A Z-BUS MATRIX BUILDING ALGORITHM FOR A BALANCED POWER SYSTEM USING INSPECTION METHOD

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

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in

ELECTRICAL ENGINEERING

(With Specialization in Power System Engineering)

By

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CANDIDATE'S DECLARATION

I here declare that the work presented in this dissertation entitled **"A Z-bus Matrix Building Algorithm for A Balanced Power System Using Inspection Method"** submitted in partial fulfillment of the requirements for the award of the degree of Master of Technology with specialization in Power System Engineering in the Department of Electrical Engineering, Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out from June 2005 to June 2006 under the guidance of **Dr. R.N. Patel,** lecturer, Department of Electrical Engineering, Indian Institute of Technology Roorkee, Roorkee.

I have not submitted the matter embodied in this report for the award of any other degree or diploma.

Date: 30 June 2006

Place: Roorkee

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CERTIFICATE

This is to certify that the above statement made by the candidate is true to the best of my knowledge and belief.

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(P. VARA PRASAD).

ABSTRACT

Computer application for power systems is one of the many technologies undergoing rapid evolution. In the operation of a power system, the most often-used simulation tools are Load flow, Short Circuit and Dynamics Programs. The first short circuit or fault problem was solved by a Gauss-Siedel load flow type in 1955. Then came the bus impedance matrix, which matured by axes discarding technique to solve large systems. For several decades, short circuit calculation was computed using the elements of the bus impedance matrix. Despite the variety of applications of Zbus, in power system analysis, like fault analysis, contingency analysis, detection of over loaded lines, etc., the use of Zbus matrix has been constrained principally to mainframe computers because of the computational burden and large memory requirement.

Conventional methods to form Zbus matrix i.e., Inversion of Ybus matrix and Building algorithm method have large computational burden. Therefore, a new Zbus matrix building algorithm, deriving from the concepts of the circuit analysis, traditional Zbus matrix building technique, is proposed in this dissertation work. The new method is systematic, effective and programmable. The proposed method is tested on different IEEE test systems (IEEE 14, 30, 39, 57, 118 and 300 bus systems). Moreover, detailed analysis and results of a detailed Zbus matrix formation of IEEE 39 bus system and IEEE 300 bus systems are provided. Results are obtained using MATLAB 7.1. It has been proved that the proposed method can be used for large systems.

CONTENTS

LIST OF FIGURES

1. INTRODUCTION

1.1 General

Recent increases in the processor speed and memory capabilities of personal computers have made PCs important tools in the power system industry and research applications. Recently, many power system analysis algorithms, such as state estimation and load flow for balanced systems, have been implemented on personal computers. One of the applications of personal computers in power system analysis is the bus impedance matrix formation. The bus impedance matrix also known, as Zbus matrix, is one of the most powerful matrices used in power system fault analysis. Despite the variety of applications of Zbus in power system analysis, like fault calculations, contingency analysis, economic dispatch, etc., its use has been constrained principally to mainframe computers because of the computational burden and large memory requirement of the Zbus building algorithm.

The work required for constructing a Zbus matrix is much greater than that of the admittance matrix (Ybus matrix), but the information content in the Zbus matrix is also much more than Ybus matrix. For instance, each diagonal element of Zbus matrix represents the Thevenin equivalent impedance at the corresponding bus looking into the system. Thevenin impedance provides important information for short-circuit analysis. Unlike the Ybus matrix, Zbus matrix is never sparse and contains zeros only if the system is split into independent islands.

Before proceeding with the details of the formation of the Zbus matrix by inspection method, a brief description and a few applications of Zbus matrix are discussed. The diagonal elements of the bus impedance matrix or Zbus matrix contain the driving point impedance of every node with respect to a reference bus. The driving point impedance of a node is the equivalent impedance between it and the reference. The off diagonals are the transfer impedance between each bus of the network and every other bus with respect to the reference bus. The Zbus, also known as "bus impedance matrix" is built from the branch data consisting of the positive sequence, negative sequence, and the zero sequence impedances. For practical purposes the positive and negative sequence impedances are treated equally.

The most common use of the bus impedance matrix is fault analysis [1]. If the transmission lines are assumed to be perfectly transposed fault analysis may be performed using the zero, positive and negative sequence Zbus values. Another application of the positive sequence bus impedance matrix is in economic dispatch [2]. In this problem a series of transformations are used to reduce the original Zbus into a form, which relates the generator voltages to the generator currents and an equivalent load current. The Zbus is also an important tool in contingency analysis where the objective is to simulate the removal or addition of a transmission line or transformer and determine if other in service equipment will exceed normal operating limits [3]. In particular, elements of Zbus that are related to the contingency and monitored lines are used in conjunction with pre-contingency load flow data to determine the net current change in the monitored lines following the switching operation. Recently a fast contingency method, also based on the Zbus, has been proposed which should make the method more suitable for on-line applications [4]. The Zbus matrix with a simple calculation can be used to determine the overload on any particular line.

Conventional methods to form Zbus matrix i.e., Inversion of Ybus matrix and Building algorithm method have large computational burden. Therefore, a new Zbus matrix building algorithm, deriving from the concepts of the circuit analysis, traditional Zbus matrix building technique, and retaining the performance of the LU factorization algorithm is proposed in this dissertation work. The new method is systematic, effective and programmable. Unlike the normal step-by-step growing technique [1,5,6], the proposed method is a 'one pass' process where the Kron's reduction is needed only once. Results show that the proposed method is very effective, efficient and suitable to be used for large-scale power systems.

1.2 Literature Review

Fault studies form an important part of power system analysis. The problem consists of determining bus voltages and line currents during various types of faults [1]. The first short circuit or fault problem was solved by the Gauss-Siedel load flow type in 1955. Then the bus impedance matrix came. In 1971, Tinney .W has already thought of using Ybus matrix in fault calculation, thus utilize its outstanding property of sparsity. Although the mathematical derivation of the sparse Zbus from the factored Ybus is very simple, it was not until 1973 that a paper came out by Chen et al. [7]. Since then it became an industry algorithm.

The authors, Meyer W. S. and Albertson, V.D., in their paper [2], discussed application of the positive sequence bus impedance matrix is in economic dispatch. In this problem a series of transformations are used to reduce the original Zbus into a form, which relates the generator voltages to the generator currents and an equivalent load current. The application of Zbus matrix in contingency analysis, where the objective is to simulate the removal or addition of a transmission line or transformer and determine if other in service equipment will exceed normal operating limits, is discussed by the authors Brown H.E. in his paper [3]. Recently a fast contingency method, which is suitable for on-line applications, has been proposed by the authors Makram E.B. et al., in their paper [4]. This method is also based of bus impedance matrix.

For several decades, short circuit calculation was computed using the elements of the bus impedance matrix known today as Zbus. This matrix can be formed in a step-by-step procedure, the method of Ahmed El-Abiad [8] [1,5,6]. Zbus is square and full, although a technique is employed to store only the upper triangle including the diagonal in linear array (vector). For example, only as big as 100 busses can be stored on that vector because of large core memory required and computing time. To be able to solve network of more than 100 busses, a method of deleting an unwanted rows and columns is employed Known as "axes discarding"[9]. This method can now accommodate as large as 1500 busses, 2500 branches and 100-coupled pairs on a 640 KB core memory.

In 1973, a very significant innovation was formulated by Chen et al. [7], where only the first neighborhood Zbus elements are computed from a factored bus admittance matrix, Ybus. Such matrix is called "sparse Zbus" because it has the same sparsity as the Ybus. The method of "sparse Zbus from a factored Ybus" could now solve very large network at a shorter computing time. Since then, it became the standard procedure in short circuit algorithms. Talaq J. [10] proposed a systematic procedure to solve complex and multiple fault problems of power systems. Complex faults are combinations of different common unsymmetrical faults that occur at a single bus. Multiple faults are a series of complex faults that occur at several buses at the same time. The proposed method is also based on bus impedance matrix.

One most important aspect of research is the inclusion of mutual coupling in the zero sequence networks. There are two methods of including mutual coupling in the "step-by-step" Zbus. The first one is by El-Abiad [8]. Each branch is added to the Zbus one at a time. The coupling effect is immediately added to the partial Zbus. The second method by Brown / Storry [11] compensates the coupling effect only after the Zbus is completed. The full Zbus matrix is first constructed by step-by-step algorithm using line parameters modified to remove all coupling effects, then the matrix is corrected to consider coupling. One can also construct the full Zbus matrix using the factored Ybus method of Chen [7], then correct it to include coupling. This procedure will not be practical for more than 100 busses because of huge memory storage required. In order to preserve sparsity in the sparse Zbus generated from factored Ybus using Chen's algorithm, coupling must right away be included in the Ybus matrix. Nagappan [12] showed that mutual coupling could be included in the Ybus matrix in step-by-step procedure. Undrill et al. [13] includes coupling iteratively in the Ybus matrix.

Accurate fault studies in unbalanced power systems often require three-phase modeling of the power system. The three-phase bus impedance matrix is also an important tool in contingency analysis. Peterson W.L. et al, [14] described a generalized PC based algorithm for constructing the three-phase bus impedance matrix from transmission line data and load/generator impedances. The algorithm incorporates optimal line ordering and shunt elements in the network. The direct and indirect mutual coupling effects are also being included in their paper. The next batch of paper by Mong S. et al, [15] on short circuit calculation did not explain how they include mutual coupling in the Ybus matrix.

The authors Peterson W.L. et al, [16] described a generalized PC based bus impedance matrix building algorithm for positive, negative, and zero sequence networks. The features, like optimal line ordering, mutually coupled lines effects, and shunt elements, have been included. The algorithm will handle lines that are directly and indirectly mutually coupled. In processing these mutually coupled lines the minimum dimension of the primitive impedance matrix is constructed for each mutually coupled line being assembled. This algorithm is particularly suited for personal computers because computational burden and memory requirements are less. Quanming Y. et al., [17] proposed a new viewpoint to build Z-matrix of large-scale power system. The algorithm could deal with mutual inductance or non-mutual inductance networks.

Teng J.H. et al. [18] have proposed an effective and procedural decomposition approach for Z-matrix building based on the concepts of spanning tree. In this paper the relationship between bus voltages, bus current injections and branch currents were all investigated. The building algorithm can be accomplished by a simple search technique with two proposed matrices and is easily implemented. With these two matrices, the relationships among bus current injections, branch currents and bus voltages can be found. Those matrices will be very helpful in observing the structural changes in short-circuit analysis and contingency analysis.

1.3 Organization of the thesis

This thesis report is organized in 6 chapters as follows.

Chapter 1 introduces the introductory aspects, applications, literature review and historical developments of the bus impedance matrix.

Chapter 2 explains the available traditional methods to form the bus impedance matrix briefly i.e., Ybus inversion method, current injection method and Building algorithm method have been discussed.

Chapter 3 explains the philosophy of the proposed Inspection method. In this chapter three inspections methods are being proposed along with a case study of 3 bus test system [1]. It has been proved that all the methods are giving same results. The results are verified with the Ybus inversion method. In this dissertation work method 3 is simulated and analyzed for different IEEE systems.

In **Chapter 4** the flow-charts and algorithms of Ybus inversion method, building algorithm method and proposed inspection method are discussed.

In **Chapter 5** the different IEEE test systems (IEEE 14, 30, 39, 57, 118 and 300 bus systems) are solved to properly illustrate the proposed technique. The results of IEEE 39 bus and IEEE 300 bus systems are discussed in detail. It has been proved that the proposed method is suitable for large power systems.

In **Chapter 6**, concluding observations along with possible future research directions are presented.

Finally, at the end, the system data of IEEE 39 bus system and IEEE 300 bus system used in this thesis are reported in Appendices A and B respectively.

2. METHODS TO FORM Z_{BUS} MATRIX

This chapter is intended to explain the traditional methods available for the formation of bus impedance matrix. There are 3 methods for the Zbus formulation viz,

i) Inversion of Ybus matrix

ii) Current injection Technique

iii) Zbus building algorithm

2.1 Inversion of Ybus matrix: This is the straightforward method of finding the Zbus matrix. But the matrix inversion of larger system is complicated and time consuming. Since,

$$I_{bus} = Y_{bus} V_{bus}$$
$$\Rightarrow V_{bus} = [Y_{bus}]^{-1} I_{bus} \qquad (2.1)$$
$$\Rightarrow Z_{bus} = [Y_{bus}]^{-1}$$

The sparsity of Ybus matrix may be retained by using an efficient inversion technique and nodal impedance matrix can be calculated directly from the factorized admittance matrix.

2.2 Current Injection Technique: Equation (2.1) can be written in the expanded form as

$$V_1 = Z_{11} I_1 + Z_{12} I_2 + \dots\dots\dots + Z_{1n} I_n$$
$$V_2 = Z_{21} I_1 + Z_{22} I_2 + \dots\dots\dots + Z_{2n} I_n$$
$$\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots$$
$$V_n = Z_{n1} I_1 + Z_{n2} I_2 + \dots\dots\dots + Z_{nn} I_n$$

It immediately follows from above equations that

$$Z_{ij} = \frac{V_i}{I_j} \text{ at } I_1 = I_2 = \dots\dots = I_n = 0 \text{ and } I_j \neq 0 \qquad (2.2)$$

Also $Z_{ij} = Z_{ji}$ (Zbus is symmetrical matrix)

As per equation (2.2), if a unit current is injected at bus j, while the other buses are kept open circuited, the bus voltages yield the values of the jth column of Zbus. However no organized computerizable techniques are possible for finding the bus voltages. This technique had utility in AC network analyzers where the bus voltages could be read by a voltmeter.

2.3 Zbus Building Algorithm: It is a step-by-step programmable technique which proceeds branch by branch. It has the advantage that any modification of the network does not require complete rebuilding of Zbus. Consider that Zbus has been formulated up to a certain stage and another branch is now added. Upon adding a new branch (of impedance Zb), one of the following situations will occur.

1) Zb is added from new bus to the reference bus (i.e., a new branch is added and the dimension of Zbus goes up by one). This is type-1 modification.
2) Zb is added from a new bus to an old bus (i.e., a new branch is added and the dimension of Zbus goes up by one). This type-2 modification.
3) Zb connects an old bus to the reference branch (i.e., a new loop is formed but the dimension of Zbus does not change). This is type-3 modification.
4) Zb connects two old buses (i.e., a new loop is formed but this dimension of Zbus does not change). This type-4 modification.
5) Zb connects two new buses (Zbus remains unaffected in this case). This situation can be avoided by suitable numbering of buses and from now onwards will be ignored.

Notation: i, j – old busses, r-reference bus, k-new bus

Type-1 Modification: Fig 2.1 shows a passive (linear) n-bus network in which branch with impedance Zb is added between new bus k and the reference bus r. Now

$$V_k = Z_b I_k$$

$$Z_{ki} = Z_{ik} = 0 ; i = 1, 2, \ldots, n$$

$$Z_{kk} = Z_b$$

Hence

$$Z_{bus\_new} = \left[\begin{array}{c|c} Z_{bus\_old} & \begin{matrix} 0 \\ \vdots \\ 0 \end{matrix} \\ \hline 0 \text{------} 0 & Z_b \end{array}\right] \tag{2.3}$$

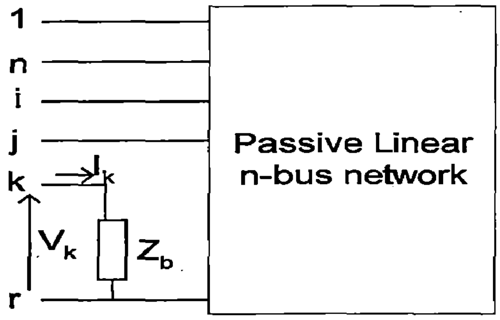


Fig 2.1: Type – 1 Modification

Type-2 Modification: Z_b is added from new bus k to the old bus j as in fig 2.2

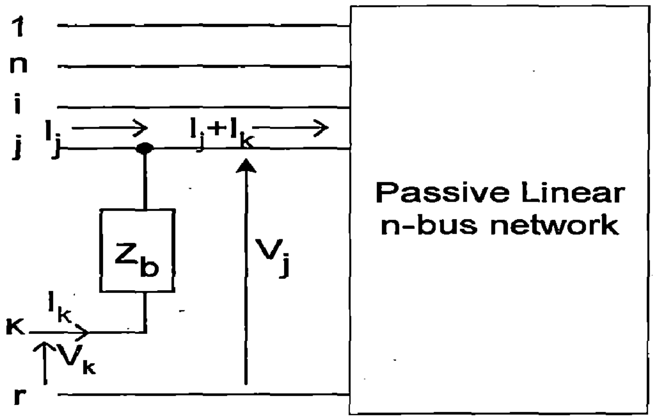


Fig 2.2: Type – 2 Modification

It follows from figure that

$$V_k = Z_b I_k + V_j$$

$$= Z_b I_k + Z_{j1} I_1 + Z_{j2} I_2 + \dots\dots\dots + Z_{jj}(I_j + I_k) + \dots\dots Z_{jn} I_n$$

rearranging

$$V_k = Z_{j1} I_1 + Z_{j2} I_2 + \dots\dots\dots + Z_{jj} I_j + \dots\dots\dots + Z_{jn} I_n + (Z_{jj} + Z_b) I_k$$

Consequently

$$Z_{bus\_new} = \left[\begin{array}{c|c} Z_{bus\_old} & \begin{matrix} Z1j \\ Z2j \\ \vdots \\ Znj \end{matrix} \\ \hline Z_{j1}\ Z_{j2} \dots\dots Z_{jn} & Z_{jj} + Z_b \end{array}\right] \qquad (2.4)$$

Type-3 Modification: Z_b is connected between an old system (j) to the reference bus as in fig 2.3. This case follows from Fig 2.2 by connecting bus k to the reference bus r, i.e., by setting $V_k = 0$.

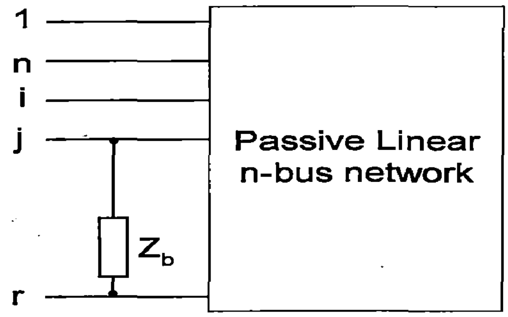


Fig 2.3: Type – 3 Modification

Thus

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \\ \hline 0 \end{bmatrix} = \left[\begin{array}{c|c} Z_{bus\_old} & \begin{matrix} Z1j \\ Z2j \\ \vdots \\ Znj \end{matrix} \\ \hline Z_{j1}\ Z_{j2} \cdots Z_{jn} & Z_{jj} + Z_b \end{array}\right] \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \\ \hline I_k \end{bmatrix}$$

Eliminate I_k from the set of above equations using kron's reduction rule

$$Z_{bus}^{new} = Zbus_{bus}^{old} - \frac{1}{Z_{jj} + Z_b} \begin{bmatrix} Z_{1j} \\ \vdots \\ Z_{nj} \end{bmatrix} \begin{bmatrix} Z_{j1} & \cdots & Z_{jn} \end{bmatrix} \tag{2.5}$$

Type 4 Modification: Z_b connects two old buses i and j as in fig 2.4. Equations can be written as follows for all the network buses in matrix form as

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \\ \hline 0 \end{bmatrix} = \left[\begin{array}{c|c} Z_{bus} & \begin{matrix} (Z_{1i}-Z_{ij}) \\ (Z_{2i}-Z_{2j}) \\ \vdots \\ (Z_{ni}-Z_{nj}) \end{matrix} \\ \hline (Z_{i1} - Z_{j1}) \cdots\cdots (Z_{in} - Z_{jn}) & Z_b + Z_{ii} + Z_{jj} - 2Z_{ij} \end{array}\right] \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \\ \hline I_k \end{bmatrix}$$

Eliminate I_k from the set of above equations using kron's reduction rule,

$$Z_{bus}^{new} = Zbus_{bus}^{old} - \frac{1}{Z_{ii} + Z_{jj} + Z_b - 2Z_{ij}} \begin{bmatrix} Z_{1i} - Z_{1j} \\ \vdots \\ Z_{ni} - Z_{nj} \end{bmatrix} \begin{bmatrix} Z_{i1} - Z_{j1} & \cdots & Z_{in} - Z_{jn} \end{bmatrix} \quad (2.6)$$

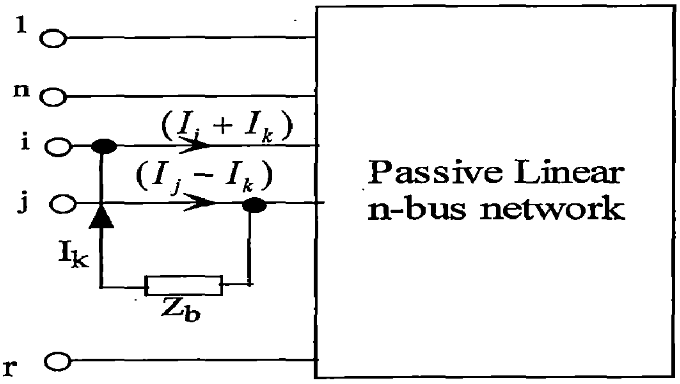


Fig 2.4: Type – 4 Modification

With the use of four relationships equations (2.3), (2.4), (2.5) and (2.6), the bus impedance matrix can be built by a step-by-step procedure. This procedure can easily be computerized. When the network undergoes changes, the modification procedures can be employed to revise the bus impedance matrix of the network. For example, the opening of a line (Zij) is equivalent to adding a branch in parallel to it with impedance –Zij.

