots + y_{pn} + \frac{1}{a}\left(\frac{1}{a} - 1\right) y_{pq} \qquad (7.2.3)$$

The mutual admittance from p to q is

$$Y_{pq} = - \frac{y_{pq}}{a} \qquad (7.2.4)$$

and self admittance at bus q is

$$Y_{qq} = y_{q1} + y_{q2} + \ldots + y_{qp/a} + \ldots + y_{qn} + \left(1 - \frac{1}{a}\right) y_{pq}$$

$$Y_{qq} = y_{q1} + y_{q2} + \ldots + y_{qp} + \ldots + y_{qn} \qquad (7.2.5)$$

7.3 Algorithms for Optimal Ordering

Non zero pattern of the bus admittance matrix is prepared as

IF Y_{ij} YES THEN $Y_{ij} = 1$

OTHERWISE $Y_{ij} = 0$

A simple illustration for preparation of non zero pattern of bus admittance matrix is given as below.

Consider a 14 nodes network of IEEE 14 BUS system. Computational efficiency of load flow analysis depends on the order in which the Gaussian elimination is performed on sparse matrices and total number of new non zero elements are generated in course of elimination. It is observed that the computational efficiency is greatly improved if the nodes are ordered in an optimal way.

The principle of solution of sparsity oriented node ordering problem can be stated as follows.

An initial segment of an optimal ordering is a group of nodes of a network which has the property that their optimally ordered elimination of the remaining nodes in a network constitutes an optimally ordered elimination of all the nodes in a network.

The principle of optimality as stated above is applied to the problem of optimal ordering of sparsity oriented nodes in power system network. This optimisation problem is solved in an iterative procedure by Dynamic Programming algorithm following an optimum decision policy. The objective of the sparsity oriented optimum ordering of nodes is to determine the best possible way of performing Gaussian elimination, so that the amount of fill in or the valency of the elimination is minimum ; the valency of a node is the number of new paths added among the remaining set of nodes as a result of elimination of the node and the valency of an ordering is the total number of new paths generated in the process of performing the node elimination in the order specified.

The objective function for optimal ordering is stated as

$$\text{Minimise } J\left[u(k)\right] = \sum_{k=1}^{n} f\left[x(k), u(k)\right] \qquad (7.3.1)$$

where

k : stage variable. Indicates the step of the elimination algorithm.

x(k) : State variable. Node to be eliminated at stage k.

u(k) ; Decision variable. Pointer indicating which node x(k) is to be eliminated at stage k.

$f\left[\ ,\ \right]$: Valency of node x(k)

n is the total number of nodes to be eliminated. The state and decision variables are related by the state equation,

$$x(k+1) = x(k) + u(k) \qquad (7.3.2)$$

with

$$x(k) \in X(k) = \left\{ i \,/\, i = 1,2,\ldots, n \right\} \qquad (7.3.3)$$

$$x(k) \neq x(i) \quad \text{for} \quad i = 1,2,\ldots,(k-1) \qquad (7.3.4)$$

and

$$u(k) \in U(k) = \left\{ i/i = \pm 1, \pm 2, \ldots, + (n-1) \right\} \qquad (7.3.5)$$

The problem of optimisation is formulated as follows :

Given the state equation (7.3.2) and the constraints (7.3.3), (7.3.4) and (7.3.5), find the control sequence u(1), u(2),..., u(n) that minimises the objective function (7.3.1). The optimisation problem is solved by dynamic programming algorithm.

The computational procedure is implemented as follows :

Initially at stage 1, the valency of each node is calculated and stored in the first column of a cost matrix ; zeros are stored in the first column of a corresponding decision or control matrix. Then starting with node 1 of stage 2, the valency af every ordering sequence consting of a node at stage 1 and node 1 of stage 2 is evaluated. The ordering sequence with minimum valency is kept by storing the valency in combined elimination of row 1 column 2 of the cost matrix.

At the corresponding location of the decision matrix a control value is stored which traces backwards from node 1 to the selected node at stage 1. This process is repeated for the all the nodes in stage 2. Similarly the process described just above is repeated for 3,4,..., (n - 1), and n stages. In the n - th stage the smallest value in the cost matrix is obtained at the j - th node, the j - th node is the last node in optimal ordering sequence. The other nodes in the optimal ordering can be obtained recursively with the help of decision matrix.

7.4 An Illustrative Example

Consider the example as stated above. The non zero pattern of the matrix is shown in Table 7.4.1. At stage 1, the valency is stored in the first column of the cost matrix, Table 7.4.2 and the control u = o is stored in column 1 of the decision matrix, Table 7.4.3 . After completion of all the stages the cost matrix, the decision matrix and the sequence of nodes eliminated are shown in Tables 7.4.2, 7.4.3, 7.4.4. Non zero pattern of the unordered and ordered buses are shown in Table 7.4.5 and 7.4.6 respectively.

Reordering of buses

After the optimal ordering of the buses is known the bus admittance matrix is reordered and the nodes are also reordered.

TABLE 7.4.1

1 - 0 - PATTERN OF BUS ADMITTANCE MATRIX OF IEEE 14 BUS SYSTEM

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	1	0	0	1	0	0	0	0	0	0	0	0	0
2	1	1	1	1	1	0	0	0	0	0	0	0	0	0
3	0	1	1	1	0	0	0	0	0	0	0	0	0	0
4	0	1	1	1	1	0	1	0	1	0	0	0	0	0
5	1	1	0	1	1	1	0	0	0	0	0	0	0	0
6	0	0	0	0	1	1	0	0	0	0	1	1	1	0
7	0	0	0	1	0	0	1	1	1	0	0	0	0	0
8	0	0	0	0	0	0	1	1	0	0	0	0	0	0
9	0	0	0	1	0	0	1	0	1	1	0	0	0	1
10	0	0	0	0	0	0	0	0	1	1	1	0	0	0
11	0	0	0	0	0	1	0	0	0	1	1	0	0	0
12	0	0	0	0	0	1	0	0	0	0	0	1	1	0
13	0	0	0	0	0	1	0	0	0	0	0	1	1	1
14		0	0	0	0	0	0	0	1	0	0	0	1	1

TABLE 7.4.2

DIFFERENT STAGES OF COST MATRIX

Stages/ Nodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	0	0	x	x	x	x	x	x	x	x	x	x
2	3	1	0	0	0	0	1	x	x	x	x	x	x	x
3	0	0	0	0	0	1	x	x	x	x	x	x	x	x
4	7	4	4	2	2	1	1	2	3	x	x	x	x	x
5	4	2	2	1	1	1	1	2	3	3	x	x	x	x
6	5	3	3	3	3	3	3	4	5	5	4	4	x	x
7	2	0	0	0	0	1	x	x	x	x	x	x	x	x
8	0	0	0	0	1	x	x	x	x	x	x	x	x	x
9	5	5	3	3	3	3	3	4	5	5	4	4	4	x
10	1	1	1	1	1	1	1	2	3	4	4	4	4	4
11	1	1	1	1	1	1	1	2	3	4	4	4	4	4
12	0	0	0	0	0	0	1	x	x	x	x	x	x	x
13	2	1	1	1	1	1	1	2	x	x	x	x	x	x
14	1	1	1	1	1	1	1	2	3	3	4	x	x	x