This chapter explains the philosophy of the Zbus formation by inspection method. Detailed analysis of the formation of Zbus matrix of 3-bus system [6] is explained as case study.

According to the current injection method (ref chapter 2.2),

$$Z_{ii} = \frac{V_i}{I_i} \text{ at } I_1 = I_2 = \ldots\ldots = I_n = 0 \text{ and } I_i \neq 0 \quad (3.1)$$

$$Z_{ij} = \frac{V_i}{I_j} \text{ at } I_1 = I_2 = \ldots\ldots = I_n = 0 \text{ and } I_j \neq 0 \quad (3.2)$$

It immediately follows from equation (3.1) that Z_{ii} is the driving point impedance viewing into the network from node i with respect to a reference node. It is assumed that the slack bus voltage is low and hence all the currents injected at different buses will travel towards the slack bus. For the power system network, which is in the form of tree network that means for a power system, which has no interconnections, the exact path of the current injected at node i, can easily be determined. Hence the driving point impedance viewing into the given network from node i, which is nothing but the element Z_{ii} of the Zbus matrix. It can be observed that this driving point impedance (or) Z_{ii} is the sum of the impedances through which the injected current I_i will pass through, until it reaches ground. If ground node is not given, then the slack bus (or) the reference bus will take the role of ground. Hence the diagonal elements of the Zbus matrix can be formed easily, by just looking at the given power system, which should be in the form of tree network.

Eq (3.2) shows that the off-diagonal elements of the Zbus matrix are the transfer impedance between each bus of the network and every other bus with respect to the reference bus. For the same power system considered in the above case i.e., for the power system having no interconnections the exact path through which both the currents I_i *and* I_j will pass through, can easily be determined. Hence the transfer impedance between the nodes i and j can easily be determined by just adding the impedances through which both the currents I_i *and* I_j will pass through, until they reach the ground node (or) reference bus (or) slack bus. This value is nothing but the Z_{ij} element of the Zbus matrix. Hence the off-diagonal elements of Zbus matrix can be formed easily, by just looking at the given network, which should be in the form tree. The proposed rules to be followed in forming the Zbus are:

- The diagonal element Z_{ij} is equal to the sum of the impedances through which the injected current I_i at bus i will pass through, until I_i reaches the ground or the slack bus or reference bus.
- The off diagonal element Z_{ij} is equal to the sum of the impedances through which both the injected currents I_i and I_j at buses i and j respectively, will pass through, until I_i and I_j reaches the ground or the slack bus or reference bus.

Practical power system will always have interconnections. In order to form the complete Zbus matrix, of a practical power system three methods are being proposed.

3.1 Method 1

In this method, the remaining links (or) interconnections of the given power system network, are to be added to the Zbus_old matrix using normal building algorithm rules.

Steps: The different steps to be followed for the formation of the Zbus matrix are

1) Select a tree from the given network, such that the reference node (ground) is connected to as maximum number of nodes as possible, via branches.
2) Form the Zbus matrix, by inspection method using the rules discussed above.
3) Add the remaining links to the tree network one by one until, original network is obtained and in each step new Zbus matrix is to be formed by using normal Zbus building algorithm rules (Type 4 modification discussed in the section 2.3).

3.2 Method 2

In this method, the given power system network having interconnections, is to be converted into a tree network, using $\Delta - Y$ conversion method. In this method, a few extra nodes known as "virtual nodes" will generate.

There is no need of considering these virtual nodes in the formation of the Zbus matrix since at these virtual nodes, no currents are injected. The remaining interconnections, which are not covered by $\Delta - Y$ conversion method, are to be included in the Zbus matrix using normal building algorithm method rules.

Steps: The steps to be followed by this method are

1. Convert the given graph network, having N nodes into a tree network, having N nodes and a few extra virtual nodes, using $\Delta - Y$ conversion method.
2. Remove the links, which are not covered by the $\Delta - Y$ conversion method.
3. Form the Zbus matrix of size N x N using the rules discussed above. There is no need of considering virtual nodes. Since no currents will be injected at these virtual nodes.
4. Include the remaining links in the Zbus matrix, using normal building algorithm rules (Type 4 modification discussed in the section 2.3).

3.3 Method 3

In this method, the given power system network having interconnections is to be converted into a tree network having increased node points i.e., few nodes have been divided into two different nodes. It should be observed that the voltages of these two nodes are same as that of their parent node. For this new tree network Zbus matrix of size m x m is to be formed using the rules given above. Here m is the number of branches of the given power system. The Zbus matrix of m x m size is to be reduced to the size N x N, where N is the number of buses of the given power system, using partition of matrices method and Kron's reduction technique as described in the case study.

Steps The steps to be followed for the formation of the Zbus matrix are

1. Convert the given graph-network having nodes N into a tree network, having m nodes. Here N and m are number of nodes and number of branches of the given system respectively.
2. Form Zbus matrix of size m x m using the rules discussed above.
3. Reduce the Zbus to size N x N, using partition of matrices method and kron's reduction technique.

Hence the Zbus matrix can be formed easily. In this dissertation work, method 3 is simulated and analyzed for different IEEE systems using MATLAB 7.1 package.

3.4 Case study – 3 bus test system [1]

The bus impedance matrix is to be constructed for the network shown in fig 3.1(a). It consists of 3 nodes and a ground.

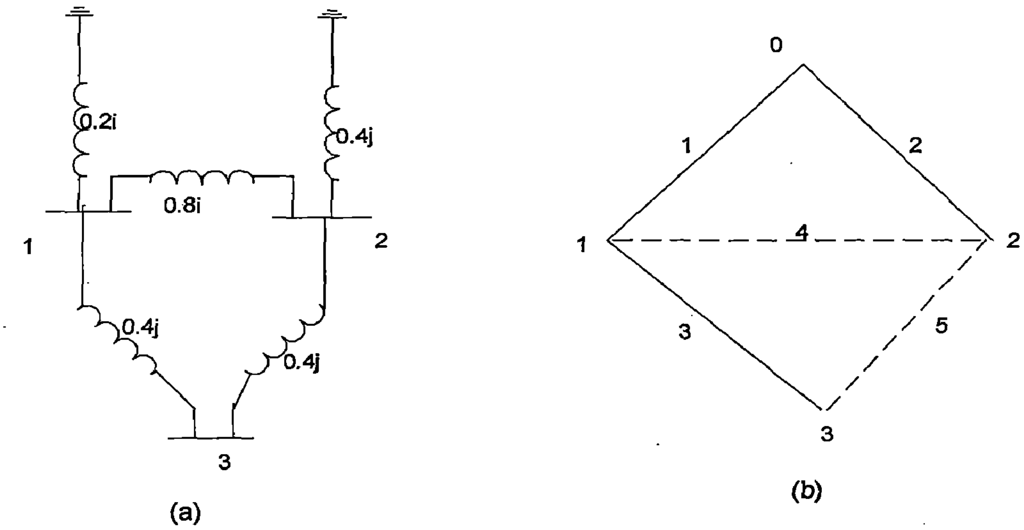


Fig 3.1 (a) Circuit Diagram (b) Proper tree network (solid lines)

Method 1

The proper tree network (solid) and the links (dotted) of the network, shown in fig 3.1(a), is drawn in fig 3.1(b). The elements 1, 2 and 3 are in tree network and the elements 4 and 5 are links. The Zbus matrix for this tree network using the steps and rules discussed in section 3.1, can be constructed as

$$Z_{bus} = \begin{bmatrix} 0.2j & 0 & 0.2i \\ 0 & 0.4j & 0 \\ 0.2j & 0 & 0.6j \end{bmatrix}$$

Now adding element 4, between nodes 2 and 1,

$$Z_{bus} = \begin{bmatrix} 0.2i & 0 & 0.2j & -0.2j \\ 0 & 0.4j & 0 & 0.4j \\ -0.2j & 0 & 0.6j & -0.2j \\ -0.2j & 0.4j & -0.2j & Zx \end{bmatrix}$$

$where\ Zx = 0.8j + 0.2j + 0.4j - 2(0j) = 1.4j$

Simplifying the above eq, using the formula

$$Z_{bus}^{new} = Z_{bus}^{old} - \frac{\Delta Z \Delta Z^T}{Zx} \quad \text{where } \Delta Z^T = \begin{bmatrix} -0.2j & 0.4j & -0.2j \end{bmatrix}$$

The new Zbus matrix would be

$$Z_{bus} = \begin{bmatrix} j0.17143 & j0.05714 & j0.17143 \\ j0.05714 & j0.28571 & j0.05714 \\ j0.17143 & j0.05714 & j0.57143 \end{bmatrix} \qquad (3.3)$$

Adding the link 5, available between the nodes 3 and 2,

$$Z_{bus} = \begin{bmatrix} j0.17143 & j0.05714 & j0.17143 & j0.11429 \\ j0.05714 & j0.28571 & j0.05714 & -j0.22857 \\ j0.17143 & j0.05714 & j0.57143 & j0.51429 \\ j0.11429 & -j0.22857 & j0.51429 & Zx \end{bmatrix} \qquad (3.4)$$

where $Zx = j0.4 + j0.28571 + j0.57143 - 2(j0.05714) = j1.14j$

Simplifying the above eq (3.4), using the formula

$$Z_{bus}^{new} = Z_{bus}^{old} - \frac{\Delta Z \Delta Z^T}{Zx} \quad \text{where } \Delta Z^T = \begin{bmatrix} -0.2j & 0.4j & -0.2j \end{bmatrix}$$

The final Zbus matrix would be

$$Z_{bus} = \begin{bmatrix} j0.16 & j0.08 & j0.12 \\ j0.08 & j0.24 & j0.16 \\ j0.12 & j0.16 & j0.34 \end{bmatrix} \qquad (3.5)$$

Method 2

The given system is shown in fig 3.2(a). The modified network after converting the loop 1-2-3-1, using delta - star conversion method is shown in fig 3.2(b). The dotted line indicates the link, which cannot be covered by the delta - star conversion method.

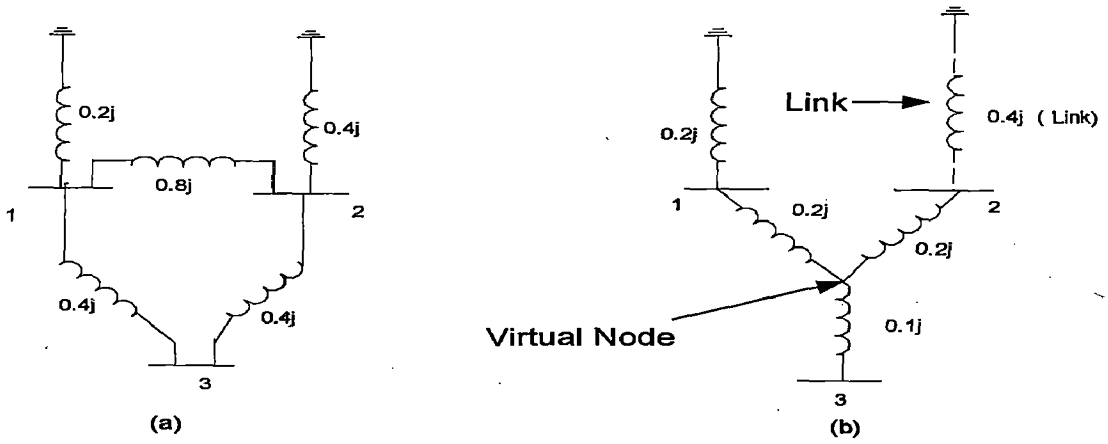


Fig 3.2 (a) Circuit diagram (b) After Delta-Star Conversion

The Zbus matrix for this tree network using the steps and rules discussed in section 3.2, can be constructed as

$$Z_{bus} = \begin{bmatrix} 0.2j & 0.2i & 0.2j \\ 0.2j & 0.6j & 0.4j \\ 0.2j & 0.4j & 0.5j \end{bmatrix}$$

Adding the remaining link 2, available between the nodes 2 and 0 (ground node),

$$Z_{bus} = \begin{bmatrix} 0.2j & 0.2j & 0.2j & 0.2j \\ 0.2j & 0.6j & 0.4j & 0.6j \\ 0.2j & 0.4j & 0.5j & 0.4j \\ 0.2j & 0.6j & 0.4j & Zx \end{bmatrix}$$

where Zx = 0.6j + 0 - 2(0j) = 0.6j

Applying the Kron's reduction technique,

$$Z_{bus} = \begin{bmatrix} 0.2j & 0.2j & 0.2j \\ 0.2j & 0.6j & 0.4j \\ 0.2j & 0.4j & 0.5i \end{bmatrix} - \frac{1}{Zx} \begin{bmatrix} 0.2i \\ 0.6j \\ 0.4j \end{bmatrix} \begin{bmatrix} 0.2j & 0.6j & 0.4j \end{bmatrix}$$

The final Zbus matrix would be

$$Z_{bus} = \begin{bmatrix} j0.16 & j0.08 & j0.12 \\ j0.08 & j0.24 & j0.16 \\ j0.12 & j0.16 & j0.34 \end{bmatrix} \qquad (3.6)$$

Method 3: The given system and the extended tree network are shown in fig 3.3(a) and 3.3(b). It should be observed that there are no links in fig 3.3(b) and the number of nodes have been increased to 5. The Zbus matrix for this tree network using the steps and rules discussed in section 3.3, can be constructed as

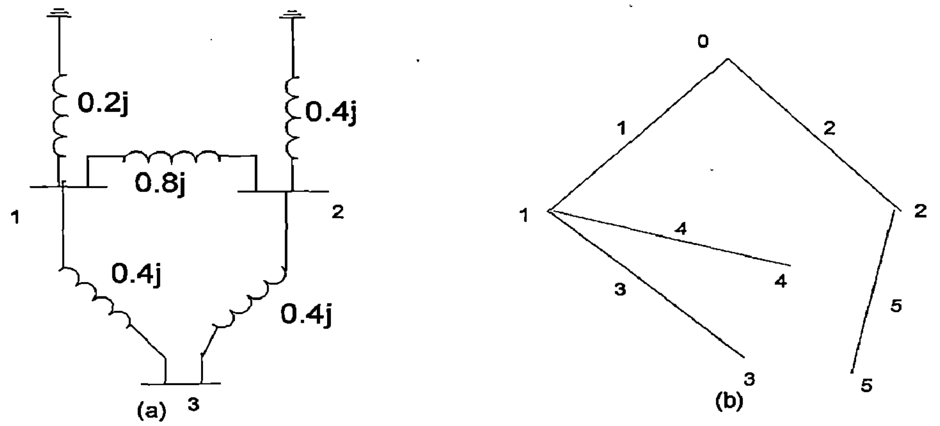


Fig 3.3 (a) Circuit diagram (b) Extended Tree network

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \end{bmatrix} = \begin{bmatrix} 0.2j & 0 & 0.2j & 0.2j & 0 \\ 0 & 0.4j & 0 & 0 & 0.4j \\ 0.2j & 0 & 0.6j & 0.2j & 0 \\ 0.2j & 0 & 0.2j & 1.0j & 0 \\ 0 & 0.4j & 0 & 0 & 0.8j \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \end{bmatrix}$$

But $V_4 = V_2$ and $V_5 = V_3$ Hence the above set of equations can be simplified to

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0.2j & 0 & 0.2j & 0.2j & -0.2j \\ 0 & 0.4j & 0 & -0.4j & 0.4j \\ 0.2j & 0 & 0.6j & 0.2j & -0.6j \\ 0.2j & -0.4j & 0.2j & 1.4j & -0.6j \\ -0.2j & 0.4j & -0.6j & -0.6j & 1.4j \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \end{bmatrix}$$

Using Kron's reduction technique A – B C^{-1} D,

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \left\{ \begin{bmatrix} 0.2j & 0 & 0.2j \\ 0 & 0.4j & 0 \\ 0.2j & 0 & 0.6j \end{bmatrix} - \begin{bmatrix} 0.2j & -0.2j \\ -0.4j & 0.4j \\ 0.2j & -0.6j \end{bmatrix} \begin{bmatrix} 1.4j & -0.6j \\ -0.6j & 1.4j \end{bmatrix} \begin{bmatrix} 0.2j & -0.4j & 0.2j \\ -0.2j & 0.4j & -0.6j \end{bmatrix} \right\} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} j0.16 & j0.08 & j0.12 \\ j0.08 & j0.24 & j0.16 \\ j0.12 & j0.16 & j0.34 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix}$$

Hence the final Zbus matrix is

$$Z_{bus} = \begin{bmatrix} j0.16 & j0.08 & j0.12 \\ j0.08 & j0.24 & j0.16 \\ j0.12 & j0.16 & j0.34 \end{bmatrix} \tag{3.7}$$

Verification: In order to verify the above-discussed methods, the Zbus matrix of the system shown in fig 3.3 (a), is formed using Ybus matrix inversion method. The bus admittance matrix, Ybus for the given network is

$$Y_{bus} = \begin{matrix} 0 \\ 1 \\ 2 \\ 3 \end{matrix} \begin{bmatrix} -7.5j & 5j & 2.5j & 0 \\ 5j & -8.75j & 1.25j & 2.5j \\ 2.5j & 1.25j & -6.25j & 2.5j \\ 0 & 2.5j & 2.5j & -5.0j \end{bmatrix}$$

Removing the row and columns indicating the slack bus or ground bus (first column and first row)

$$Y_{bus} = \begin{bmatrix} -8.75j & 1.25j & 2.5j \\ 1.25j & -6.25j & 2.5j \\ 2.5j & 2.5j & -5.0j \end{bmatrix}$$

Inversion of the above matrix is nothing but the bus impedance matrix of the given system. Hence the final Zbus matrix is

$$Z_{bus} = \begin{bmatrix} j0.16 & j0.08 & j0.12 \\ j0.08 & j0.24 & j0.16 \\ j0.12 & j0.16 & j0.34 \end{bmatrix} \tag{3.8}$$

From equations (3.5), (3.6), (3.7) and (3.8) it can be concluded that the proposed methods are giving accurate results. Hence these methods are verified.

4. ALGORITHMS AND FLOW CHARTS

This chapter is intended to explain the different logics, algorithms and flow charts used in this dissertation work.

4.1 Inversion of Bus admittance matrix

This method is the straightforward method. In this method first the bus admittance matrix is formed. Later Ybus matrix inversion is performed to obtain the bus impedance matrix, using one of the available matrix inversion methods. In this dissertation work, matrix inversion using LU factorization method is used.

4.1.1 Algorithm

STEP 1: Start

STEP 2: Start the clock

STEP 3: Read the system data in the table form into DATA as

Bus no	Bus no	Z(impedance) in p.u.

STEP 4: Read the slack bus number into 'slack'

STEP 5: Read the number of buses and branches into N and m respectively

STEP 6: Initialize the Ybus matrix of size N x N to zero

STEP 7: For p = 1 TO m, If yes go to STEP 8, otherwise go to STEP 10

STEP 8: a = DATA(p,1), b = DATA(p,2), y = 1 / DATA(p,3)

STEP 9: Calculate Ybus (a,a) = Ybus (a,a) + y

Ybus (b,b) = Ybus (b,b) + y

Ybus (a,b) = Ybus (a,b) - y

Ybus (b,a) = Ybus (a,b) and go to STEP 7

STEP 10: Remove the slack bus'th row and slack bus'th column from Ybus and transfer that matrix into A

STEP 11: Initialize L & U matrices of sizes (N-1) x (N-1) to zeros

STEP 12: For P= 1 TO N-1, if yes continue, else go to STEP 27

STEP 13: FOR q = 1 TO N-1, if yes continue, else go to STEP 12

STEP 14: If p = = q continue else go to STEP 16

STEP 15: L(p,q) = 1

STEP 16: If p <= q continue else go to 21

STEP 17: sum = 0

STEP 18: For k = 1 TO p-1, if yes continue, else go to STEP 20

STEP 19: sum = sum + L(p,k) x U (k,q) and then go to STEP 18

STEP 20: U(p,q) = A(p,q) – sum

STEP 21: If p > q continue else go to STEP 26

STEP 22: sum = 0

STEP 23: For k =1 TO p-1, if yes continue else go to STEP 25

STEP 24: sum = sum + L(p,k) x U(k,p) and then go to STEP 23

STEP 25: L(p,q) = [A(p,q) – sum] / U(q,q)

STEP 26: go to STEP 13

STEP 27: Initialize two matrices Y, X of sizes (N-1) x (N-1) to zero

STEP 28: For m = 1 To N-1, if yes continue, else go to STEP 37

STEP 29: For k = 1 TO N-1, if yes continue, else go to STEP 28

STEP 30: If m = =k continue else go to STEP 32

STEP 31: temp = 1 then go to STEP 33

STEP 32: temp = 0

STEP 33: sum = 0

STEP 34: for p =1 TO m-1, if yes continue else go to STEP 36

STEP 35: sum = sum + L(m,p) x U(p,k) and then go to STEP 34

STEP 36: Y(m,k) = temp – sum and then go to STEP 29

STEP 37: For m = N-1 TO 1, if yes continue else go to STEP 43

STEP 38: For k = N-1 TO 1, if yes continue else go to STEP 37

STEP 39: Sum = 0

STEP 40: For p = N-1 TP m+1, if yes continue, else go to STEP 42

STEP 41: Sum = Sum + U(m,p) x X(p,k) and then go to STEP 40

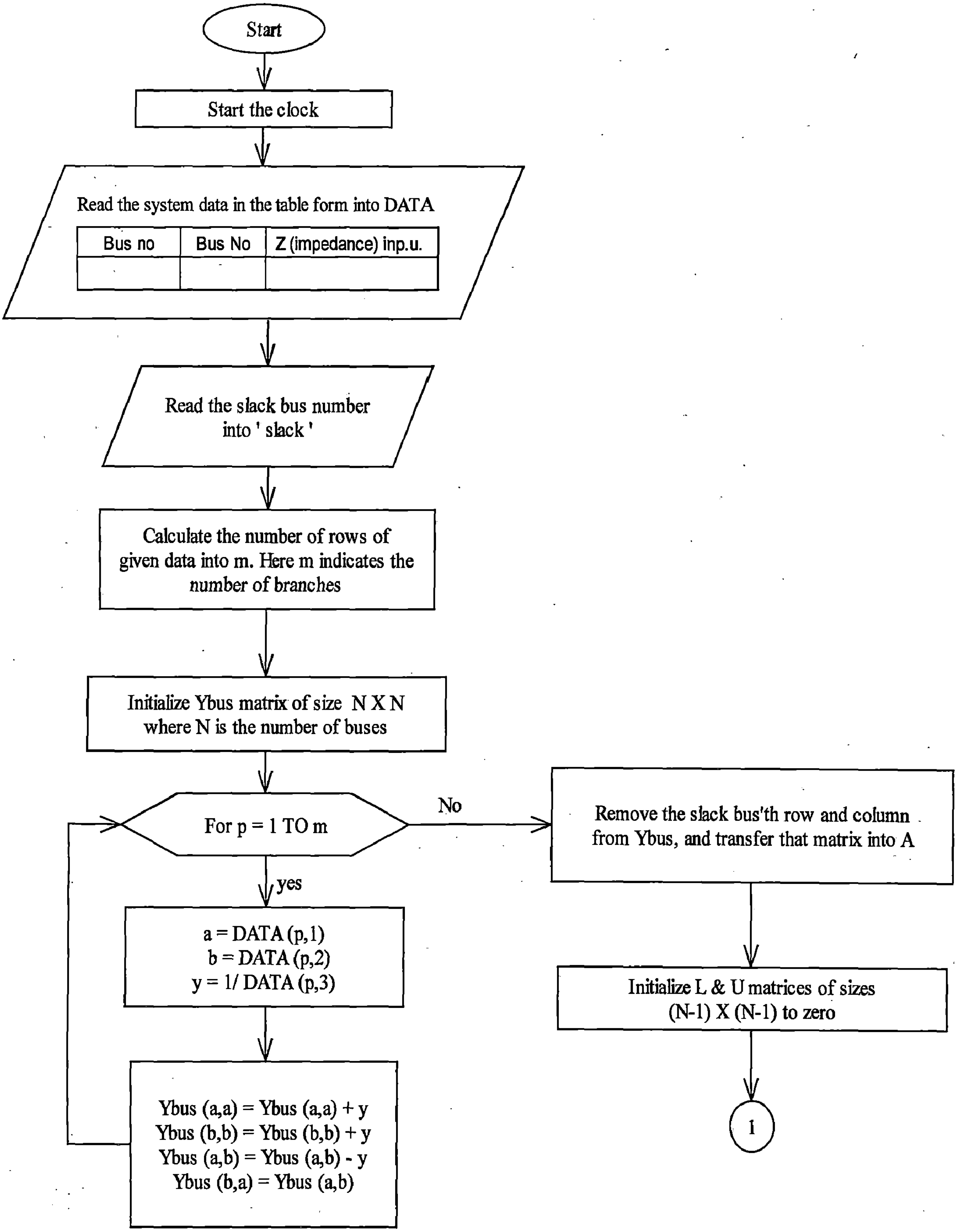
STEP 42: X(m,k) = [Y(m,k) – Sum] / U(m,m) then go to STEP 38

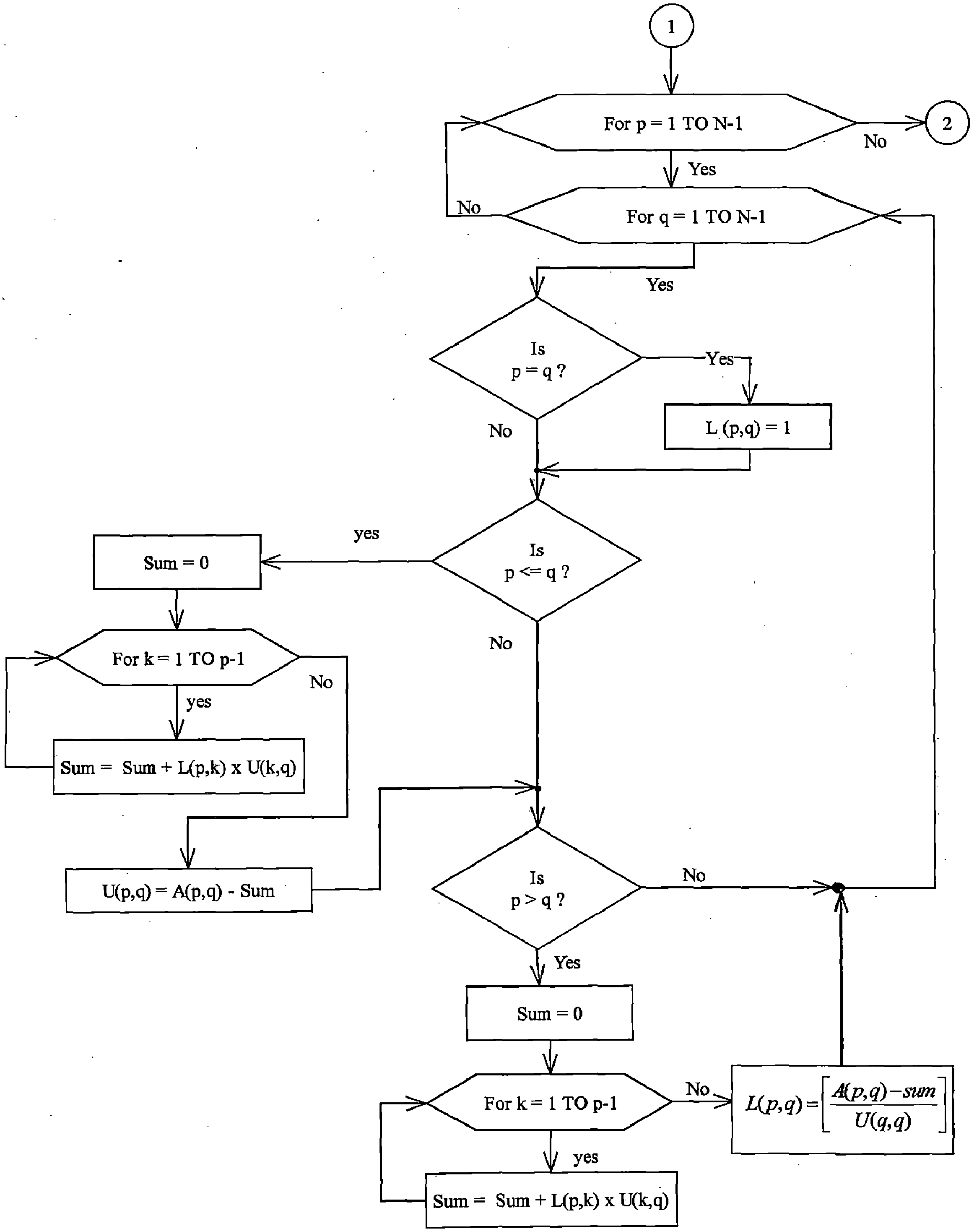
STEP 43: Print X matrix, which is nothing but the Zbus matrix of given DATA

STEP 44: Stop the clock and note down the time of computation

STEP 45: Stop

4.1.2 Flow chart





1
For p = 1 TO N-1
No
2
Yes
No
For q = 1 TO N-1
Yes
Is
p = q ?
Yes
L (p,q) = 1
No
yes
Sum = 0
Is
p <= q ?
No
For k = 1 TO p-1
No
yes
Sum = Sum + L(p,k) x U(k,q)
U(p,q) = A(p,q) - Sum
Is
p > q ?
No
Yes
Sum = 0
For k = 1 TO p-1
No
$L(p,q)=\left[\frac{A(p,q)-sum}{U(q,q)}\right]$
yes
Sum = Sum + L(p,k) x U(k,q)

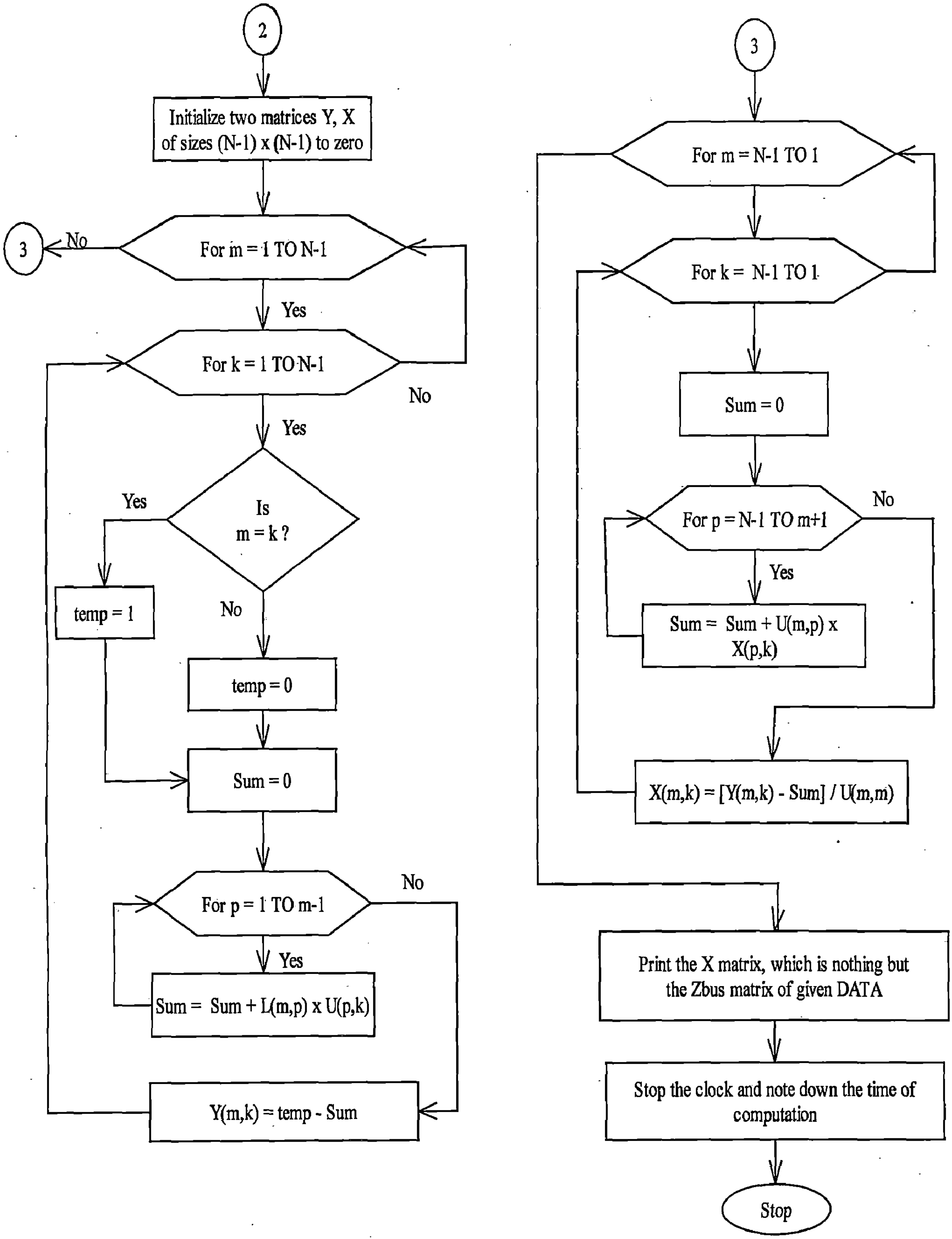


Fig 4.1 Flow chart - Inversion of Ybus matrix method

4.2 Building algorithm method:

Using this algorithm the Impedance Matrix *Zbus* can be build starting with a single element and adding elements one by one till all the elements of the system are included in the Impedance Matrix. During the Zbus construction process, the new element or branch may be connected to two new buses, which are not included into the Zbus. This situation can be avoided by suitable numbering of buses. This is accomplished by consecutively renumbering, from one to N, the bus numbers in the list of busses being processed. A look up table is formed to allow the user to recover the original bus numbers after the Zbus has been formed. This look up table will not have to be addressed at any point in the Zbus building process. Similarly, the optimally ordered bus numbers in the line list are renumbered using the renumbered bus data look up table. The renumbered line list shows that all branch bus numbers increase consecutively from one to N as they are being assembled. Also, the bus numbers of any link being assembled are smaller than the dimension of the matrix at the time when the link is processed. Therefore, the elements of the Zbus matrix may be addressed directly using the bus numbers and loop indices, which run consecutively from one to the dimension of the matrix i.e., N. From now onwards these situations are ignored i.e., the renumbering of the buses has not implemented in this thesis. In this algorithm the elements are added in such a way that first the tree network is formed later the links are included.

4.2.1 Algorithm:

STEP 1: Start

STEP 2: Start the clock

STEP 3: Read the system data in the table form into DATA as

Bus no	Bus no	Z(impedance) in p.u.

STEP 4: Read the slack bus number into 'slack'

STEP 5: Read the number of buses and branches into nbus and nbr respectively

STEP 6: Initialize the Zbus and a variable tree to zero

STEP 7: For I = 1 TO nbr, if yes continue otherwise go to STEP 15

STEP 8: ntree(I) = 1

STEP 9: if ith row of DATA contains slack bus, continue else go to STEP 7

STEP 10: copy the other bus number which is linked to the slack bus in to n

STEP 11: if Zbus(n,n) = 0 continue, else go to STEP 13

STEP 12: calculate Zbus(n,n) = ZB (I) and tree = tree + 1, go to STEP 14

STEP 13: calculate $Zbus(n,n) = \dfrac{Zbus(n,n) \text{ x } ZB(I)}{Zbus(n,n) + ZB(I)}$

STEP 14: ntree(I) = 2 and then go to STEP 7

STEP 15: while tree < nbus, if yes continue else go to STEP 27

STEP 16: for n= 1 TO nbus if yes continue else go to STEP 15

STEP 17: nadd = 1

STEP 18: if Zbus(n,n) =0 continue else go to STEP 16

STEP 19: for I = 1 TO nbr, if yes continue else go to STEP 18

STEP 20: if nadd = 1, if yes continue else go to STEP 19

STEP 21: if Ith row of DATA contains bus n, continue else go to STEP 19

STEP 22: copy the other bus number which is linked to the bus n in to k

STEP 23: if Zbus (k,k) is not equal to zero, continue else go to STEP 19

STEP 24: duplicate the k th row and k th column of Zbus into n th row and n th column of Zbus except the diagonal element i.e., Zbus (n,n)

STEP 25: Zbus(n,n) = Zbus(k,k) + ZB(I) ; tree = tree + 1; nadd = 2; ntree (I) = 2

STEP 26: Go to STEP 19

STEP 27: for n = 1 TO nbus, if yes continue else go to STEP 40

STEP 28: for I = 1 to nbr, if yes continue else go to STEP 27

STEP 29: if ntree(I) = 1, continue else go to STEP 28

STEP 30: if I th row of DATA contains slack bus, continue else go to STEP 28

STEP 31: copy the other bus number which is linked to the slack bus in to n

STEP 32: DM = Zbus(n,n) + Zbus(k,k) + ZB(I) - 2 * Zbus(n,k)

STEP 33: for jj = 1 TO nbus , if yes continue else go to STEP 38

STEP 34: AP = Zbus (jj,n) - Zbus(jj,k)

STEP 35: for kk = 1to nbus, if yes continue else go to STEP 33

STEP 36: AT = Zbus(n,kk) - Zbus(k,kk)

STEP 37: DELZ(jj,kk) = AP*AT/DM and then go to STEP 35

STEP 38: calculate the matrix subtraction Zbus = Zbus – DELZ

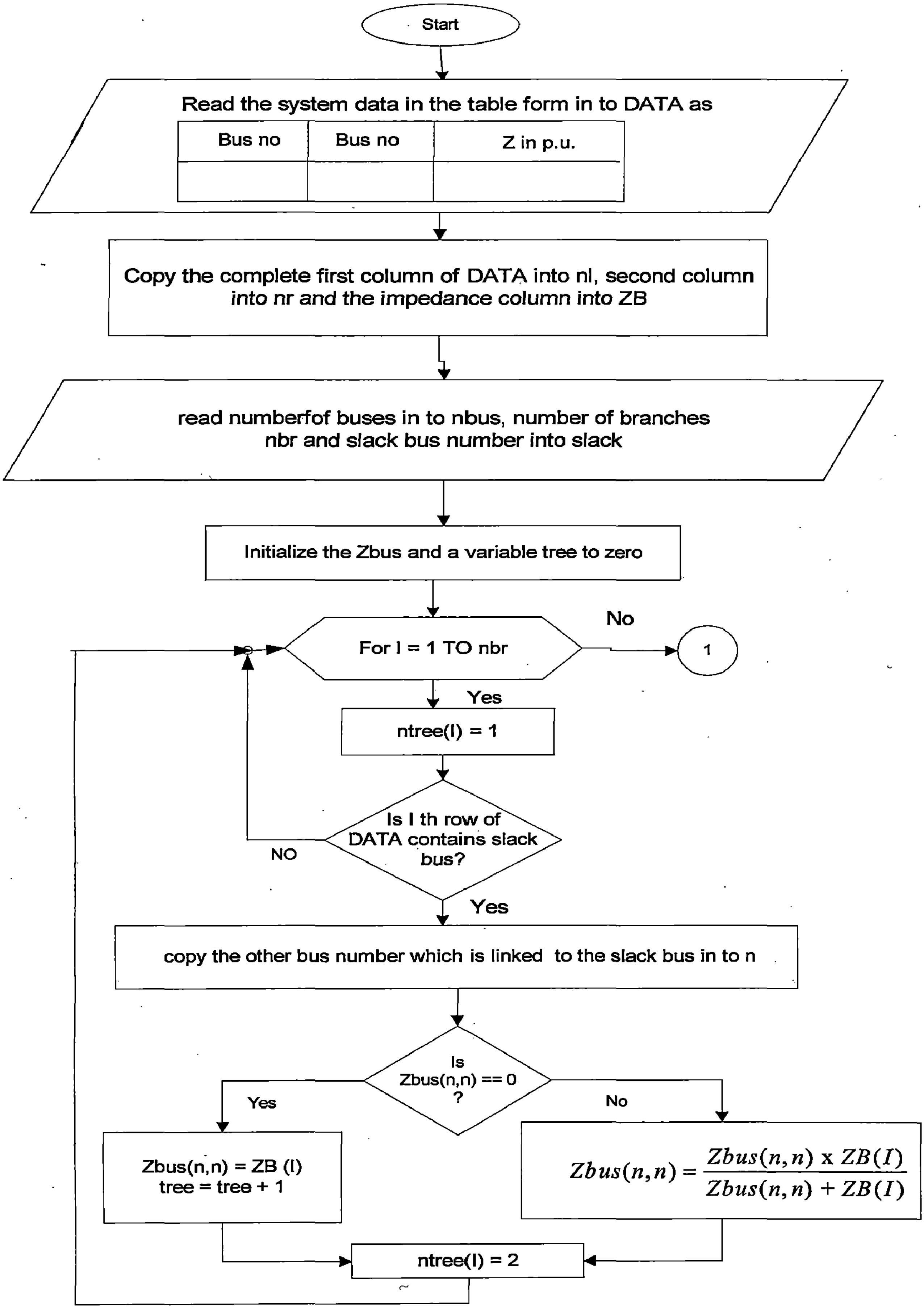
STEP 39: ntree (I) = 2 and then go to 28