TABLE 7.4.2

DIFFERENT STAGES OF DECISION MATRIX

Stages/ Nodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	-2	-6	-2	x	x	x	x	x	x	x	x	x	x
2	0	1	1	-6	1	-1	-1	x	x	x	x	x	x	x
3	0	2	-4	2	-9	-10	x	x	x	x	x	x	x	x
4	0	1	3	2	3	2	2	2	-1	x	x	x	x	x
5	0	4	4	3	3	3	3	3	1	-9	x	x	x	x
6	0	-6	-6	-6	-6	3	4	4	2	2	1	-3	x	x
7	0	-1	-1	-1	5	2	x	x	x	x	x	x	x	x
8	0	7	7	6	3	x	x	x	x	x	x	x	x	x
9	0	8	2	8	8	7	7	7	5	5	4	3	-1	x
10	0	9	9	9	9	8	8	8	6	6	5	4	1	x
11	0	10	10	10	10	9	9	9	7	7	6	6	2	-1
12	0	11	11	11	11	10	8	x	x	x	x	x	x	1
13	0	1	1	1	1	10	11	9	x	x	x	x	x	x
14	0	13	13	13	13	12	12	12	10	10	4	x	x	x

TABLE 7.4.4

DIFFERENT STAGES OF NODE ELIMINATION

1	2	3	4	5
1	3 - 1	8-7-1	7-7-3-1	x
2	1 - 2	3-1-2	3-1-8-2	8-7-3-1-2
3	1 - 3	8-7-3	8-7-1-3	8-7-1-12-3
4	3 - 4	3-1-4	3-1-2-4	8-7-3-1-4
5	1 - 5	3-1-5	3-1-2-5	3-1-8-2-5
6	12- 6	1-12-6	3-1-12-6	8-7-1-12-6
7	8 - 7	1-8-7	3-1-8-7	3-1-8-2-7
8	1 - 8	3-1-8	3-1-2-8	3-1-2-5-8
9	1 - 9	8-7-9	8-7-1-9	8-7-3-1-9
10	1 - 10	3-1-10	8-7-1-10	8-7-3-1-10
11	1 - 11	3-1-11	8-7-1-11	8-7-3-1-11
12	1 - 12	3-1-12	8-7-1-12	8-7-3-1-12
13	12-13	1-12-13	3-1-12-13	8-7-1-12-13
14	1 - 14	3-1-14	8-7-1-14	8-7-3-1-14

TABLE 7.4.4 (Continued)

	6	7	8
1	x	x	x
2	8-7-1-12-3-2	8-7-1-12-13-3-2	x
3	8-7-1-12-13-3	x	x
4	8-7-3-1-2-4	8-7-1-12-3-2-4	8-7-1-12-13-3-2-4
5	8-7-3-1-2-5	8-7-1-12-3-2-5	8-7-1-12-13-3-2-5
6	8-7-1-12-3-6	8-7-1-12-3-2-6	8-7-1-12-13-3-2-6
7	3-1-8-2-5-7	x	x
8	x	x	x
9	8-7-3-1-2-9	8-7-1-12-3-2-9	8-7-1-12-13-3-2-9
10	8-7-3-1-2-10	8-7-1-12-3-2-10	8-7-1-12-13-3-2-10
11	8-7-3-1-2-11	8-7-1-12-3-2-11	8-7-1-12-13-3-2-11
12	8-7-3-1-2-12	8-7-3-1-2-4-12	x
13	8-7-1-12-3-13	8-7-1-12-3-2-13	8-7-1-12-3-2-4-13
14	8-7-3-1-2-14	8-7-1-12-3-2-14	8-7-1-12-13-3-2-14

TABLE 7.4.4 (Continued)

	9	10
1	x	x
2	x	x
3	x	x
4	8-7-1-12-13-3-2-5-4	x
5	8-7-1-12-13-3-2-4-5	8-7-1-12-13-3-2-4-14-5
6	8-7-1-12-13-3-2-4-6	8-7-1-12-13-3-2-5-4-6
7	x	x
8	x	x
9	8-7-1-12-13-3-2-4-9	8-7-1-12-13-3-2-5-4-9
10	8-7-1-12-13-3-2-4-10	8-7-1-12-13-3-2-5-4-10
11	8-7-1-12-13-3-2-4-11	8-7-1-12-13-3-2-5-4-11
12	x	x
13	x	x
14	8-7-1-12-13-3-2-4-14	8-7-1-12-13-3-2-5-4-14

TABLE 7.4.4 (Continued)