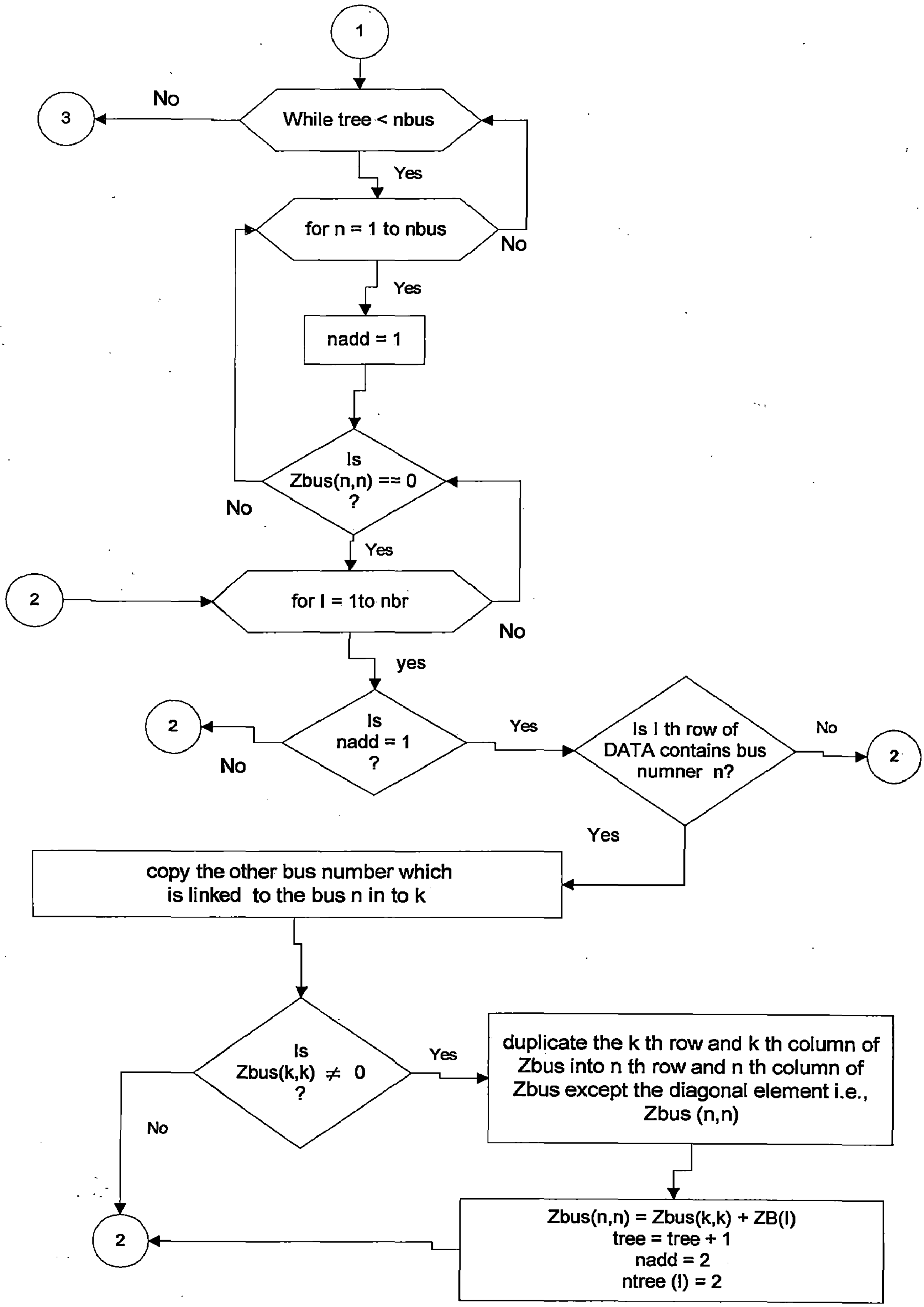
STEP 40: Print the Zbus matrix

STEP 41: stop the clock and note down the reading

STEP 42: stop

4.2.2 Flow chart




1
While tree < nbus
No
3
Yes
for n = 1 to nbus
No
Yes
nadd = 1
Is
Zbus(n,n) == 0
?
No
Yes
2
for l = 1to nbr
No
yes
2
Is
nadd = 1
?
No
Yes
Is l th row of
DATA contains bus
numner n?
No
2
Yes
copy the other bus number which
is linked to the bus n in to k
Is
Zbus(k,k) ≠ 0
?
Yes
duplicate the k th row and k th column of
Zbus into n th row and n th column of
Zbus except the diagonal element i.e.,
Zbus (n,n)
No
2
Zbus(n,n) = Zbus(k,k) + ZB(l)
tree = tree + 1
nadd = 2
ntree (l) = 2

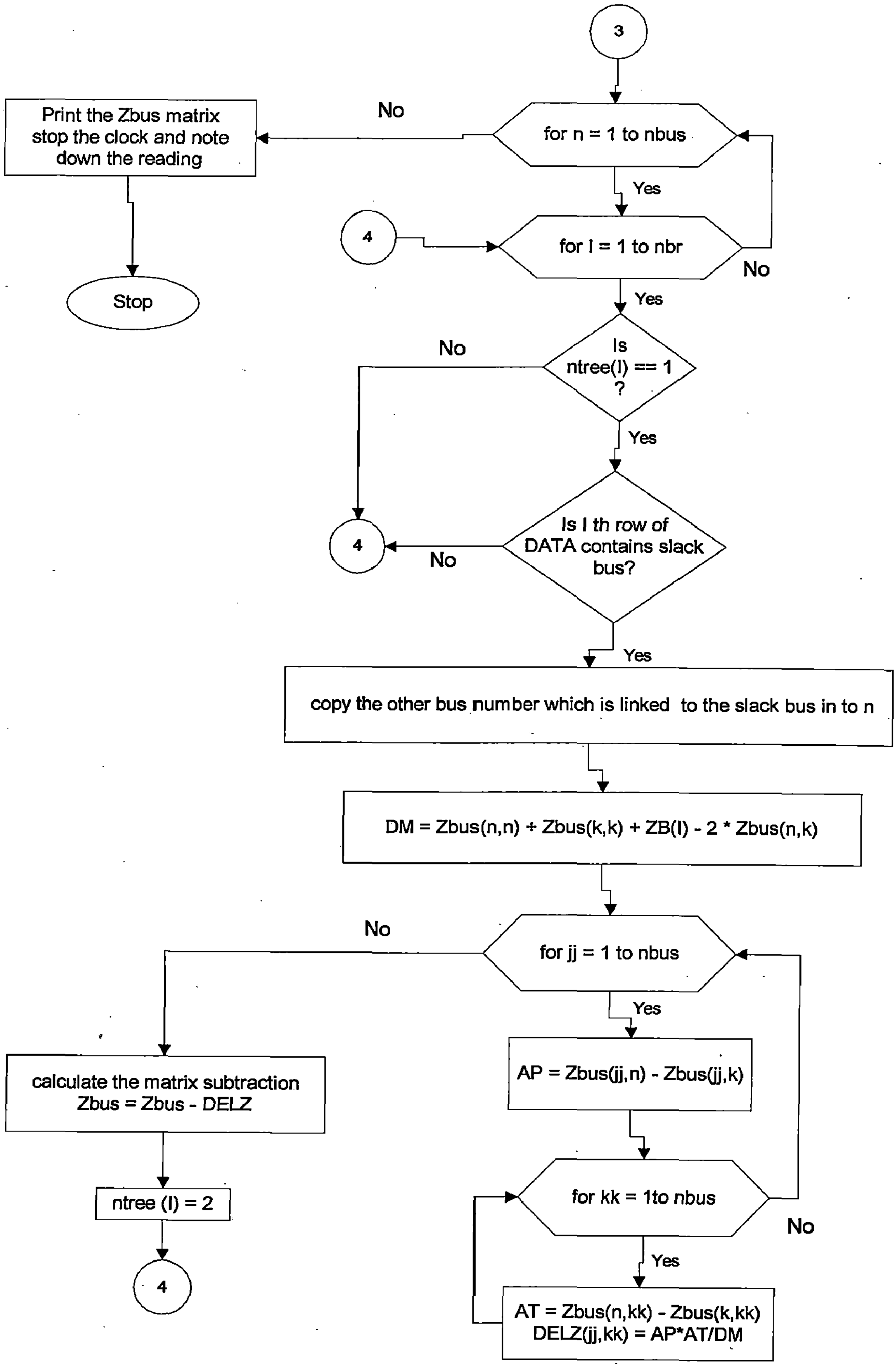


Fig 4.2: Flow Chart – Building algorithm method

4.3 Inspection method

According to this method the given graph is to be converted into a extended tree network. The tree network may contain more number of nodes than the given graph. Initially tree starts with slack bus. Sequential search is performed on the given input DATA. The links are converted into tree nodes by dividing into two nodes as discussed in sections 3.3 and 3.4. In this section the algorithm and flow chart of the method 3, explained in the section 3.3 is implemented.

4.3.1 Algorithm

STEP 1: Start

STEP 2: Start the clock

STEP 3: Read the system data in the table form into DATA as

Bus no	Bus no	Z(impedance) in p.u.

STEP 4: Initialize the matrices CN, temp, MDATA, extra and Zbus of sizes 1 x N, m x 1, (m+1) x 3, (m - N +1) x 2 and (m + 1) x (m + 1) respectively to zeros where N and m represents the number of buses and number of lines

STEP 5: read slack bus number into slack and set
MDATA (slack,1) = 1
CN (slack = 1)
q = 0
checking = 1

STEP 6: while checking = 1, if yes continue, else go to STEP 19

STEP 7: checking = 0

STEP 8: for p = 1 TO m, if yes continue, else go to STEP 6

STEP 9: x = DATA(p,1)
y = DATA(p,2)
Zn = DATA(p,3)

STEP 10: if (CN(x) = 1 and CN(y) = 0) continue else go to STEP 12

STEP 11: MDATA (y,1) = y

MDATA(y,2) = x

MDATA(y,3) = Zn

temp (p) = 1

CN (y) =1 then go to STEP 8

STEP 12: if (CN(x) = 0 and CN(y) = 1) continue else go to STEP 14

STEP 13: MDATA (x,1) = x

MDATA(x,2) = y

MDATA(x,3) = Zn

temp (p) = 1

CN (x) =1 then go to STEP 8

STEP 14: if (CN(x) = 0 and CN(y) = 0) continue else go to STEP 16

STEP 15: checking = 1 and then go to STEP 8

STEP 16: if (CN(x) = 1 and CN(y) = 1) continue else go to STEP 8

STEP 17: if temp(p) = 1, continue else go to STEP 8

STEP 18: q = q +1

MDATA (q + N , 1) = q + N

MDATA (q + N , 2) = x

MDATA (q + N , 3) = Zn

extra (q,1) = q + N

extra (q,2) = y

temp (p) = 1 go to STEP 8

STEP 19: for p = 1 TO m+1, if yes continue else go to STEP 38

STEP 20: for q = 1 TO m+1, if yes continue else go to STEP 19

STEP 21: if p=q continue, else go to STEP 26

STEP 22: set x = q and sum = 0

STEP 23: while (x ≠ slack), if yes continue else go to STEP 25

STEP 24: sum = sum + MDATA(x,3)

x = MDATA(x,2) go to STEP 23

STEP 25: Zbus (p,q) = sum then go to STEP 20

STEP 26: Set y = p, x = q and sum =0

STEP 27: While (y ≠ x), if yes continue else go to STEP 32

STEP 28: If (x = slack) continue else go to STEP 31

STEP 29: x = q and y = MDATA (y,2)

STEP 30: if y = slack go to STEP 32 else go to STEP 27

STEP 31: x = MDATA(x,2) then go to STEP 27

STEP 32: sum = 0

STEP 33: if Zbus (x,y) = 0, continue else go to STEP 36

STEP 34: while ($x \neq$ slack), if yes continue else go to STEP 37

STEP 35: sum = sum + MDATA(x,3)

x = MDATA(x,2) then go to STEP 34

STEP 36: sum = Zbus(x,y)

STEP 37: Zbus(p,q) = sum then go to STEP 20

STEP 38: for p = 1 TO m – N +1, if yes continue then go to STEP

STEP 39: set x = extra(p,1) and y = extra(p,2)

STEP 40: Subtract the x th row from y th row of Zbus matrix and replace the xth row of Zbus matrix with this result

STEP 41: Subtract the x th column from y th column of Zbus matrix and replace the x th column of Zbus matrix with this result. Then go to STEP 38

STEP 42: Remove the slack bus th row and slack bus th column from Zbus

STEP 43: Set A = Zbus (1 to N-1, 1 to N-1)

B = Zbus (1 to N-1, N to m)

C = Zbus (N to m, N to m)

D = transpose (B)

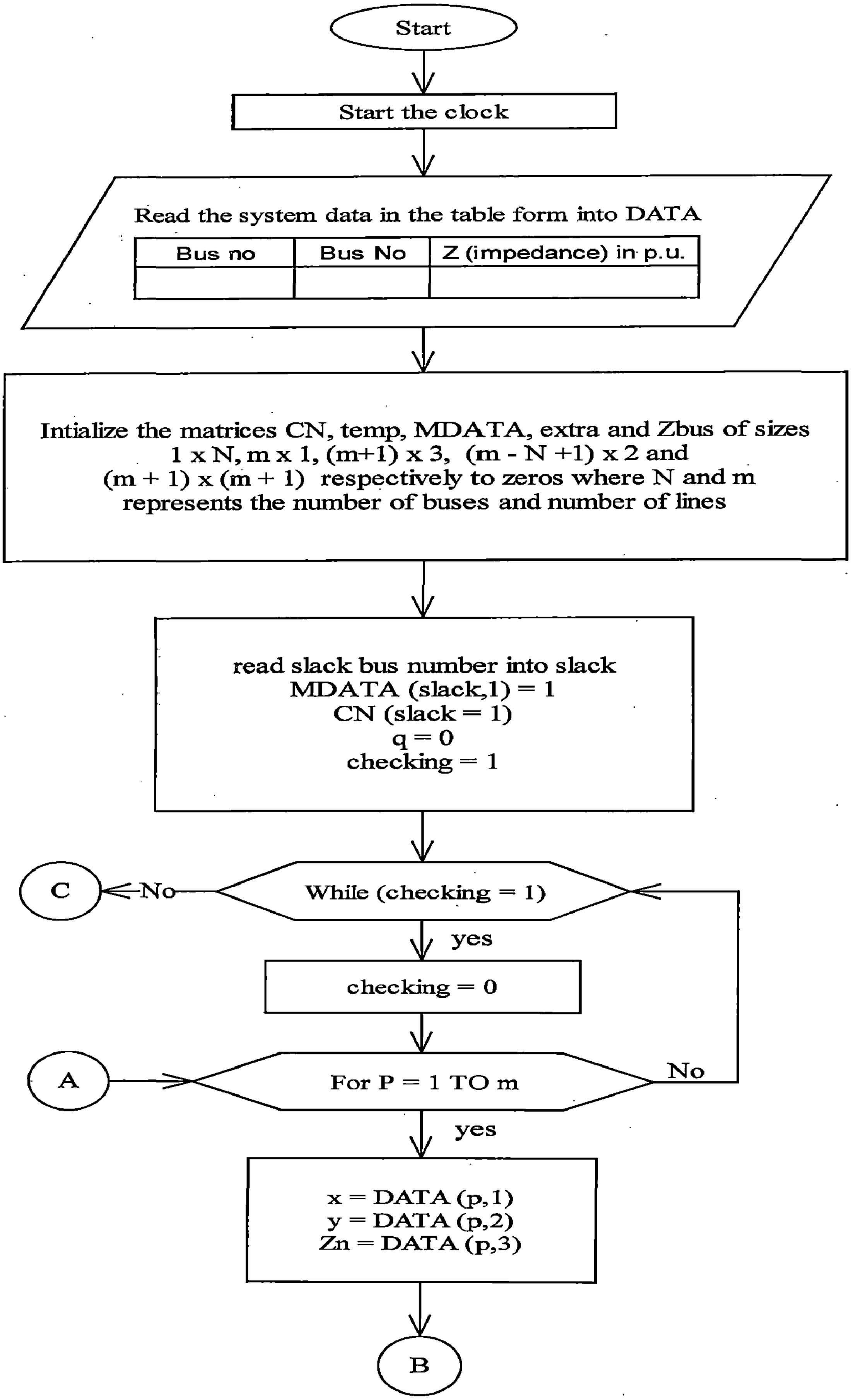
STEP 44: Compute the matrix inversion of C using L-U factorization method and copy the result into matrix X

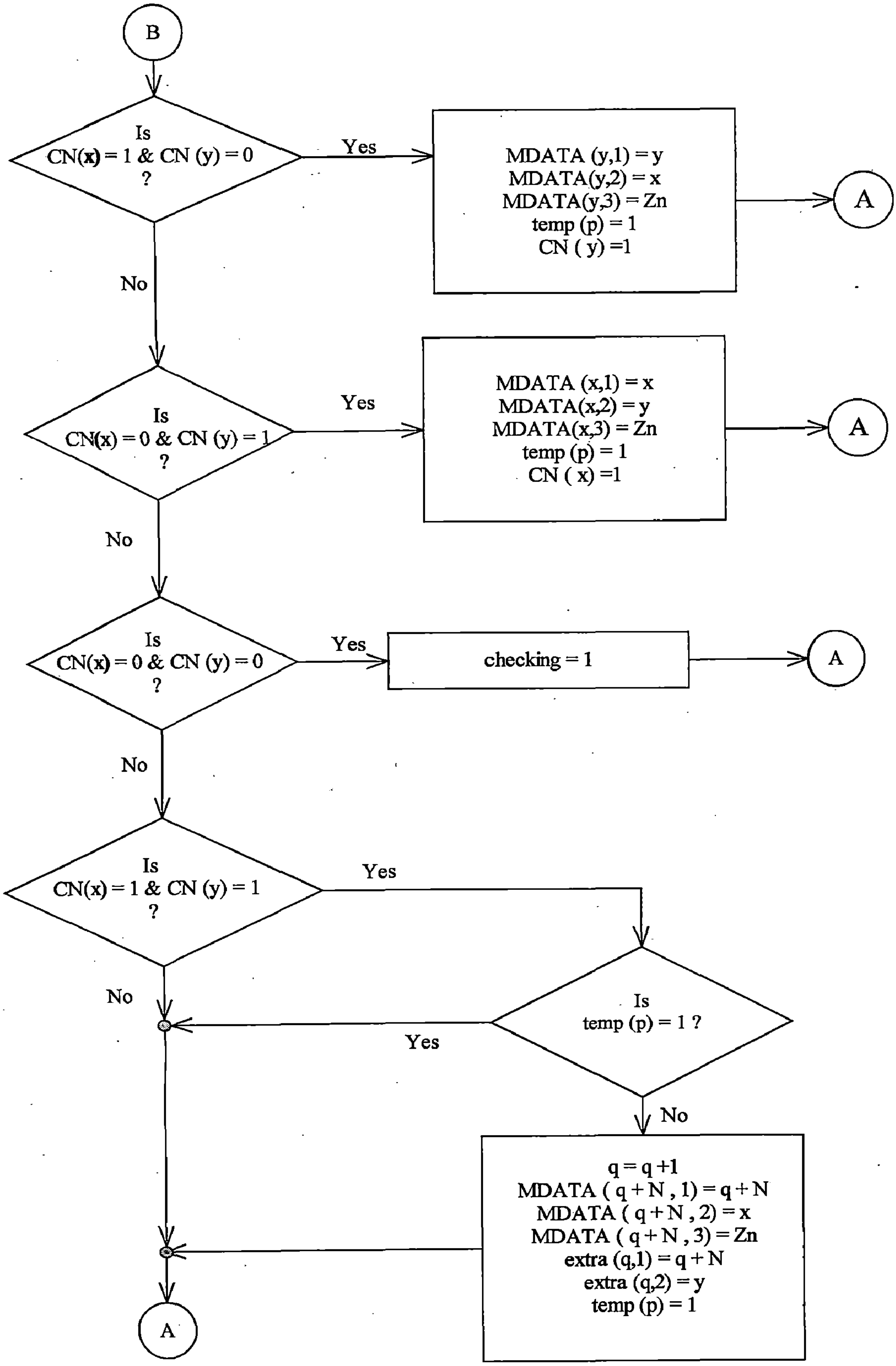
STEP 45: Compute Zbus = A - B*X*D and Print the Zbus matrix

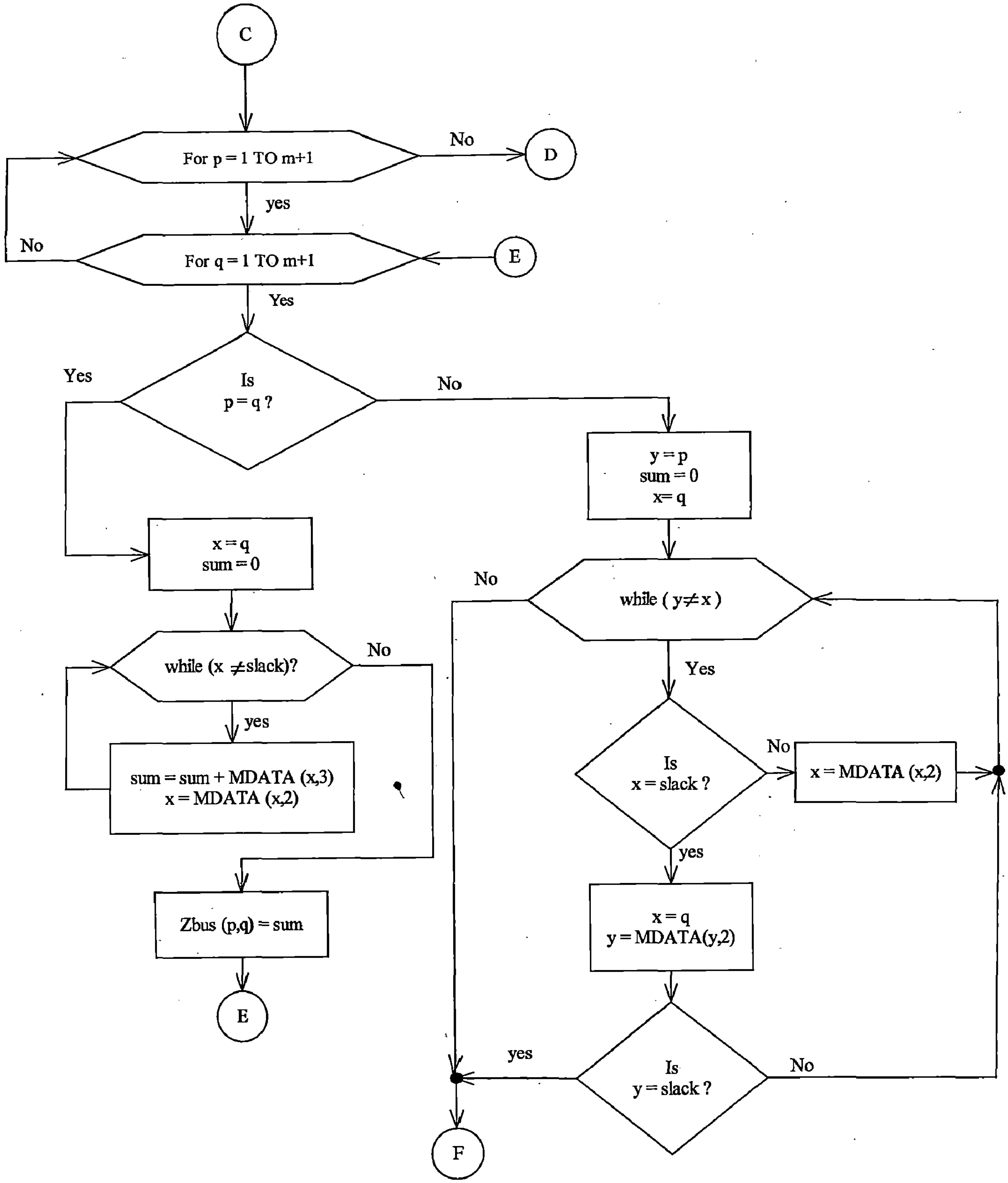
STEP 46: stop the clock and note down the time of computation