	11	12
1	x	x
2	x	x
3	x	x
4	x	x
5	x	x
6	8-7-1-12-13-3-2-4-14-5-6	8-7-1-12-13-3-2-4-14-5-2-6
7	x	x
8	x	x
9	8-7-1-12-13-3-2-4-14-5-9	8-7-1-12-13-3-2-4-14-5-6-9
10	8-7-1-12-13-3-2-4-14-5-10	8-7-1-12-13-3-2-4-14-5-6-10
11	8-7-1-12-13-3-2-4-14-5-11	8-7-1-12-13-3-2-4-14-5-6-11
12	x	x
13	x	x
14	8-7-1-12-13-3-2-5-4-10-14	x

TABLE 7.4.4 (Continued)

	13	14
1	x	x
2	x	x
3	x	x
4	x	x
5	x	x
6	x	x
7	x	x
8	x	x
9	8-7-1-12-13-3-2-4-14-5-6-10-9	x
10	8-7-1-12-13-3-2-4-14-5-6-9-10	8-7-1-12-13-3-2-4-14-5-6-9-11-10
11	8-7-1-12-13-3-2-4-14-5-6-9-11	8-7-1-12-13-3-2-4-14-5-6-9-10-11
12	x	x
13	x	x
14	x	x

TABLE 7.4.5

UNORDERED BUSES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	x	x			x									
2	x	x		x	x									
3		x	x	x										
4		x	x	x	x		x		x					
5	x	x		x	x	x								
6					x	x					x	x	x	
7				x			x	x	x					
8							x	x						
9				x			x		x	x				x
10									x	x	x			
11						x				x	x			
12						x						x	x	
13						x						x	x	x
14									x				x	x

TABLE 7.4.6

OPTIMALLY ORDERED BUSES

	8	7	1	12	13	3	2	4	14	5	6	9	10	11
8	x	x												
7	x	x						x				x		
1			x			x	x			x				
12				x	x						x			
13				x	x				x		x			
3						x	x	x						
2						x	x	x		x				
4		x				x	x	x		x		x		
14					x				x			x		
5			x					x		x	x			
6				x	x					x	x			x
9								x	x			x	x	
10												x	x	x
11													x	x

7.5 Solution Techniques

A bus with largest generation is assumed as a slack bus or any other bus as specified. The solution of the load flow problem is initialised assuming voltages for all buses except the slack bus. At the slack bus voltage is specified. The currents are calculated for all buses except the slack bus s from the bus loading equation

$$I_p = \frac{(P_{Gp} - P_{Lp}) - j(Q_{Gp} - Q_{Lp})}{E_p^*}$$

$$p = 1, 2, \ldots, n \qquad (7.5.1)$$
$$p \neq s$$

and

$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_p \\ I_n \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & \cdots & Y_{1n} \\ Y_{21} & Y_{22} & \cdots & Y_{1n} \\ \vdots & & & \\ Y_{p1} & Y_{p2} & \cdots & Y_{pn} \\ & & & \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_p \\ \vdots \\ E_n \end{bmatrix} \qquad (7.5.2)$$

It follows from equation (7.5.2)

$$Y_{pp} E_p + \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq} E_q = I_p \qquad (7.5.3)$$

Hence

$$E_p = \frac{1}{Y_{pp}} \left[I_p - \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq} E_q \right] \quad p = 1, 2, \ldots, n \quad p \neq s \qquad (7.5.4)$$

The equation (7.5.4) involves only the bus voltages as variables. The corresponding voltage equations are non-linear in form and require iterative techniques for their solution.