STEP 47: Stop

4.3.2 Flow Chart




B
Is
CN(x) = 1 & CN (y) = 0
?
Yes
MDATA (y,1) = y
MDATA(y,2) = x
MDATA(y,3) = Zn
temp (p) = 1
CN (y) =1
A
No
Is
CN(x) = 0 & CN (y) = 1
?
Yes
MDATA (x,1) = x
MDATA(x,2) = y
MDATA(x,3) = Zn
temp (p) = 1
CN (x) =1
A
No
Is
CN(x) = 0 & CN (y) = 0
?
Yes
checking = 1
A
No
Is
CN(x) = 1 & CN (y) = 1
?
Yes
No
Is
temp (p) = 1 ?
Yes
No
q = q +1
MDATA (q + N , 1) = q + N
MDATA (q + N , 2) = x
MDATA (q + N , 3) = Zn
extra (q,1) = q + N
extra (q,2) = y
temp (p) = 1
A


C
For p = 1 TO m+1
No
D
yes
No
For q = 1 TO m+1
E
Yes
Yes
Is
p = q ?
No
y = p
sum = 0
x= q
x = q
sum = 0
No
while (y≠x)
while (x ≠slack)?
No
Yes
yes
sum = sum + MDATA (x,3)
x = MDATA (x,2)
Is
x = slack ?
No
x = MDATA (x,2)
yes
Zbus (p,q) = sum
x = q
y = MDATA(y,2)
E
yes
Is
y = slack ?
No
F

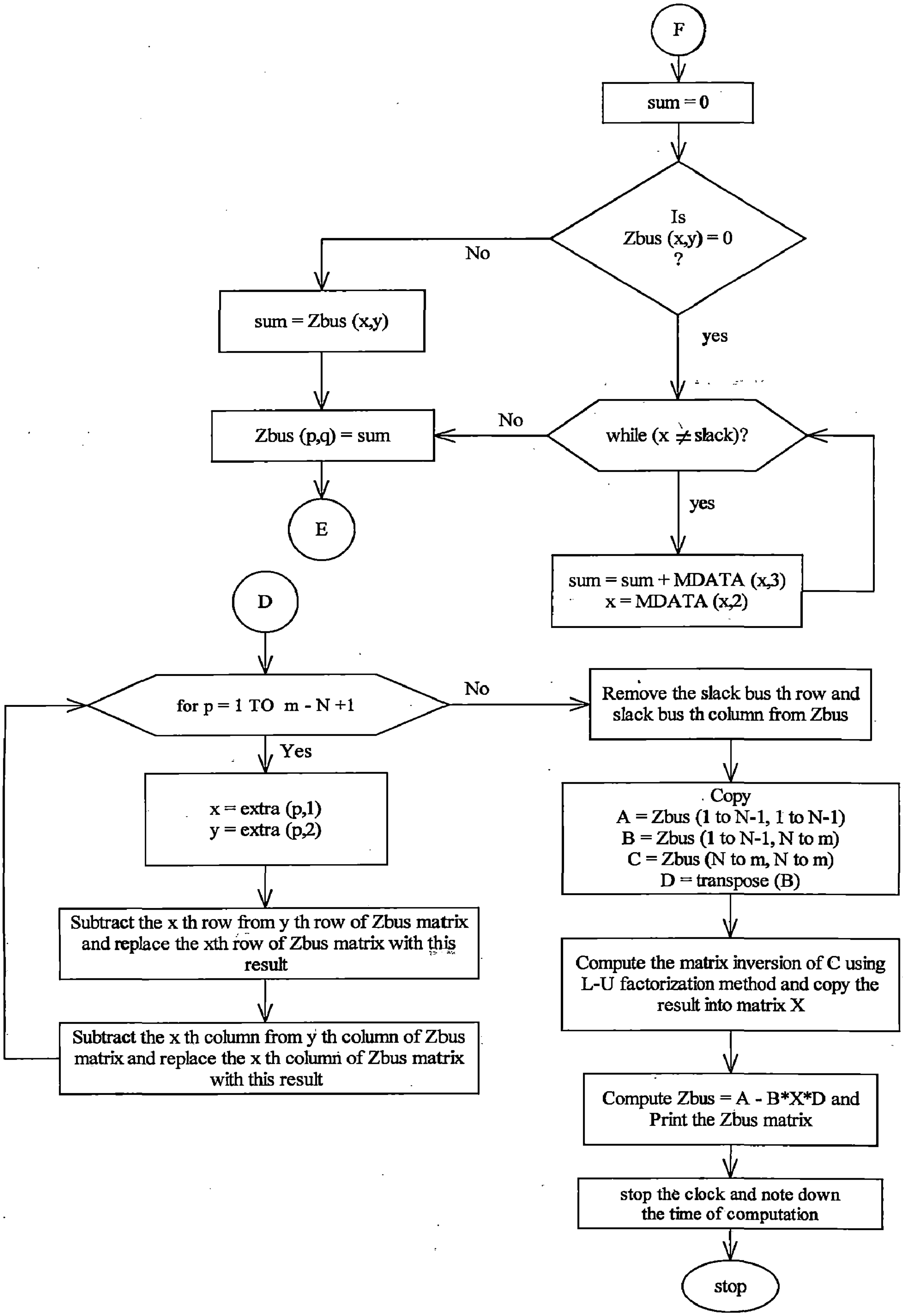


Fig 4.3 Flow Chart – Inspection method

5. RESULTS

This Chapter is intended to validate and verify the proposed approach. Results of different IEEE test systems (IEEE 14, 30, 39, 57, 118 and 300 bus test systems) are provided in this chapter to validate the overall proposed method. The system data used is provided in the Appendices. Appendices A and B provide information on the IEEE 39 and 300 bus systems, respectively. Moreover, analysis and results of a detailed Zbus matrix formation of IEEE 39 and IEEE 300 bus systems are also provided.

In this method the following assumptions have been made:

- The slack bus number should not be zero
- The injected currents at different buses will flow towards the slack bus only i.e., the slack bus voltage magnitude is low
- The power system is balanced so that single line per unit diagram of the system can be used.
- The shunt admittance and the transformer tapping effects are ignored
- The mutual coupling effects are ignored.

5.1 Test System: IEEE 39 - bus System [19]

The 39-bus system is a standard system for testing new methods. It represents a greatly reduced model of the power system in New England. It has been used by numerous researchers to study both static and dynamic problems in power systems. The 39-bus system has 10 generators, 19 loads, 36 transmission lines and 12 transformers.

The single line diagram for IEEE 39 bus is shown in Figure 5.1. The bus data and the branch data for the IEEE 39 bus system were obtained from [19]. This data is the input data for the Zbus matrix formation. Each bus is assigned a type, which corresponds to a slack bus, a PV bus or a load bus. A slack bus is denoted by number '3' a PV bus is denoted by '2' and a load bus is denoted by '1' (as shown in Appendix A). The branch and the generator data for this system are given in Appendix A.

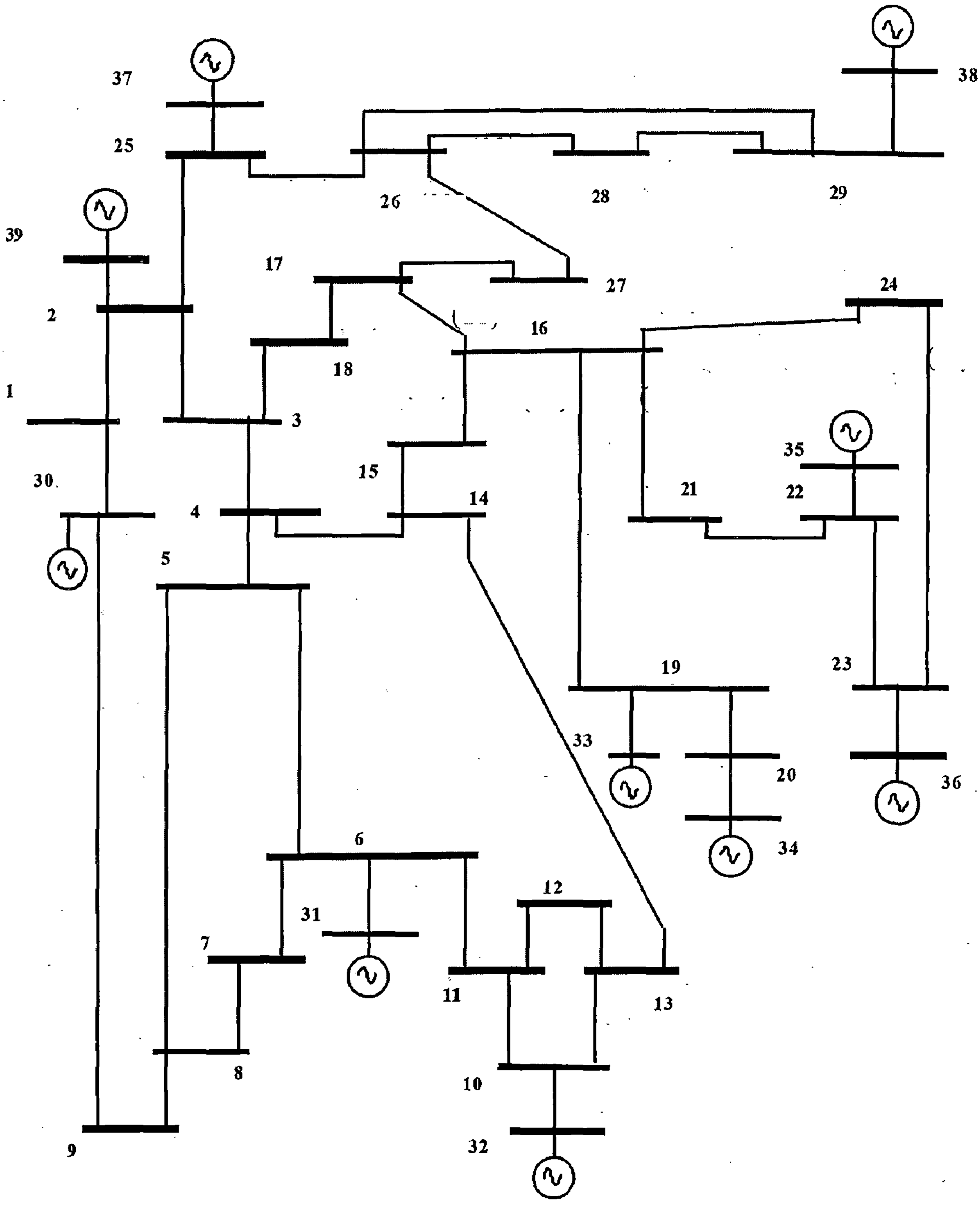


Fig 5.1 Single line diagram of IEEE-39 bus system

The times of computation of Zbus matrix formation for the IEEE 39 bus test system, by inversion of Ybus matrix, Building algorithm method and the proposed inspection method are 1.1253 sec, 0.1641 sec and 0.89 sec respectively. The maximum absolute error between Ybus inversion method & inspection method and building algorithm method & inspection method are (0.27 + 1.9 i) x 1e-16 Ω and (0.02 - 0.048 i) x 1e-16 Ω respectively. It can be concluded that the proposed method is accurate but inferior to the other available methods for the case of IEEE 39 bus test system.

5.2 Test System: IEEE 300 - bus System [20]: The IEEE 300 bus test case was initially developed by the IEEE Test Systems Task Force in 1993 based on data from a northeast power pool. The particular data set used in this analysis is available from the University of Washington Power System Test Case archive. The site http://www.ee.washington.edu/research/pstca/ provides World Wide Web access to power system data (test cases) and is maintained by Richard D. Christie, a Professor (christie@ee.washintington.edu) at the University of Washington, Seattle, Washington, USA. The system consists of three connected regions as depicted in Figure 5.2 with 69 generators, 51 regulating transformers and 411 transmission elements.

The site http://pw.elec.kitami-it.ac.jp/ueda/demo/WebPF/testdata.html provides World Wide Web access to renumbered system branch data of IEEE 300 bus system. This data is the input data for the Zbus matrix formation. Each bus is assigned a type, which corresponds to a slack bus, a PV bus or a load bus. A slack bus is denoted by number 'BS,' a PV bus is denoted by 'BV' and a load bus is denoted by 'BQ' (as shown in Appendix B). The branch data and the generator data for this system are given in Appendix B. The scanned IEEE 300 bus system single line diagram is given in fig 5.2.

The times of computation of Zbus matrix formation for the IEEE 300 bus test system, by inversion of Ybus matrix, Building algorithm method and the proposed inspection method are 517.189 sec, 795.0122 sec and 98.34856 sec respectively. The maximum absolute error between Ybus inversion method & inspection method and building algorithm method & inspection method are (-3.05 –

10.8 i) x 1e-16 Ω and (4.37 + 14.1 i) x 1e-16 Ω respectively. It can be concluded that the proposed method is accurate and superior to the other available methods for the case of IEEE 300 bus test system. The times of computations and maximum absolute errors for the IEEE 14, 30, 39, 57, 118, and 300 systems are shown in Table 5.1 and Table 5.2 respectively.

Table 5.1 Times of computation of impedance matrix for IEEE 14,30,39,57,118 and 300 bus systems

Model	Building Algorithm Method	Inspection method	Inversion of Ybus method
IEEE 14	0.0802	0.3049	0.4163
IEEE 30	0.1499	0.7776	0.6362
IEEE 39	0.1641	0.8900	1.1253
IEEE 57	0.4000	3.3423	2.9770
IEEE 118	15.6564	12.014	29.812
IEEE 300	795.0122	98.34856	517.189

Table 5.2 Maximum errors of impedance matrixes formed by different methods for IEEE 14, 30, 39, 57, 118 and 300 bus systems

Model	Building algorithm method and Inspection method (X 1e-16 ohm)	Ybus Inversion method and Inspection method (X 1e-16 ohm)
IEEE 14	0 + 1.66i	0.83 + 4.44i
IEEE 30	-2.1 + 6.9i	- 1.6 - 5.5i
IEEE 39	0.02 - 0.048i	0.27 + 1.9i
IEEE 57	33 + 207i	33 - 206i
IEEE 118	-0.14 – 8.3i	-3.05 – 10.8i
IEEE 300	4.37 + 14.1i	-6.52 – 94.9i

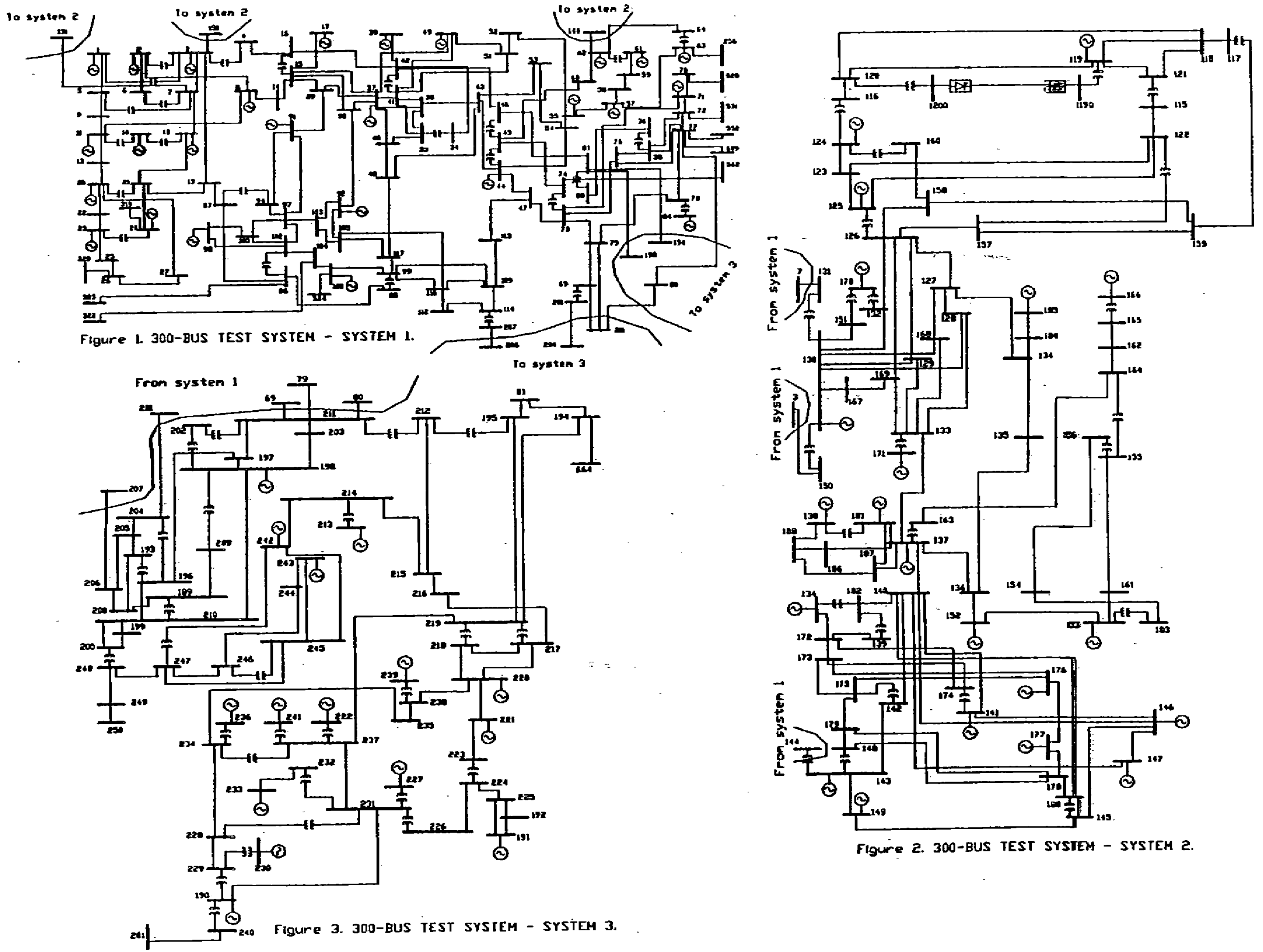


Fig 5.2 Scanned IEEE 300 bus test system diagram

The comparison between the times of computation of impedance matrix by Inversion Ybus method – Inspection method and Building algorithm method – Inspection method is shown in Table 5.3. It can be concluded that the proposed method is 8 times faster than traditional building algorithm and 5.26 times faster than inversion of bus admittance matrix method for the IEEE 300 bus test system.

Table 5.3 Comparison between the times of computations of impedance matrix

Model	Building algorithm method and Inspection method	Ybus Inversion method and Inspection method
IEEE 14	1 : 3.8	1.365 : 1
IEEE 30	1: 5.2	1 : 1.222
IEEE 39	1 : 5.4	1.26 : 1
IEEE 57	1 : 8.35	1 : 1.12
IEEE 118	1.3 : 1	2.5 : 1
IEEE 300	8 : 1	5.26 : 1

The diagrammatic representation of the times of computations of Zbus by different methods is shown in fig 5.3.

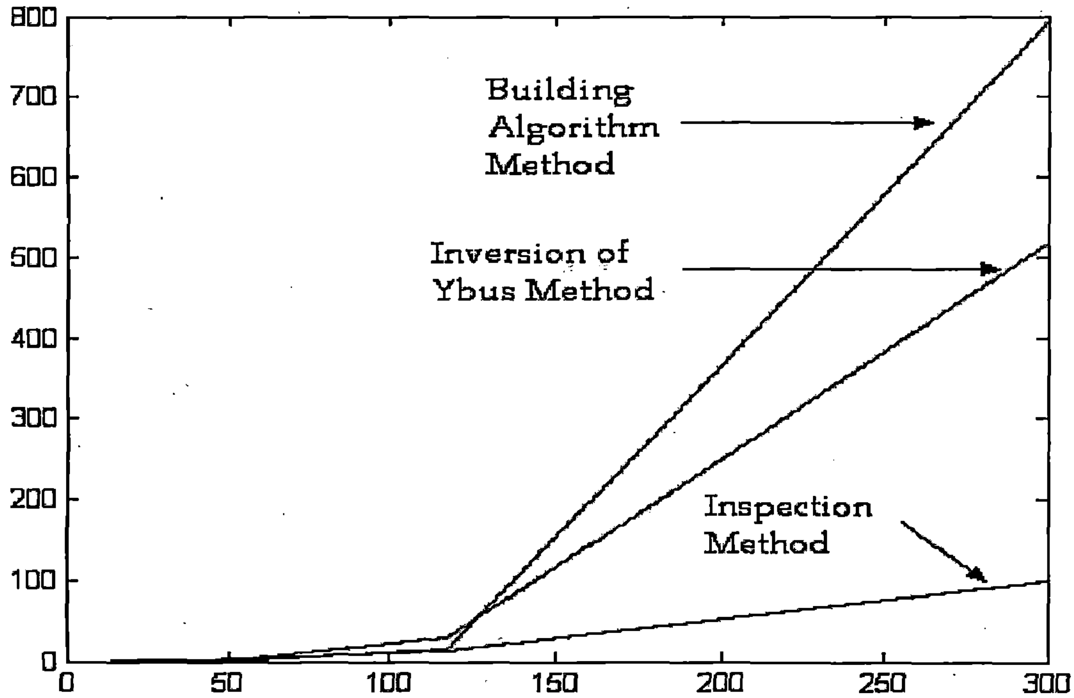


Fig 5.3 Relation showing Time of Computations Vs size of the system of different methods.

The overall benefits offered by each of this approach are summarized as follows:

- Higher speed can be achieved in forming the Bus impedance matrix for larger power systems.
- Accuracy has been improved
- In general the shunt elements are ignored in forming the Zbus. But in this method the Shunt elements can be included to improve the accuracy.

The drawbacks of this approach are summarized as follows:

- This method is particularly suited for large power systems only. The results have proved that this method is not suitable for smaller power systems
- When the network undergoes changes, the modification procedure is difficult. At this situation, normal building algorithm method should be used i.e., addition of new link between two existing buses should be used.

From the above analysis it can concluded that the proposed inspection method is superior to the other available methods for the cases of large power systems and inferior to the other methods for smaller power systems. Since the mathematical computations are less in the inspection method, it can be concluded that the proposed inspection method is accurate compared to the other methods.

6. CONCLUSIONS AND FUTURE STUDIES

A new inspection method has been presented in this dissertation work to form the Bus impedance matrix. The algorithm, flow charts and philosophy of this method have been discussed. The accuracy of this method has been verified by comparing the results with the results of the conventional methods i.e., inversion of admittance matrix method and the normal building algorithm method, for different IEEE test systems. The results of IEEE 30 bus system and the IEEE 300 bus systems have been analyzed. The results have proved that the newly developed inspection method can be applied to large power systems.

The overall benefits offered by each of this approach are summarized as follows:

- This method is simple method
- Higher speed can be achieved in forming the Bus impedance matrix for larger power systems.
- Accuracy has been improved
- In general the shunt elements are ignored in forming the Zbus. But in this method the Shunt elements can be included to improve the accuracy.
- Mutual couple lines can be included in the Zbus formation at ease.

The drawbacks of this approach are summarized as follows:

- This method is particularly suited for large power systems only. The results have proved that this method is not suitable for smaller power systems
- When the network undergoes changes, the modification procedure is difficult. At this situation, normal building algorithm method should be used i.e., addition of new link between two existing buses should be used.

This algorithm is particularly suited for personal computers because it does not form and invert the full network primitive impedance matrix. Instead, as each mutually coupled line is processed the primitive admittance matrix for that line is computed, thus reducing. Since the amount of memory required by this algorithm is less.

To form the impedance matrix, by the proposed inspection method, the first step is to select the tree network from the given graph data. If this first step is removed, by giving the tree network data and links or interconnections data separately; much more speed in forming the bus impedance matrix can be achieved. Hence the proposed method can be used for the practical power systems.

Future Studies

The inspection method developed in this dissertation work, is limited to large system data only. It is recommended, in future studies on bus impedance matrix by inspection method, that developed algorithm will be suitable for all types of systems. One most important aspect of research is the inclusion of mutual coupling effects in the zero sequence network. In this dissertation work the mutual coupling effects are not included. The development of an algorithm in which the mutual coupling effects are included, is recommended.

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APPENDIX – A

SYSTEM DATA – IEEE 39 BUS SYSTEM [19]

This section is intended to provide system data for the IEEE 39-bus system that is used in this document to validate the proposed approach. The IEEE 39 Bus test system is shown in Figure 5.1 (chapter 5). The system data for this system is provided in Tables A.1 and Table A.2. Bus 31 is the slack bus.

Bus type:

1: PQ bus or load bus

2: PV bus or generator bus

3: Swing bus or slack bus

Pg, Qg: Generation; Pd, Qd: Load and Gsh, Bsh: Shunt G & B

Table A.1 Bus Data

Bus No	*Type*	*Voltage (p.u.)*	Pg	Qg	Pd	Qd
1	1	1.0467	0.0	0.0	0.0	0.0
2	1	1.0467	0.0	0.0	0.0	0.0
3	1	1.025	0.0	0.0	322	2.4
4	1	0.9925	0.0	0.0	500	184
5	1	0.9889	0.0	0.0	0.0	0.0
6	1	0.9902	0.0	0.0	0.0	0.0
7	1	0.9807	0.0	0.0	233.8	84
8	1	0.9804	0.0	0.0	522	176
9	1	1.0217	0.0	0.0	0.0	0.0
10	1	1.0063	0.0	0.0	0.0	0.0
11	1	0.9996	0.0	0.0	0.0	0.0
12	1	0.9879	0.0	0.0	8.5	88
13	1	1.0036	0.0	0.0	0.0	0.0
14	1	1.0019	0.0	0.0	0.0	0.0
15	1	1.0103	0.0	0.0	320	153
16	1	1.0287	0.0	0.0	329	32.3
17	1	1.0302	0.0	0.0	0.0	0.0
18	1	1.0269	0.0	0.0	158	30
19	1	1.0487	0.0	0.0	0.0	0.0
20	1	0.9902	0.0	0.0	680	103
21	1	1.0296	0.0	0.0	274	115
22	1	1.0487	0.0	0.0	0.0	0.0
23	1	1.0436	0.0	0.0	247.5	84.6
24	1	1.0345	0.0	0.0	308.6	-92.2
25	1	1.0558	0.0	0.0	224	47.2
26	1	1.05	0.0	0.0	139	17

Bus No	*Type*	*Voltage (p.u.)*	Pg	Qg	Pd	Qd
27	1	1.035	0.0	0.0	281	75.5
28	1	1.0491	0.0	0.0	206	27.6
29	1	1.0492	0.0	0.0	283.5	26.9
30	2	1.0475	250	157.73	0.0	0.0
31	3	0.9386	573.61	99.99	9.2	4.6
32	2	0.9831	650	255.57	0.0	0.0
33	2	0.9972	632	117.44	0.0	0.0
34	2	1.0123	508	170.93	0.0	0.0
35	2	1.0493	650	220.66	0.0	0.0
36	2	1.0635	560	105.85	0.0	0.0
37	2	1.0278	540	8.14	0.0	0.0
38	2	1.0265	830	27.55	0.0	0.0
39	2	1.03	1000	117.67	1104	250

Table A.2: Branch data

S. No	Bus	Bus	R (p.u.)	X (p.u.)	G (p.u.)	B (p.u.)	Tap
1	2	1	0.0035	0.0411	0	0.6987	1
2	39	1	0.001	0.025	0	0.75	1
3	3	2	0.0013	0.0151	0	0.2572	1
4	25	2	0.007	0.0086	0	0.146	1
5	4	3	0.0013	0.0213	0	0.2214	1
6	18	3	0.0011	0.0133	0	0.2138	1
7	5	4	0.0008	0.0128	0	0.1342	1
8	14	4	0.0008	0.0129	0	0.1382	1
9	6	5	0.0002	0.0026	0	0.0434	1
10	8	5	0.0008	0.0112	0	0.1476	1
11	7	6	0.0006	0.0092	0	0.113	1
12	11	6	0.0007	0.0082	0	0.1389	1
13	8	7	0.0004	0.0046	0	0.078	1
14	9	8	0.0023	0.0363	0	0.3804	1
15	39	9	0.001	0.025	0	1.2	1
16	11	10	0.0004	0.0043	0	0.0729	1
17	13	10	0.0004	0.0043	0	0.0729	1
18	14	13	0.0009	0.0101	0	0.1723	1
19	15	14	0.0018	0.0217	0	0.366	1
20	16	15	0.0009	0.0094	0	0.171	1
21	17	16	0.0007	0.0089	0	0.1342	1
22	19	16	0.0016	0.0195	0	0.304	1
23	21	16	0.0008	0.0135	0	0.2548	1
24	24	16	0.0003	0.0059	0	0.068	1
25	18	17	0.0007	0.0082	0	0.1319	1
26	27	17	0.0013	0.0173	0	0.3216	1
27	22	21	0.0008	0.014	0	0.2565	1
28	23	22	0.0006	0.0096	0	0.1846	1
29	24	23	0.0022	0.035	0	0.361	1
30	26	25	0.0032	0.0323	0	0.513	1
31	27	26	0.0014	0.0147	0	0.2396	1
32	28	26	0.0043	0.0474	0	0.7802	1

S. No	Bus	Bus	R (p.u.)	X (p.u.)	G (p.u.)	B(p.u)	Tap
33	29	26	0.0057	0.0625	0	1.029	1
34	29	28	0.0014	0.0151	0	0.249	1
35	12	11	0.0016	0.0435	0	0	1.006
36	12	13	0.0016	0.0435	0	0	1.006
37	6	31	0	0.025	0	0	1.07
38	10	32	0	0.02	0	0	1.07
39	19	33	0.0007	0.0142	0	0	1.07
40	20	34	0.0009	0.018	0	0	1.009
41	22	35	0	0.0143	0	0	1.025
42	23	36	0.0005	0.0272	0	0	1
43	25	37	0.0006	0.0232	0	0	1.025
44	2	30	0	0.0181	0	0	1.025
45	29	38	0.0008	0.0156	0	0	1.025
46	19	20	0.0007	0.0138	0	0	1.06

APPENDIX – B

SYSTEM DATA – IEEE 300 BUS SYSTEM [20]

This section is intended to provide system data for the IEEE 300-bus system that is used throughout the document to validate the proposed approach. The IEEE 300 Bus test system is shown in Figure 5.2 (chapter 5). The data for this system is provided in Tables B.1 and Table B.2. The Slack bus is 257

Bus type:
BQ: PQ bus or load bus
BV: PV bus or generator bus
BS: Swing bus or slack bus
Pg, Qg: Generation;
Pd, Qd: Load and Gsh, Bsh: Shunt G & B

Table B.1 Generator Data

Type	Bus	V	Pg	Qg	Pd	Qd	Gsh	Bsh
BQ	1	1.028	0.000	0.000	0.900	0.490	0.0000	0.0000
BQ	2	1.035	0.000	0.000	0.560	0.150	0.0000	0.0000
BQ	3	0.997	0.000	0.000	0.200	0.000	0.0000	0.0000
BQ	4	1.031	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	5	1.019	0.000	0.000	3.530	1.300	0.0000	0.0000
BQ	6	1.031	0.000	0.000	1.200	0.410	0.0000	0.0000
BQ	7	0.993	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	8	1.015	-0.050	0.000	0.580	0.140	0.0000	0.0000
BQ	9	1.003	0.000	0.000	0.960	0.430	0.0000	0.0000
BV	10	1.020	-0.050	0.000	1.480	0.330	0.0000	0.0000
BQ	11	1.006	0.000	0.000	0.830	0.210	0.0000	0.0000
BQ	12	0.997	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	13	0.998	0.000	0.000	0.580	0.100	0.0000	0.0000
BQ	14	0.999	0.000	0.000	1.600	0.600	0.0000	0.0000
BQ	15	1.034	0.000	0.000	1.267	0.230	0.0000	0.0000

Type	Bus	V	Pg	Qg	Pd	Qd	Gsh	Bsh
BQ	16	1.031	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	17	1.065	0.000	0.000	5.610	2.200	0.0000	0.0000
BQ	18	0.982	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	19	1.001	-0.100	0.000	5.950	1.200	0.0000	0.0000
BQ	20	0.975	0.000	0.000	0.770	0.010	0.0000	0.0000
BQ	21	0.996	0.000	0.000	0.810	0.230	0.0000	0.0000
BQ	22	1.050	0.000	0.000	0.210	0.070	0.0000	0.0000
BQ	23	1.006	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	24	1.023	0.000	0.000	0.450	0.120	0.0000	0.0000
BQ	25	0.999	0.000	0.000	0.280	0.090	0.0000	0.0000
BQ	26	0.975	0.000	0.000	0.690	0.130	0.0000	0.0000
BQ	27	1.024	0.000	0.000	0.550	0.060	0.0000	0.0000
BQ	28	1.041	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	29	0.976	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	30	1.001	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	31	1.020	0.000	0.000	0.850	0.320	0.0000	0.0000
BQ	32	1.020	0.000	0.000	1.550	0.180	0.0000	0.0000
BQ	33	1.054	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	34	1.022	0.000	0.000	0.460	-0.210	0.0000	0.0000
BQ	35	1.029	0.000	0.000	0.860	0.000	0.0000	0.0000
BQ	36	1.045	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	37	1.001	0.000	0.000	0.390	0.090	0.0000	0.0000
BQ	38	1.009	0.000	0.000	1.950	0.290	0.0000	0.0000
BQ	39	1.021	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	40	1.034	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	41	0.978	0.000	0.000	0.580	0.118	0.0000	0.0000
BQ	42	1.002	0.000	0.000	0.410	0.190	0.0000	0.0000
BQ	43	1.048	0.000	0.000	0.920	0.260	0.0000	0.0000
BQ	44	1.025	0.000	0.000	-0.050	0.050	0.0000	0.0000
BQ	45	0.998	0.000	0.000	0.610	0.280	0.0000	0.0000
BQ	46	0.996	0.000	0.000	0.690	0.030	0.0000	0.0000

Type	Bus	V	Pg	Qg	Pd	Qd	Gsh	Bsh
BQ	47	1.005	0.000	0.000	0.100	0.010	0.0000	0.0000
BQ	48	1.015	0.000	0.000	0.220	0.100	0.0000	0.0000
BQ	49	1.033	0.000	0.000	0.980	0.200	0.0000	0.0000
BQ	50	0.992	0.000	0.000	0.140	0.010	0.0000	0.0000
BQ	51	0.979	0.000	0.000	2.180	1.060	0.0000	0.0000
BQ	52	1.025	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	53	0.991	0.000	0.000	2.270	1.100	0.0000	0.0000
BQ	54	1.016	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	55	0.958	0.000	0.000	0.700	0.300	0.0000	0.0000
BQ	56	0.948	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	57	0.963	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	58	0.951	0.000	0.000	0.560	0.200	0.0000	0.0000
BQ	59	0.979	0.000	0.000	1.160	0.380	0.0000	0.0000
BQ	60	0.970	0.000	0.000	0.570	0.190	0.0000	0.0000
BQ	61	0.978	0.000	0.000	2.240	0.710	0.0000	0.0000
BQ	62	0.996	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	63	0.963	0.000	0.000	2.080	1.070	0.0000	0.0000
BQ	64	0.984	0.000	0.000	0.740	0.280	0.0000	0.0000
BQ	65	0.990	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	66	0.982	0.000	0.000	0.480	0.140	0.0000	0.0000
BQ	67	0.987	0.000	0.000	0.280	0.070	0.0000	0.0000
BQ	68	1.034	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	69	1.025	3.750	0.000	0.370	0.130	0.0000	0.0000
BQ	70	0.987	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	71	0.991	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	72	0.992	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	73	1.015	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	74	1.032	0.000	0.000	0.442	0.000	0.0000	0.0000
BQ	75	1.027	0.000	0.000	0.660	0.000	0.0000	0.0000
BV	76	1.052	1.550	0.000	0.174	0.000	0.0000	0.0000
BV	77	1.052	2.900	0.000	0.158	0.000	0.0000	0.0000

Type	Bus	V	Pg	Qg	Pd	Qd	Gsh	Bsh
BQ	78	0.993	0.000	0.000	0.603	0.000	0.0000	0.0000
BQ	79	1.018	0.000	0.000	0.399	0.000	0.0000	0.0000
BV	80	1.000	0.680	0.000	0.667	0.000	0.0000	0.0000
BQ	81	0.989	0.000	0.000	0.835	0.000	0.0000	0.0000
BQ	82	1.006	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	83	1.001	0.000	0.000	0.778	0.000	0.0000	0.0000
BQ	84	1.029	0.000	0.000	0.320	0.000	0.0000	0.0000
BQ	85	0.996	0.000	0.000	0.086	0.000	0.0000	0.0000
BQ	86	1.022	0.000	0.000	0.496	0.000	0.0000	0.0000
BQ	87	1.010	0.000	0.000	0.046	0.000	0.0000	0.0000
BV	88	0.990	1.170	0.000	1.121	0.000	0.0000	0.0000
BQ	89	0.975	0.000	0.000	0.307	0.000	0.0000	0.0000
BQ	90	0.973	0.000	0.000	0.630	0.000	0.0000	0.0000
BQ	91	0.973	0.000	0.000	0.196	0.000	0.0000	0.0000
BQ	92	0.970	0.000	0.000	0.262	0.000	0.0000	0.0000
BQ	93	0.975	0.000	0.000	0.182	0.000	0.0000	0.0000
BQ	94	0.960	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	95	1.025	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	96	0.935	0.000	0.000	0.000	0.000	0.0000	3.2500
BQ	97	0.930	0.000	0.000	0.141	6.500	0.0000	0.0000
BV	98	1.043	19.300	0.000	0.000	0.000	0.0000	0.0000
BQ	99	0.958	0.000	0.000	7.770	2.150	0.0000	0.5500
BQ	100	0.987	0.000	0.000	5.350	0.550	0.0000	0.0000
BQ	101	0.973	0.000	0.000	2.291	0.118	0.0000	0.0000
BQ	102	1.001	0.000	0.000	0.780	0.014	0.0000	0.0000
BV	103	1.023	2.400	0.000	2.764	0.593	0.0000	0.0000
BV	104	1.010	0.000	0.000	5.148	0.827	0.0000	0.0000
BQ	105	0.998	0.000	0.000	0.579	0.051	0.0000	0.0000
BQ	106	1.000	0.000	0.000	3.808	0.370	0.0000	0.0000
BQ	107	1.002	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	108	1.003	0.000	0.000	0.000	0.000	0.0000	0.0000

Type	Bus	V	Pg	Qg	Pd	Qd	Gsh	Bsh
BQ	109	1.019	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	110	0.986	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	111	1.005	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	112	1.002	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	113	1.022	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	114	1.019	0.000	0.000	1.692	0.416	0.0000	0.0000
BQ	115	1.048	0.000	0.000	0.552	0.182	0.0000	0.0000
BQ	116	1.047	0.000	0.000	2.736	0.998	0.0000	0.0000
BV	117	1.055	-1.925	0.000	8.267	1.352	0.0000	0.0000
BQ	118	1.012	0.000	0.000	5.950	0.833	0.0000	0.0000
BQ	119	1.043	0.000	0.000	3.877	1.147	0.0000	0.0000
BV	120	1.051	2.810	0.000	1.450	0.580	0.0000	0.0000
BQ	121	1.015	0.000	0.000	0.565	0.245	0.0000	0.0000
BV	122	1.043	6.960	0.000	0.895	0.355	0.0000	0.0000
BQ	123	1.016	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	124	1.008	0.000	0.000	0.240	0.140	0.0000	0.0000
BV	125	1.053	0.840	0.000	0.000	0.000	0.0000	0.0000
BV	126	1.053	2.170	0.000	0.000	0.000	0.0000	0.0000
BQ	127	1.058	0.000	0.000	0.630	0.250	0.0000	0.0000
BV	128	1.074	1.030	0.000	0.000	0.000	0.0000	0.0000
BQ	129	0.987	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	130	1.005	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	131	1.054	3.720	0.000	0.170	0.090	0.0000	0.0000
BV	132	1.043	2.160	0.000	0.000	0.000	0.0000	0.0000
BQ	133	0.966	0.000	0.000	0.700	0.050	0.0000	0.3450
BQ	134	1.018	0.000	0.000	2.000	0.500	0.0000	0.0000
BV	135	0.963	0.000	0.000	0.750	0.500	0.0000	0.0000
BQ	136	0.984	0.000	0.000	1.235	-0.243	0.0000	0.0000
BQ	137	0.999	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	138	0.987	0.000	0.000	0.330	0.165	0.0000	0.0000
BQ	139	1.000	0.000	0.000	0.000	0.000	0.0000	0.0000