Let $L_p = \frac{1}{Y_{pp}}$, the equation (7.5.4) can be written as

$$E_p = L_p \left[\frac{(P_{Gp} - P_{Lp}) - j\,(Q_{Gp} - Q_{Lp})}{E_p^*} - \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq} E_q \right] \qquad \ldots (7.5.5)$$

$$E_p = \frac{KL_p}{E_p^*} - \sum_{\substack{q=1 \\ q \neq p}}^{n} YL_{pq} E_q \quad p = 1, 2, \ldots, n \quad p \neq s \qquad (7.5.6)$$

where

$$KL_p = \left[(P_{Gp} - P_{Lp}) - j\,(Q_{Gp} - Q_{Lp}) \right] L_p$$

is known as the bus parameters

and

$$KL_{pq} = L_p \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq}$$ is the line parameters.

If the bus p is a voltage controlled bus KL_p is to be recomputed for every iteration.

7.6 Voltage Controlled Buses

In Gauss-Seidel method with Y_{BUS} the reactive power at a voltage controlled bus p must be calculated before calculating the voltage at that bus. Separating the real and imaginary parts of the bus power equation

$$(P_{Gp} - P_{Lp}) - j(Q_{Gp} - Q_{Lp}) = E_p^* \sum_{q=1}^{n} Y_{pq} E_q ,$$ the reactive

bus power

$$Q_{GP} - Q_{LP} = e_p^2 B_{pp} + f_p^2 B_{pp} + \sum_{\substack{q=1 \\ p \neq q}}^{n} \Big\{ f_p (e_q G_{pq} + f_q B_{pq})$$

$$- e_p (f_q G_{pq} - e_q B_{pq}) \Big\} \qquad (7.6.1)$$

where

$Y_{pq} = G_{pq} - jB_{pq}$ and

$$e_{pp}^2 + f_p^2 = \left\{ \left| E_p \text{ (scheduled)} \right| \right\}^2 \qquad (7.6.2)$$

In order to calculate the reactive bus power needed to give the scheduled bus voltage, the equation (7.6.1) must be satisfied. The present estimate of e_p^k and f_p^k must be adjusted accordingly. The phase angle of the estimated bus voltage is

$\delta_p^k = \arctan \dfrac{f_p}{e_p^k}$. The adjusted estimate of e_p^k and f_p

are $e_p^k \text{ (new)} = e_p \text{ scheduled} \cos \delta_p^k$

$f_p^k \text{ (new)} = E_p \text{ scheduled} \sin \delta_p^k$

where superfix k is the iteration count in Gauss-Seidel method. Substituting e_p^k (new) and f_p^k (new) in equation (7.6.1) the reactive power Q_p^k is obtained and is used with E_p^k (new) for calculating the new voltage estimate E_p^{k+1}.

If the calculated Q_p^k exceeds the $Q_{p\,(max)}$ then $Q_{p\,(max)}$ is considered as the reactive power of the bus ; if Q_p^k is less than $Q_{p\,(min)}$ then $Q_{p\,(min)}$ is considered as the reactive power of the bus, and the bus is considered as P - Q. The bus parameter KL_p is recomputed.

Then the equation (7.5.6) is solved by Gauss-Seidel iterative method. In this method the new calculated E_p^{k+1} immediately replaces E_p^k and is used in solution of the subsequent equations.

7.7 Line Flow Equations

After the voltages of the buses are converged to a solution iteratively, the line flows are determined as

$$P_{pq} - jQ_{pq} = E_p^*(E_p - E_q)\, y_{pq} + E_p^* E_p\, y'_{pq}/2 \qquad (7.7.1)$$

where y_{pq} is the line admittance

y_{pq}' is the total line charging admittance.

The reversed power flow is

$$P_{qp} - jQ_{qp} = E_q^*(E_q - E_p)\, y_{pq} + E_q^* E_q\, y'_{pq}/2$$

The slack bus power can be determined by summing the flows on the lines terminating at the slack bus.

Tolerance test was made to achieve convergence as

$$E_p^{k+1} - E_p^k = \Delta E_p^{k+1}$$

The calculation will be terminated when ΔE_p^{k+1} is a predetermined small value ξ.

To achieve quicker convergence the voltage is accelerated as

$$E_p^{k+1} = E_p^{k} + \alpha \Delta E_p^{k+1}$$

where α is a predetermined value empirically obtained in the neighbourhood of 1.6.

A complete flow chart for Gauss-Seidel Load Flow Analysis with optimally ordered nodes is shown in Fig.7.7.1.

Another method of sub-optimal ordering is also included in the illustration. This technique states that

> "This scheme partly simulates the Gauss elimination process and requires that at each step of row - column elimination, the node with least number of off-diagonal terms be eliminated next. If more than one row - column meets this criterion, select any one."

The above scheme of sub-optimal ordering is known as Tinney's second scheme. Computation time for this scheme is less than that of optimatimal ordering by dynamic programming.

7.8 Illustration

IEEE 14 bus system is considered for the load flow analysis. Sub-optimal bus ordering according to Tinney's Second Scheme was obtained as 1,3,2,8,7,12,4,5,10,11,6,9, 13,14 and the valency of ordering was 5.

Optimal bus ordering according to Dynamic Programming algorithm was obtained as 8,7,1,12,13,3,2,4,14,5, 6,9,11,10 and the valency of ordering was 4. For a tolerance limit of 0.01 the Gauss-Seidel load flow calculation converged after 14 iteration [92]. Fig. 7.8.1 shows the IEEE 14 BUS system and the Table 7.8.1 shows the description of the IEEE 14 BUS system. The software developed in BASIC language is given the Appendix as A5.1, A5.2 and A5.3.