Type	Bus	V	Pg	Qg	Pd	Qd	Gsh	Bsh
BQ	140	1.036	0.000	0.000	0.350	0.150	0.0000	0.0000
BQ	141	0.992	0.000	0.000	0.850	0.240	0.0000	0.0000
BQ	142	1.041	0.000	0.000	0.000	0.004	0.0000	0.0000
BQ	143	0.984	0.000	0.000	0.000	0.000	0.0000	-2.1200
BQ	144	1.000	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	145	0.997	0.000	0.000	0.000	0.000	0.0000	-1.0300
BQ	146	0.971	0.000	0.000	2.999	0.957	0.0000	0.0000
BQ	147	1.002	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	148	0.988	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	149	0.929	2.050	0.000	4.818	2.050	0.0000	0.0000
BV	150	0.983	0.000	0.000	7.636	2.911	0.0000	0.0000
BQ	151	1.024	0.000	0.000	0.265	0.000	0.0000	0.0000
BQ	152	0.984	0.000	0.000	1.635	0.430	0.0000	0.5300
BQ	153	1.062	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	154	0.973	0.000	0.000	1.760	0.830	0.0000	0.0000
BV	155	1.052	2.280	0.000	0.050	0.040	0.0000	0.0000
BV	156	1.008	0.840	0.000	0.280	0.120	0.0000	0.0000
BQ	157	0.940	0.000	0.000	4.274	1.736	0.0000	0.0000
BQ	158	0.970	0.000	0.000	0.740	0.290	0.0000	0.4500
BQ	159	0.979	0.000	0.000	0.695	0.493	0.0000	0.0000
BQ	160	1.052	0.000	0.000	0.734	0.000	0.0000	0.0000
BQ	161	1.045	0.000	0.000	2.407	0.890	0.0000	0.0000
BQ	162	0.972	0.000	0.000	0.400	0.040	0.0000	0.0000
BQ	163	1.039	0.000	0.000	1.368	0.166	0.0000	0.0000
BV	164	1.052	2.000	0.000	0.000	0.000	0.0000	0.0000
BV	165	1.065	12.000	0.000	0.598	0.243	0.0000	0.0000
BV	166	1.065	12.000	0.000	0.598	0.243	0.0000	0.0000
BQ	167	1.053	0.000	0.000	1.826	0.436	0.0000	0.0000
BQ	168	0.998	0.000	0.000	0.070	0.020	0.0000	0.0000
BV	169	1.055	4.750	0.000	0.000	0.000	0.0000	-1.5000
BV	170	1.043	19.730	0.000	4.890	0.530	0.0000	0.0000

Type	Bus	V	Pg	Qg	Pd	Qd	Gsh	Bsh
BQ	171	0.937	0.000	0.000	8.000	0.720	0.0000	0.0000
BQ	172	0.990	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	173	1.049	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	174	1.036	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	175	0.970	0.000	0.000	0.100	0.030	0.0000	0.0000
BQ	176	0.991	0.000	0.000	0.430	0.140	0.0000	0.0000
BV	177	1.015	4.240	0.000	0.640	0.210	0.0000	0.0000
BQ	178	0.953	0.000	0.000	0.350	0.120	0.0000	0.0000
BQ	179	0.955	0.000	0.000	0.270	0.120	0.0000	0.0000
BQ	180	0.969	0.000	0.000	0.410	0.140	0.0000	0.0000
BQ	181	0.991	0.000	0.000	0.380	0.130	0.0000	0.0000
BQ	182	1.003	0.000	0.000	0.420	0.140	0.0000	0.0000
BQ	183	0.972	0.000	0.000	0.720	0.240	0.0000	0.0000
BQ	184	0.984	0.000	0.000	0.000	-0.050	0.0000	0.0000
BQ	185	0.999	0.000	0.000	0.120	0.020	0.0000	0.0000
BQ	186	1.014	0.000	0.000	-0.210	-0.142	0.0000	0.0000
BQ	187	0.993	0.000	0.000	0.070	0.020	0.0000	0.0000
BQ	188	1.000	0.000	0.000	0.380	0.130	0.0000	0.0000
BQ	189	0.979	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	190	1.002	0.000	0.000	0.960	0.070	0.0000	0.0000
BQ	191	1.013	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	192	1.010	2.720	0.000	0.000	0.000	0.0000	0.0000
BQ	193	0.992	0.000	0.000	0.220	0.160	0.0000	0.0000
BQ	194	0.987	0.000	0.000	0.470	0.260	0.0000	0.0000
BQ	195	0.975	0.000	0.000	1.760	1.050	0.0000	0.0000
BQ	196	1.021	0.000	0.000	1.000	0.750	0.0000	0.0000
BQ	197	1.008	0.000	0.000	1.310	0.960	0.0000	0.0000
BQ	198	1.055	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	199	1.008	1.000	0.000	2.850	1.000	0.0000	0.0000
BV	200	1.000	4.500	0.000	1.710	0.700	0.0000	0.0000
BV	201	1.050	2.500	0.000	3.280	1.880	0.0000	0.0000
BQ	202	0.997	0.000	0.000	4.280	2.320	0.0000	0.0000

Type	Bus	V	Pg	Qg	Pd	Qd	Gsh	Bsh
BQ	203	1.000	0.000	0.000	1.730	0.990	0.0000	0.0000
BQ	204	0.945	0.000	0.000	4.100	0.400	0.0000	0.0000
BQ	205	1.018	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	206	1.000	3.030	0.000	5.380	3.690	0.0000	0.0000
BQ	207	1.042	0.000	0.000	2.230	1.480	0.0000	0.0000
BQ	208	1.050	0.000	0.000	0.960	0.460	0.0000	0.0000
BV	209	1.040	3.450	0.000	0.000	0.000	0.0000	0.0000
BQ	210	1.054	0.000	0.000	1.590	1.070	0.0000	-3.0000
BQ	211	1.041	0.000	0.000	4.480	1.430	0.0000	0.0000
BV	212	1.000	3.000	0.000	4.040	2.120	0.0000	0.0000
BQ	213	1.039	0.000	0.000	5.720	2.440	0.0000	0.0000
BQ	214	1.010	0.000	0.000	2.690	1.570	0.0000	0.0000
BV	215	1.016	6.000	0.000	0.000	0.000	0.0000	0.0000
BQ	216	1.056	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	217	1.010	2.500	0.000	2.550	1.490	0.0000	-1.5000
BV	218	1.000	5.500	0.000	0.000	0.000	0.0000	0.0000
BQ	219	1.024	0.000	0.000	0.000	0.000	0.0000	-1.4000
BV	220	1.050	5.754	0.000	0.000	0.000	0.0000	0.0000
BV	221	0.993	1.700	0.000	0.000	0.000	0.0000	0.0000
BV	222	1.010	0.840	0.000	0.080	0.030	0.0000	0.0000
BQ	223	0.992	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	224	0.971	0.000	0.000	0.610	0.300	0.0000	0.0000
BQ	225	0.965	0.000	0.000	0.770	0.330	0.0000	0.0000
BQ	226	0.969	0.000	0.000	0.610	0.300	0.0000	0.0000
BQ	227	0.976	0.000	0.000	0.290	0.140	0.0000	0.4560
BQ	228	0.975	0.000	0.000	0.290	0.140	0.0000	0.0000
BQ	229	1.020	0.000	0.000	-0.230	-0.170	0.0000	0.0000
BQ	230	1.025	0.000	0.000	-0.331	-0.294	0.0000	0.0000
BQ	231	1.015	0.000	0.000	1.158	-0.240	0.0000	0.0000
BQ	232	1.015	0.000	0.000	0.024	-0.126	0.0000	0.0000
BQ	233	1.000	0.000	0.000	0.024	-0.039	0.0000	0.0000
BQ	234	0.981	0.000	0.000	-0.149	0.265	0.0000	0.0000

Type	Bus	V	Pg	Qg	Pd	Qd	Gsh	Bsh
BQ	235	0.975	0.000	0.000	0.247	-0.012	0.0000	0.0000
BQ	236	0.943	0.000	0.000	1.453	-0.349	0.0000	0.0000
BQ	237	0.972	0.000	0.000	0.281	-0.205	0.0000	0.0000
BQ	238	0.960	0.000	0.000	0.140	0.025	0.0000	0.0000
BQ	239	1.001	0.000	0.000	-0.111	-0.014	0.0000	0.0000
BQ	240	0.978	0.000	0.000	0.505	0.174	0.0000	0.0000
BQ	241	0.958	0.000	0.000	0.296	0.006	0.0000	0.0000
BQ	242	1.031	0.000	0.000	-1.137	0.767	0.0000	0.0000
BQ	243	1.013	0.000	0.000	1.003	0.292	0.0000	0.0000
BQ	244	1.024	0.000	0.000	-1.000	0.342	0.0000	0.0000
BQ	245	1.012	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	246	0.965	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	247	1.051	4.670	0.000	0.000	0.000	0.0000	0.0000
BV	248	1.051	6.230	0.000	0.000	0.000	0.0000	0.0000
BV	249	1.032	12.100	0.000	0.000	0.000	0.0000	0.0000
BV	250	1.015	2.340	0.000	0.000	0.000	0.0000	0.0000
BV	251	1.051	3.720	0.000	0.000	0.000	0.0000	0.0000
BV	252	1.051	3.300	0.000	0.000	0.000	0.0000	0.0000
BV	253	1.051	1.850	0.000	0.000	0.000	0.0000	0.0000
BV	254	1.029	4.100	0.000	0.000	0.000	0.0000	0.0000
BV	255	1.050	5.000	0.000	0.000	0.000	0.0000	0.0000
BV	256	1.015	0.370	0.000	0.000	0.000	0.0000	0.0000
BS	257	1.051	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	258	0.997	0.450	0.000	0.000	0.000	0.0000	0.0000
BV	259	1.021	1.650	0.000	0.000	0.000	0.0000	0.0000
BV	260	1.015	4.000	0.000	0.000	0.000	0.0000	0.0000
BV	261	1.002	4.000	0.000	0.000	0.000	0.0000	0.0000
BV	262	0.989	1.160	0.000	0.000	0.000	0.0000	0.0000
BV	263	1.051	12.920	0.000	0.000	0.000	0.0000	0.0000
BV	264	1.051	7.000	0.000	0.000	0.000	0.0000	0.0000
BV	265	1.015	5.530	0.000	0.000	0.000	0.0000	0.0000
BQ	266	1.012	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	267	0.994	-0.042	0.000	0.000	0.000	0.0000	0.0000

Type	Bus	V	Pg	Qg	Pd	Qd	Gsh	Bsh
BQ	268	0.983	0.000	0.000	0.027	0.009	0.0014	0.0240
BQ	269	0.977	0.000	0.000	0.009	0.003	0.0000	0.0000
BQ	270	1.012	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	271	1.003	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	272	0.991	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	273	1.002	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	274	0.989	0.000	0.000	0.048	0.016	0.0000	0.0000
BQ	275	0.965	0.000	0.000	0.015	0.005	0.0008	0.0000
BQ	276	0.975	0.000	0.000	0.000	0.000	0.0000	0.0000
BQ	277	0.971	0.000	0.000	0.014	0.005	0.0007	0.0000
BQ	278	0.965	0.000	0.000	0.004	0.002	0.0002	0.0000
BQ	279	0.966	0.000	0.000	0.004	0.002	0.0002	0.0000
BQ	280	0.932	0.000	0.000	0.018	0.006	0.0010	0.0000
BQ	281	0.944	0.000	0.000	0.014	0.005	0.0007	0.0000
BQ	282	0.929	0.000	0.000	0.019	0.006	0.0010	0.0000
BQ	283	0.997	0.000	0.000	0.015	0.005	0.0008	0.0172
BQ	284	0.951	0.000	0.000	0.017	0.006	0.0009	0.0000
BQ	285	0.960	0.000	0.000	0.030	0.010	0.0000	0.0000
BQ	286	0.957	0.000	0.000	0.019	0.006	0.0010	0.0000
BQ	287	0.939	0.000	0.000	0.026	0.009	0.0014	0.0000
BQ	288	0.964	0.000	0.000	0.010	0.003	0.0005	0.0000
BQ	289	0.950	0.000	0.000	0.008	0.003	0.0004	0.0000
BQ	290	0.965	0.000	0.000	0.016	0.005	0.0000	0.0000
BQ	291	0.979	0.000	0.000	0.000	0.000	0.0000	0.0000
BV	292	1.000	-0.358	0.000	0.000	0.000	0.0000	0.0000
BQ	293	0.979	0.000	0.000	0.300	0.230	0.0000	0.0000
BV	294	1.000	-0.265	0.000	0.000	0.000	0.0000	0.0000
BV	295	1.000	0.500	0.000	0.000	0.000	0.0000	0.0000
BV	296	1.000	0.080	0.000	0.000	0.000	0.0000	0.0000
BQ	297	0.975	0.000	0.000	0.010	0.003	0.0005	0.0000
BQ	298	0.980	0.000	0.000	0.010	0.003	0.0005	0.0000
BQ	299	0.980	0.000	0.000	0.038	0.013	0.0000	0.0000
BQ	300	1.040	0.000	0.000	0.012	0.004	0.0010	0.0000

Table B.2 Branch Data (Base Values 100 MVA , 100 KV)

S.No	Bus	Bus	R	X	G	B	Tap
1	257	266	0.00006	0.00046	0.0000	0.0000	1.008
2	266	270	0.00080	0.00348	0.0000	0.0000	1.000
3	266	271	0.02439	0.43682	0.0000	0.0000	0.967
4	266	273	0.03624	0.64898	0.0000	0.0000	0.980
5	270	292	0.01578	0.37486	0.0000	0.0000	1.043
6	270	293	0.01578	0.37486	0.0000	0.0000	0.939
7	270	294	0.01602	0.38046	0.0000	0.0000	1.043
8	270	295	0.00000	0.15200	0.0000	0.0000	1.043
9	270	296	0.00000	0.80000	0.0000	0.0000	1.043
10	271	272	0.05558	0.24666	0.0000	0.0000	1.000
11	271	268	0.05559	0.24666	0.0000	0.0000	1.000
12	273	267	0.03811	0.21643	0.0000	0.0000	1.000
13	267	274	0.05370	0.07026	0.0000	0.0000	1.000
14	274	276	1.10680	0.95278	0.0000	0.0000	1.000
15	274	275	0.44364	2.81520	0.0000	0.0000	1.000
16	267	277	0.50748	3.22020	0.0000	0.0000	1.000
17	276	278	0.66688	3.94400	0.0000	0.0000	1.000
18	276	279	0.61130	3.61520	0.0000	0.0000	1.000
19	272	297	0.44120	2.96680	0.0000	0.0000	1.000
20	272	298	0.30792	2.05700	0.0000	0.0000	1.000
21	272	268	0.05580	0.24666	0.0000	0.0000	1.000
22	268	280	0.73633	4.67240	0.0000	0.0000	1.000
23	268	281	0.76978	4.88460	0.0000	0.0000	1.000
24	268	282	0.75732	4.80560	0.0000	0.0000	1.000
25	268	291	0.07378	0.06352	0.0000	0.0000	1.000
26	291	269	0.03832	0.02894	0.0000	0.0000	1.000
27	269	288	0.36614	2.45600	0.0000	0.0000	1.000
28	269	289	1.05930	5.45360	0.0000	0.0000	1.000
29	269	290	0.15670	1.69940	0.0000	0.0000	1.000
30	268	283	0.13006	1.39120	0.0000	0.0000	1.000
31	268	284	0.54484	3.45720	0.0000	0.0000	1.000
32	268	285	0.15426	1.67290	0.0000	0.0000	1.000

S.No	Bus	Bus	R	X	G	B	Tap
33	268	286	0.38490	2.57120	0.0000	0.0000	1.000
34	268	287	0.44120	2.96680	0.0000	0.0000	1.000
35	273	299	0.23552	0.99036	0.0000	0.0000	1.000
36	294	300	0.00000	0.75000	0.0000	0.0000	0.958
37	1	5	0.00100	0.00600	0.0000	0.0000	1.000
38	2	6	0.00100	0.00900	0.0000	0.0000	1.000
39	2	8	0.00600	0.02700	0.0000	0.0540	1.000
40	3	7	0.00000	0.00300	0.0000	0.0000	1.000
41	3	18	0.00800	0.06900	0.0000	0.1390	1.000
42	3	129	0.00100	0.00700	0.0000	0.0000	1.000
43	4	16	0.00200	0.01900	0.0000	1.1270	1.000
44	5	9	0.00600	0.02900	0.0000	0.0180	1.000
45	7	12	0.00100	0.00900	0.0000	0.0700	1.000
46	7	110	0.00100	0.00700	0.0000	0.0140	1.000
47	8	11	0.01300	0.05950	0.0000	0.0330	1.000
48	8	14	0.01300	0.04200	0.0000	0.0810	1.000
49	9	11	0.00600	0.02700	0.0000	0.0130	1.000
50	11	13	0.00800	0.03400	0.0000	0.0180	1.000
51	12	20	0.00200	0.01500	0.0000	0.1180	1.000
52	13	19	0.00600	0.03400	0.0000	0.0160	1.000
53	14	15	0.01400	0.04200	0.0000	0.0970	1.000
54	15	31	0.06500	0.24800	0.0000	0.1210	1.000
55	15	74	0.09900	0.24800	0.0000	0.0350	1.000
56	15	75	0.09600	0.36300	0.0000	0.0480	1.000
57	16	36	0.00200	0.02200	0.0000	1.2800	1.000
58	18	20	0.00200	0.01800	0.0000	0.0360	1.000
59	18	72	0.01300	0.08000	0.0000	0.1510	1.000
60	19	21	0.01600	0.03300	0.0000	0.0150	1.000
61	19	26	0.06900	0.18600	0.0000	0.0980	1.000
62	20	23	0.00400	0.03400	0.0000	0.2800	1.000
63	21	22	0.05200	0.11100	0.0000	0.0500	1.000
64	22	24	0.01900	0.03900	0.0000	0.0180	1.000
65	23	231	0.00700	0.06800	0.0000	0.1340	1.000

S.No	Bus	Bus	R	X	G	B	Tap
66	24	25	0.03600	0.07100	0.0000	0.0340	1.000
67	25	26	0.04500	0.12000	0.0000	0.0650	1.000
68	25	232	0.04300	0.13000	0.0000	0.0140	1.000
69	27	28	0.00000	0.06300	0.0000	0.0000	1.000
70	27	32	0.00250	0.01200	0.0000	0.0130	1.000
71	27	34	0.00600	0.02900	0.0000	0.0200	1.000
72	27	35	0.00700	0.04300	0.0000	0.0260	1.000
73	28	36	0.00100	0.00800	0.0000	0.0420	1.000
74	29	60	0.01200	0.06000	0.0000	0.0080	1.000
75	29	63	0.00600	0.01400	0.0000	0.0020	1.000
76	29	64	0.01000	0.02900	0.0000	0.0030	1.000
77	30	73	0.00400	0.02700	0.0000	0.0430	1.000
78	31	32	0.00800	0.04700	0.0000	0.0080	1.000
79	31	34	0.02200	0.06400	0.0000	0.0070	1.000
80	31	35	0.01000	0.03600	0.0000	0.0200	1.000
81	31	43	0.01700	0.08100	0.0000	0.0480	1.000
82	31	74	0.10200	0.25400	0.0000	0.0330	1.000
83	31	75	0.04700	0.12700	0.0000	0.0160	1.000
84	32	35	0.00800	0.03700	0.0000	0.0200	1.000
85	32	37	0.03200	0.08700	0.0000	0.0400	1.000
86	33	36	0.00060	0.00640	0.0000	0.4040	1.000
87	34	42	0.02600	0.15400	0.0000	0.0220	1.000
88	35	36	0.00000	0.02900	0.0000	0.0000	1.000
89	35	43	0.06500	0.19100	0.0000	0.0200	1.000
90	35	44	0.03100	0.08900	0.0000	0.0360	1.000
91	36	40	0.00200	0.01400	0.0000	0.8060	1.000
92	37	38	0.02600	0.07200	0.0000	0.0350	1.000
93	37	42	0.09500	0.26200	0.0000	0.0320	1.000
94	37	46	0.01300	0.03900	0.0000	0.0160	1.000
95	38	41	0.02700	0.08400	0.0000	0.0390	1.000
96	38	47	0.02800	0.08400	0.0000	0.0370	1.000
97	39	52	0.00700	0.04100	0.0000	0.3120	1.000
98	39	62	0.00900	0.05400	0.0000	0.4110	1.000

S.No	Bus	Bus	R	X	G	B	Tap
99	40	68	0.00500	0.04200	0.0000	0.6900	1.000
100	41	61	0.05200	0.14500	0.0000	0.0730	1.000
101	41	92	0.04300	0.11800	0.0000	0.0130	1.000
102	42	87	0.02500	0.06200	0.0000	0.0070	1.000
103	43	44	0.03100	0.09400	0.0000	0.0430	1.000
104	44	45	0.03700	0.10900	0.0000	0.0490	1.000
105	45	48	0.02700	0.08000	0.0000	0.0360	1.000
106	46	47	0.02500	0.07300	0.0000	0.0350	1.000
107	47	48	0.03500	0.10300	0.0000	0.0470	1.000
108	48	49	0.06500	0.16900	0.0000	0.0820	1.000
109	49	50	0.04600	0.08000	0.0000	0.0360	1.000
110	49	55	0.15900	0.53700	0.0000	0.0710	1.000
111	50	51	0.00900	0.02600	0.0000	0.0050	1.000
112	51	53	0.00200	0.01300	0.0000	0.0150	1.000
113	52	54	0.00900	0.06500	0.0000	0.4850	1.000
114	54	56	0.01600	0.10500	0.0000	0.2030	1.000
115	54	123	0.00100	0.00700	0.0000	0.0130	1.000
116	55	236	0.02650	0.17200	0.0000	0.0260	1.000
117	57	190	0.05100	0.23200	0.0000	0.0280	1.000
118	57	66	0.05100	0.15700	0.0000	0.0230	1.000
119	58	59	0.03200	0.10000	0.0000	0.0620	1.000
120	58	237	0.02000	0.12340	0.0000	0.0280	1.000
121	59	60	0.03600	0.13100	0.0000	0.0680	1.000
122	59	61	0.03400	0.09900	0.0000	0.0470	1.000
123	60	64	0.01800	0.08700	0.0000	0.0110	1.000
124	60	238	0.02560	0.19300	0.0000	0.0000	1.000
125	61	63	0.02100	0.05700	0.0000	0.0300	1.000
126	61	66	0.01800	0.05200	0.0000	0.0180	1.000
127	62	73	0.00400	0.02700	0.0000	0.0500	1.000
128	62	240	0.02860	0.20130	0.0000	0.3790	1.000
129	63	64	0.01600	0.04300	0.0000	0.0040	1.000
130	64	65	0.00100	0.00600	0.0000	0.0070	1.000
131	64	67	0.01400	0.07000	0.0000	0.0380	1.000