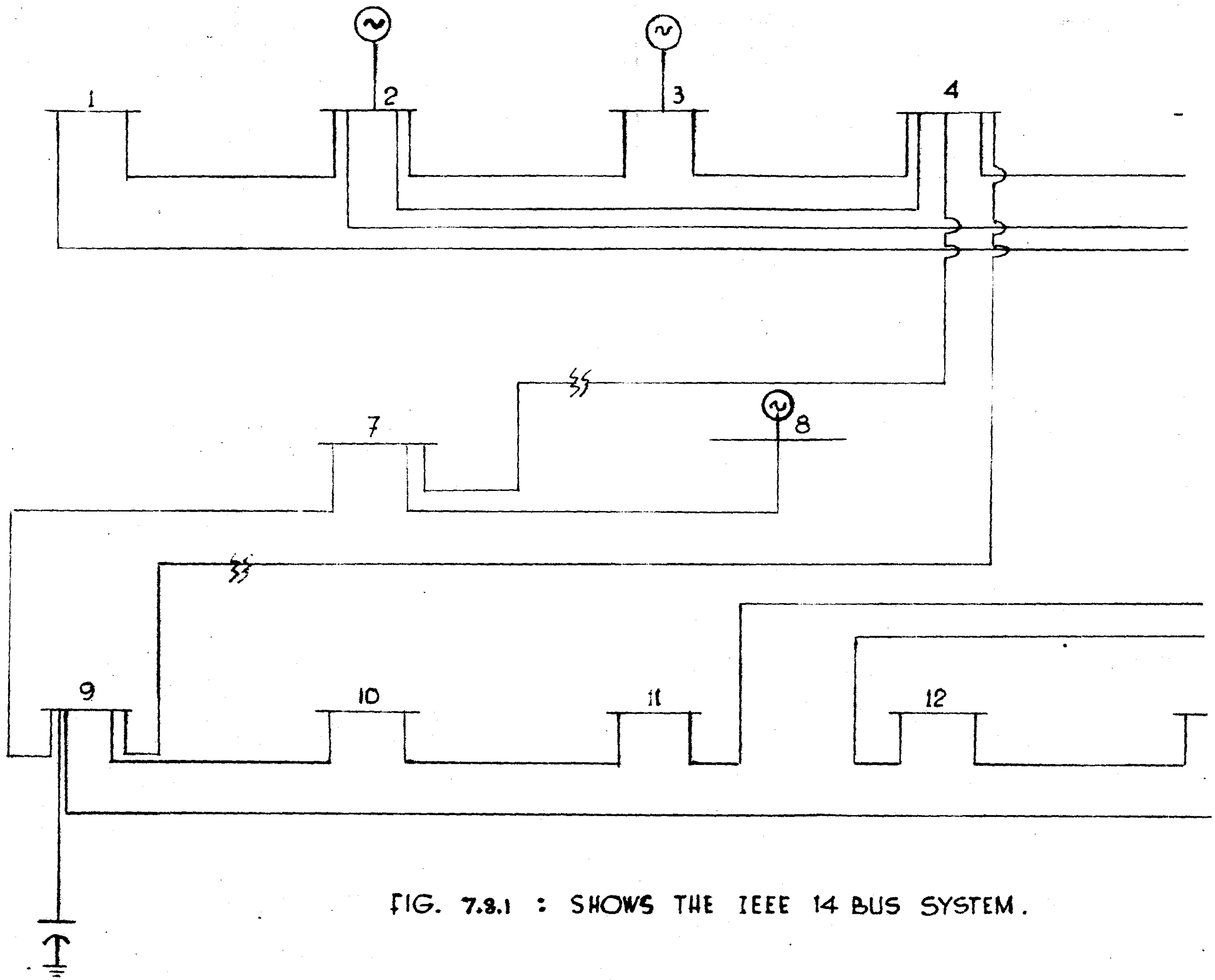

FIG. 7.8.1 : SHOWS THE IEEE 14 BUS SYSTEM.

TABLE 7.8.1

DESCRIPTION OF THE IEEE 14 BUS SYSTEM

BUS DATA

Bus No.	Generation		Load	
	Real MW	Reactive MVAR	Real MW	Reactive MVAR
1	232.4	-16.9	0.0	0.0
2	40.0	42.4	21.7	12.7
3	0.0	23.4	94.2	19.0
4	0.0	0.0	47.8	3.9
5	0.0	0.0	7.6	1.6
6	0.0	12.2	11.2	7.5
7	0.0	0.0	0.0	0.0
8	0.0	17.4	0.0	0.0
9	0.0	0.0	29.5	16.6
10	0.0	0.0	9.0	5.8
11	0.0	0.0	3.5	1.5
12	0.0	0.0	6.1	1.6
13	0.0	0.0	13.5	5.5
14	0.0	0.0	14.9	5.0

LINE DATA

Line No.	Between Buses	Line impedance		Half line charging susceptance per Unit
		R per Unit	X per Unit	
1	1-2	0.01938	0.05917	0.02640
2	2-3	0.04699	0.19797	0.02190
3	2-4	0.05811	0.17632	0.01870
4	1-5	0.05403	0.22304	0.02460
5	2-5	0.05695	0.17388	0.01700
6	3-4	0.06701	0.17103	0.01720
7	4-5	0.01335	0.04211	0.0064
8	5-6	0.0	0.25202	0.0
9	4-7	0.0	0.20912	0.0
10	7-8	0.0	0.17615	0.0
11	4-9	0.0	0.55618	0.0
12	7-9	0.0	0.11001	0.0
13	9-10	0.03181	0.08450	0.0
14	6-11	0.09498	0.19890	0.0
15	6-12	0.12291	0.25581	0.0
16	6-13	0.06615	0.13027	0.0
17	9-14	0.12711	0.27038	0.0
18	10-11	0.08205	0.19207	0.0
19	12-13	0.22092	0.19988	0.0
20	13-14	0.17093	0.34802	0.0

TRANSFORMER DATA

Transformer	Between Buses	Tap Setting
1	4 - 7	0.978
2	4 - 9	0.969
3	5 - 6	0.932

SHUNT CAPACITOR DATA

Bus Number	Susceptance per Unit
9	0.190

REGULATED BUS DATA

Bus Number	Voltage magnitude per Unit	Reactive power limits	
		Minimum MVAR	Maximum MVAR
2	1.045	- 40.0	50.0
3	1.010	0.0	40.0
6	1.070	- 6.0	24.0
8	1.090	- 6.0	24.0