S.No	Bus	Bus	R	X	G	B	Tap
132	64	239	0.08910	0.26760	0.0000	0.0290	1.000
133	64	241	0.07820	0.21270	0.0000	0.0220	1.000
134	65	66	0.00600	0.02200	0.0000	0.0110	1.000
135	65	69	0.00000	0.03600	0.0000	0.0000	1.000
136	66	190	0.09900	0.37500	0.0000	0.0510	1.000
137	67	190	0.02200	0.10700	0.0000	0.0580	1.000
138	68	173	0.00350	0.03300	0.0000	0.5300	1.000
139	68	174	0.00350	0.03300	0.0000	0.5300	1.000
140	70	71	0.00800	0.06400	0.0000	0.1280	1.000
141	71	72	0.01200	0.09300	0.0000	0.1830	1.000
142	71	234	0.00600	0.04800	0.0000	0.0920	1.000
143	74	76	0.04700	0.11900	0.0000	0.0140	1.000
144	75	77	0.03200	0.17400	0.0000	0.0240	1.000
145	76	78	0.10000	0.25300	0.0000	0.0310	1.000
146	76	79	0.02200	0.07700	0.0000	0.0390	1.000
147	77	84	0.01900	0.14400	0.0000	0.0170	1.000
148	77	86	0.01700	0.09200	0.0000	0.0120	1.000
149	78	79	0.27800	0.42700	0.0000	0.0430	1.000
150	79	82	0.02200	0.05300	0.0000	0.0070	1.000
151	79	83	0.03800	0.09200	0.0000	0.0120	1.000
152	79	84	0.04800	0.12200	0.0000	0.0150	1.000
153	80	82	0.02400	0.06400	0.0000	0.0070	1.000
154	80	83	0.03400	0.12100	0.0000	0.0150	1.000
155	81	87	0.05300	0.13500	0.0000	0.0170	1.000
156	81	88	0.00200	0.00400	0.0000	0.0020	1.000
157	81	89	0.04500	0.35400	0.0000	0.0440	1.000
158	81	90	0.05000	0.17400	0.0000	0.0220	1.000
159	82	83	0.01600	0.03800	0.0000	0.0040	1.000
160	83	85	0.04300	0.06400	0.0000	0.0270	1.000
161	84	86	0.01900	0.06200	0.0000	0.0080	1.000
162	85	88	0.07600	0.13000	0.0000	0.0440	1.000
163	85	233	0.04400	0.12400	0.0000	0.0150	1.000
164	86	87	0.01200	0.08800	0.0000	0.0110	1.000

S.No	Bus	Bus	R	X	G	B	Tap
165	86	90	0.15700	0 .40000	0.0000	0.0470	1.000
166	88	235	0.07400	0 .20800	0.0000	0.0260	1.000
167	89	90	0.07000	0.18400	0.0000	0.0210	1.000
168	89	92	0.10000	0.27400	0.0000	0.0310	1.000
169	89	93	0.10900	0.39300	0.0000	0.0360	1.000
170	90	91	0.14200	0.40400	0.0000	0.0500	1.000
171	91	93	0.01700	0.04200	0.0000	0.0060	1.000
172	94	101	0.00360	0.01990	0.0000	0.0040	1.000
173	95	99	0.00200	0.10490	0.0000	0.0010	1.000
174	96	97	0.00010	0.00180	0.0000	0.0170	1.000
175	97	98	0.00000	0.02710	0.0000	0.0000	1.000
176	97	245	0.00000	0.61630	0.0000	0.0000	1.000
177	245	99	0.00000	0.36970	0.0000	0.0000	1.000
178	97	100	0.00220	0.29150	0.0000	0.0000	1.000
179	98	99	0.00000	0.03390	0.0000	0.0000	1.000
180	98	100	0.00000	0.05820	0.0000	0.0000	1.000
181	101	102	0.08080	0.23440	0.0000	0.0290	1.000
182	101	104	0.09650	0.36690	0.0000	0.0540	1.000
183	102	103	0.03600	0.10760	0.0000	0.1170	1.000
184	102	104	0.04760	0.14140	0.0000	0.1490	1.000
185	104	105	0.00060	0.01970	0.0000	0.0000	1.000
186	105	106	0.00590	0.04050	0.0000	0.2500	1.000
187	105	108	0.01150	0.11060	0.0000	0.1850	1.000
188	105	111	0.01980	0.16880	0.0000	0.3210	1.000
189	105	136	0.00500	0.05000	0.0000	0.3300	1.000
190	105	137	0.00770	0.05380	0.0000	0.3350	1.000
191	105	148	0.01650	0.11570	0.0000	0.1710	1.000
192	106	107	0.00590	0.05770	0.0000	0.0950	1.000
193	106	113	0.00490	0.03360	0.0000	0.2080	1.000
194	106	147	0.00590	0.05770	0.0000	0.0950	1.000
195	107	109	0.00780	0.07730	0.0000	0.1260	1.000
196	107	112	0.00260	0.01930	0.0000	0.0300	1.000
197	108	109	0.00760	0.07520	0.0000	0.1220	1.000

S.No	Bus	Bus	R	X	G	B	Tap
198	108	112	0.00210	0.01860	0.0000	0.0300	1.000
199	109	111	0.00160	0.01640	0.0000	0.0260	1.000
200	109	130	0.00170	0.01650	0.0000	0.0260	1.000
201	109	146	0.00790	0.07930	0.0000	0.1270	1.000
202	109	147	0.00780	0.07840	0.0000	0.1250	1.000
203	112	116	0.00170	0.01170	0.0000	0.2890	1.000
204	112	147	0.00260	0.01930	0.0000	0.0300	1.000
205	112	148	0.00210	0.01860	0.0000	0.0300	1.000
206	112	150	0.00020	0.01010	0.0000	0.0000	1.000
207	113	114	0.00430	0.02930	0.0000	0.1800	1.000
208	113	163	0.00390	0.03810	0.0000	0.2580	1.000
209	114	115	0.00910	0.06230	0.0000	0.3850	1.000
210	115	116	0.01250	0.08900	0.0000	0.5400	1.000
211	115	131	0.00560	0.03900	0.0000	0.9530	1.000
212	116	119	0.00150	0.01140	0.0000	0.2840	1.000
213	116	160	0.00050	0.00340	0.0000	0.0210	1.000
214	116	165	0.00070	0.01510	0.0000	0.1260	1.000
215	116	167	0.00050	0.00340	0.0000	0.0210	1.000
216	118	151	0.05620	0.22480	0.0000	0.0810	1.000
217	119	120	0.01200	0.08360	0.0000	0.1230	1.000
218	119	121	0.01520	0.11320	0.0000	0.6840	1.000
219	119	124	0.04680	0.33690	0.0000	0.5190	1.000
220	119	125	0.04300	0.30310	0.0000	0.4630	1.000
221	119	126	0.04890	0.34920	0.0000	0.5380	1.000
222	119	161	0.00130	0.00890	0.0000	0.1190	1.000
223	120	125	0.02910	0.22670	0.0000	0.3420	1.000
224	121	122	0.00600	0.05700	0.0000	0.7670	1.000
225	122	124	0.00750	0.07730	0.0000	0.1190	1.000
226	122	128	0.01270	0.09090	0.0000	0.1350	1.000
227	124	125	0.00850	0.05880	0.0000	0.0870	1.000
228	124	128	0.02180	0.15110	0.0000	0.2230	1.000
229	125	126	0.00730	0.05040	0.0000	0.0740	1.000
230	127	157	0.05230	0.15260	0.0000	0.0740	1.000

S.No	Bus	Bus	R	X	G	B	Tap
231	127	158	0.13710	0.39190	0.0000	0.0760	1.000
232	131	132	0.01370	0.09570	0.0000	0.1410	1.000
233	132	140	0.00550	0.02880	0.0000	0.1900	1.000
234	133	135	0.17460	0.31610	0.0000	0.0400	1.000
235	133	162	0.08040	0.30540	0.0000	0.0450	1.000
236	134	140	0.01100	0.05680	0.0000	0.3880	1.000
237	136	138	0.00080	0.00980	0.0000	0.0690	1.000
238	137	138	0.00290	0.02850	0.0000	0.1900	1.000
239	137	139	0.00660	0.04480	0.0000	0.2770	1.000
240	141	143	0.00240	0.03260	0.0000	0.2360	1.000
241	141	144	0.00180	0.02450	0.0000	1.6620	1.000
242	142	143	0.00440	0.05140	0.0000	3.5970	1.000
243	144	145	0.00020	0.01230	0.0000	0.0000	1.000
244	146	148	0.00180	0.01780	0.0000	0.0290	1.000
245	151	152	0.06690	0.48430	0.0000	0.0630	1.000
246	151	153	0.05580	0.22100	0.0000	0.0310	1.000
247	152	153	0.08070	0.33310	0.0000	0.0490	1.000
248	152	154	0.07390	0.30710	0.0000	0.0430	1.000
249	152	155	0.17990	0.50170	0.0000	0.0690	1.000
250	154	155	0.09040	0.36260	0.0000	0.0480	1.000
251	154	158	0.07700	0.30920	0.0000	0.0540	1.000
252	155	156	0.02510	0.08290	0.0000	0.0470	1.000
253	156	157	0.02220	0.08470	0.0000	0.0500	1.000
254	157	158	0.04980	0.18550	0.0000	0.0290	1.000
255	157	159	0.00610	0.02900	0.0000	0.0840	1.000
256	160	117	0.00040	0.02020	0.0000	0.0000	1.000
257	160	166	0.00040	0.00830	0.0000	0.1150	1.000
258	163	164	0.00250	0.02450	0.0000	0.1640	1.000
259	165	167	0.00070	0.00860	0.0000	0.1150	1.000
260	166	167	0.00070	0.00860	0.0000	0.1150	1.000
261	167	117	0.00040	0.02020	0.0000	0.0000	1.000
262	168	187	0.03300	0.09500	0.0000	0.0000	1.000
263	168	188	0.04600	0.06900	0.0000	0.0000	1.000

S.No	Bus	Bus	R	X	G	B	Tap
264	169	210	0.00040	0.00220	0.0000	6.2000	1.000
265	169	219	0.00000	0.02750	0.0000	0.0000	1.000
266	170	171	0.00300	0.04800	0.0000	0.0000	1.000
267	71	204	0.00200	0.00900	0.0000	0.0000	1.000
268	172	184	0.04500	0.06300	0.0000	0.0000	1.000
269	172	187	0.04800	0.12700	0.0000	0.0000	1.000
270	173	198	0.00310	0.02860	0.0000	0.5000	1.000
271	173	242	0.00240	0.03550	0.0000	0.3600	1.000
272	174	198	0.00310	0.02860	0.0000	0.5000	1.000
273	175	176	0.01400	0.04000	0.0000	0.0040	1.000
274	175	189	0.03000	0.08100	0.0000	0.0100	1.000
275	176	177	0.01000	0.06000	0.0000	0.0090	1.000
276	176	190	0.01500	0.04000	0.0000	0.0060	1.000
277	177	181	0.33200	0.68800	0.0000	0.0000	1.000
278	177	182	0.00900	0.04600	0.0000	0.0250	1.000
279	177	189	0.02000	0.07300	0.0000	0.0080	1.000
280	177	190	0.03400	0.10900	0.0000	0.0320	1.000
281	178	179	0.07600	0.13500	0.0000	0.0090	1.000
282	178	189	0.04000	0.10200	0.0000	0.0050	1.000
283	179	189	0.08100	0.12800	0.0000	0.0140	1.000
284	180	183	0.12400	0.18300	0.0000	0.0000	1.000
285	182	190	0.01000	0.05900	0.0000	0.0080	1.000
286	183	184	0.04600	0.06800	0.0000	0.0000	1.000
287	184	185	0.30200	0.44600	0.0000	0.0000	1.000
288	185	186	0.07300	0.09300	0.0000	0.0000	1.000
289	185	187	0.24000	0.42100	0.0000	0.0000	1.000
290	191	194	0.01390	0.07780	0.0000	0.0860	1.000
291	192	193	0.00250	0.03800	0.0000	0.0000	1.000
292	193	194	0.00170	0.01850	0.0000	0.0200	1.000
293	193	221	0.00150	0.01080	0.0000	0.0020	1.000
294	194	195	0.00450	0.02490	0.0000	0.0260	1.000
295	195	196	0.00400	0.04970	0.0000	0.0180	1.000
296	196	197	0.00000	0.04560	0.0000	0.0000	1.000

S.No	Bus	Bus	R	X	G	B	Tap
297	196	198	0.00050	0.01770	0.0000	0.0200	1.000
298	196	199	0.00270	0.03950	0.0000	0.8320	1.000
299	198	216	0.00030	0.00180	0.0000	5.2000	1.000
300	199	197	0.00370	0.04840	0.0000	0.4300	1.000
301	199	200	0.00100	0.02950	0.0000	0.5030	1.000
302	199	217	0.00160	0.00460	0.0000	0.4020	1.000
303	200	202	0.00030	0.00130	0.0000	1.0000	1.000
304	201	216	0.00140	0.05140	0.0000	0.3300	1.000
305	203	204	0.01000	0.06400	0.0000	0.4800	1.000
306	203	205	0.00190	0.00810	0.0000	0.8600	1.000
307	204	170	0.00100	0.06100	0.0000	0.0000	1.000
308	205	210	0.00050	0.02120	0.0000	0.0000	1.000
309	206	210	0.00090	0.04720	0.0000	0.1860	1.000
310	207	208	0.00190	0.00870	0.0000	1.2800	1.000
311	207	210	0.00260	0.09170	0.0000	0.0000	1.000
312	207	213	0.00130	0.02880	0.0000	0.8100	1.000
313	208	169	0.00000	0.06260	0.0000	0.0000	1.000
314	210	211	0.00020	0.00690	0.0000	1.3640	1.000
315	210	216	0.00010	0.00060	0.0000	3.5700	1.000
316	211	212	0.00170	0.04850	0.0000	0.0000	1.000
317	213	214	0.00020	0.02590	0.0000	0.1440	1.000
318	213	216	0.00060	0.02720	0.0000	0.0000	1.000
319	214	217	0.00020	0.00060	0.0000	0.8000	1.000
320	220	216	0.00050	0.01540	0.0000	0.0000	1.000
321	219	230	0.00030	0.00430	0.0000	0.0090	1.000
322	221	224	0.00820	0.08510	0.0000	0.0000	1.000
323	221	226	0.01120	0.07230	0.0000	0.0000	1.000
324	222	223	0.01270	0.03550	0.0000	0.0000	1.000
325	222	224	0.03260	0.18040	0.0000	0.0000	1.000
326	223	225	0.01950	0.05510	0.0000	0.0000	1.000
327	224	225	0.01570	0.07320	0.0000	0.0000	1.000
328	224	226	0.03600	0.21190	0.0000	0.0000	1.000
329	225	226	0.02680	0.12850	0.0000	0.0000	1.000

S.No	Bus	Bus	R	X	G	B	Tap
330	226	227	0.04280	0.12150	0.0000	0.0000	1.000
331	227	228	0.03510	0.10040	0.0000	0.0000	1.000
332	228	229	0.06160	0.18570	0.0000	0.0000	1.000
333	3	1	0.00000	0.05200	0.0000	0.0000	0.947
334	3	2	0.00000	0.05200	0.0000	0.0000	0.956
335	3	4	0.00000	0.00500	0.0000	0.0000	0.971
336	7	5	0.00000	0.03900	0.0000	0.0000	0.948
337	7	6	0.00000	0.03900	0.0000	0.0000	0.959
338	10	11	0.00000	0.08900	0.0000	0.0000	1.046
339	12	10	0.00000	0.05300	0.0000	0.0000	0.985
340	15	17	0.01940	0.03110	0.0000	0.0000	0.956
341	16	15	0.00100	0.03800	0.0000	0.0000	0.971
342	20	19	0.00000	0.01400	0.0000	0.0000	0.952
343	23	22	0.00000	0.06400	0.0000	0.0000	0.943
344	30	29	0.00000	0.04700	0.0000	0.0000	1.010
345	39	38	0.00000	0.02000	0.0000	0.0000	1.008
346	39	40	0.00000	0.02100	0.0000	0.0000	1.000
347	54	53	0.00000	0.05900	0.0000	0.0000	0.975
348	55	56	0.00000	0.03800	0.0000	0.0000	1.017
349	61	62	0.00000	0.02440	0.0000	0.0000	1.000
350	68	73	0.00000	0.02000	0.0000	0.0000	1.000
351	70	81	0.00000	0.04800	0.0000	0.0000	1.000
352	71	83	0.00000	0.04800	0.0000	0.0000	1.000
353	72	78	0.00000	0.04600	0.0000	0.0000	1.015
354	93	186	0.00000	0.14900	0.0000	0.0000	0.967
355	95	103	0.00520	0.01740	0.0000	0.0000	1.010
356	100	94	0.00000	0.02800	0.0000	0.0000	1.050
357	101	136	0.00050	0.01950	0.0000	0.0000	1.000
358	109	110	0.00000	0.01800	0.0000	0.0000	1.052
359	109	129	0.00000	0.01400	0.0000	0.0000	1.052
360	111	149	0.00100	0.04020	0.0000	0.0000	1.050
361	120	153	0.00240	0.06030	0.0000	0.0000	0.975
362	121	154	0.00240	0.04980	0.0000	-0.0870	1.000

S.No	Bus	Bus	R	X	G	B	Tap
363	122	123	0.00000	0.08330	0.0000	0.0000	1.035
364	122	127	0.00130	0.03710	0.0000	0.0000	0.956
365	124	159	0.00050	0.01820	0.0000	0.0000	1.000
366	130	149	0.00100	0.03920	0.0000	0.0000	1.050
367	132	162	0.00270	0.06390	0.0000	0.0000	1.073
368	134	135	0.00080	0.02560	0.0000	0.0000	1.050
369	138	96	0.00000	0.01600	0.0000	0.0000	1.051
370	139	103	0.00120	0.03960	0.0000	0.0000	0.975
371	142	116	0.00130	0.03840	0.0000	-0.0570	0.980
372	143	134	0.00090	0.02310	0.0000	-0.0330	0.956
373	161	118	0.00030	0.01310	0.0000	0.0000	1.050
374	168	189	0.00000	0.25200	0.0000	0.0000	1.030
375	172	175	0.00000	0.23700	0.0000	0.0000	1.030
376	174	191	0.00080	0.03660	0.0000	0.0000	0.985
377	179	227	0.00000	0.22000	0.0000	0.0000	1.000
378	180	57	0.00000	0.09800	0.0000	0.0000	1.030
379	181	190	0.00000	0.12800	0.0000	0.0000	1.010
380	183	246	0.02000	0.20400	0.0000	-0.0120	1.000
381	188	177	0.02600	0.21100	0.0000	0.0000	1.030
382	190	191	0.00300	0.01220	0.0000	0.0000	1.000
383	197	198	0.00100	0.03540	0.0000	-0.0100	0.970
384	202	203	0.00120	0.01950	0.0000	-0.3640	1.000
385	208	209	0.00100	0.03320	0.0000	0.0000	1.020
386	213	215	0.00050	0.01600	0.0000	0.0000	1.070
387	217	218	0.00050	0.01600	0.0000	0.0000	1.020
388	175	246	0.00010	0.02000	0.0000	0.0000	1.000
389	98	243	0.00100	0.02300	0.0000	0.0000	1.022
390	99	244	0.00000	0.02300	0.0000	0.0000	0.928
391	248	2	0.00100	0.01460	0.0000	0.0000	1.000
392	249	3	0.00000	0.01054	0.0000	0.0000	1.000
393	260	53	0.00000	0.02380	0.0000	0.0000	1.000
394	261	54	0.00000	0.03214	0.0000	0.0000	0.950
395	265	145	0.00000	0.01540	0.0000	0.0000	1.000

S.No	Bus	Bus	R	X	G	B	Tap
396	254	23	0.00000	0.02890	0.0000	0.0000	1.000
397	247	1	0.00000	0.01953	0.0000	0.0000	1.000
398	263	109	0.00000	0.01930	0.0000	0.0000	1.000
399	250	11	0.00000	0.01923	0.0000	0.0000	1.000
400	253	22	0.00000	0.02300	0.0000	0.0000	1.000
401	257	43	0.00000	0.01240	0.0000	0.0000	1.000
402	264	118	0.00000	0.01670	0.0000	0.0000	1.000
403	251	12	0.00000	0.03120	0.0000	0.0000	1.000
404	252	17	0.00000	0.01654	0.0000	0.0000	0.942
405	255	33	0.00000	0.03159	0.0000	0.0000	0.965
406	259	49	0.00000	0.05347	0.0000	0.0000	0.950
407	256	38	0.00000	0.18181	0.0000	0.0000	0.942
408	258	48	0.00000	0.19607	0.0000	0.0000	0.942
409	262	59	0.00000	0.06896	0.0000	0.0000	0.956