

## **CHAPTER 2**

# **A NEW APPROACH TO NETWORK CONNECTIVITY FOR THE ANALYSIS OF PRE/POST FAULT ELECTRIC POWER DISTRIBUTION NETWORKS**

### **2.1 INTRODUCTION**

It is critical to determine the network topology of power systems in modern operation control centers for the number of Energy Management Systems functions, including state estimation, operators load flow, contingency analysis, and dispatch training simulator. Distribution system engineers periodically reconfigure distribution feeders by opening and closing of switches in order to increase the network reliability / to reduce the line losses, under normal operating conditions. All the load requirements must be met and the resulting feeder must remain radial. In the analysis of Electric Power Distribution System (EPDS) the basic requirement is the identification of network connectivity.

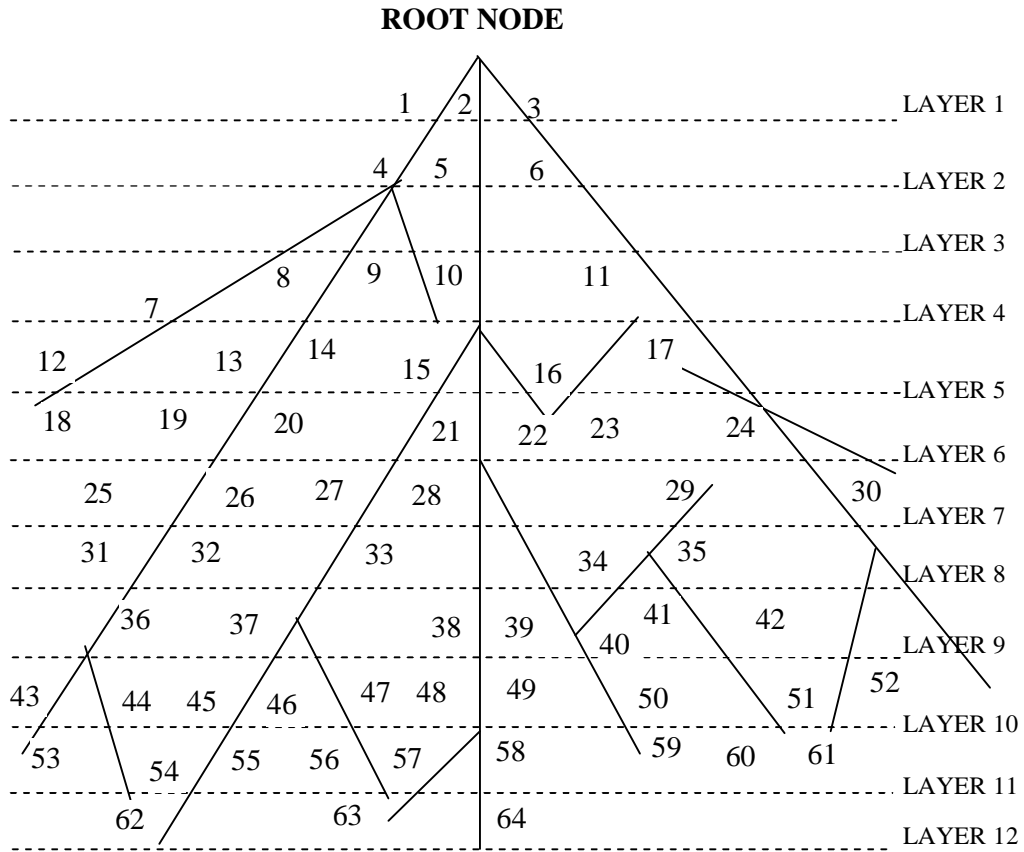
### **2.2 NETWORK CONNECTIVITY METHODS**

In the past, network connectivity is broadly classified into two categories, viz., Tree Order Method and Branch Order Method. These two methods are briefly described below:

### 2.2.1 Tree Order Method

In this method, Power Distribution Network (PDN) is viewed as a Tree consisting of several feeders which are emanating from the root node (that is, Substation) and its leaves are laterals and sub-laterals of feeder (that is, Branch of the feeder).

The power distribution networks have meshable structure, but exploited radially. The Breakers are so positioned that the power paths of each Circuit Breaker form a tree called feeder. The root of the tree is a Circuit breaker and its leaves are whatever switching devices downstream happen to be opened at the time. In most cases each line belongs to one feeder at a time. A distribution network (as shown in Figure 2.1), typically consists of three radial feeders connected to the substation transformer (Root Node), and a group of switches in their normal positions (open or closed). The status of the switches in the pre/post fault PDN is required to determine the network connectivity. In Daurish and Wayne (1989) approach, reconfiguration of the network for resistive line losses reduction, divides the PDN into several layers, i.e., Layer 1, Layer 2,.....Layer 12. The nodes connected to the bottom most layers are first found and then the nodes connected to the next upper layers are identified. This approach is repeated until layer 1 (Root node) is reached. This task needs renumbering of the nodes and it is tedious. Hence for quick Service Restoration of power supply in the EPDS, this approach is not suitable for identifying the best configuration of the PDN. The new method for the analysis of distribution networks by Renato (1990) uses graph theory approach to consider the node connectivity in PDN. But this is a tedious procedure and, moreover, this method needs analysis of more complex mathematical model.



**Figure 2.1 Branch numbering of the Radial Distribution Network**

In the optimal loss reduction of distribution networks by Slamocanin (1990) the network connectivity problem is treated as an un-capacitated transshipment problem. For the electrical power distribution engineers it is a tough task to analyze such complex mathematical model. Luo and Semlyen's (1990) efficient load flow for weakly meshed networks uses the approach of network flow tree labeling. This method, for the conversion of meshed network to radial network, requires renumbering of all the nodes in the PDN and under faulty condition change in configuration also increases the complexity of analysis of the PDN. This is its main disadvantage and hence this method is not suitable for quick service restoration of EPDS.

Phongsak and Iraj (1995) present an approach for Tracking Network Connectivity which is a Topology-based Algorithm. Though the algorithm is fast, it is a system dependent approach, that is, if the system configuration changes it needs modification in the data structure. Hence this method cannot be used as a generalized tool for the determination of network connectivity of the post fault PDN.

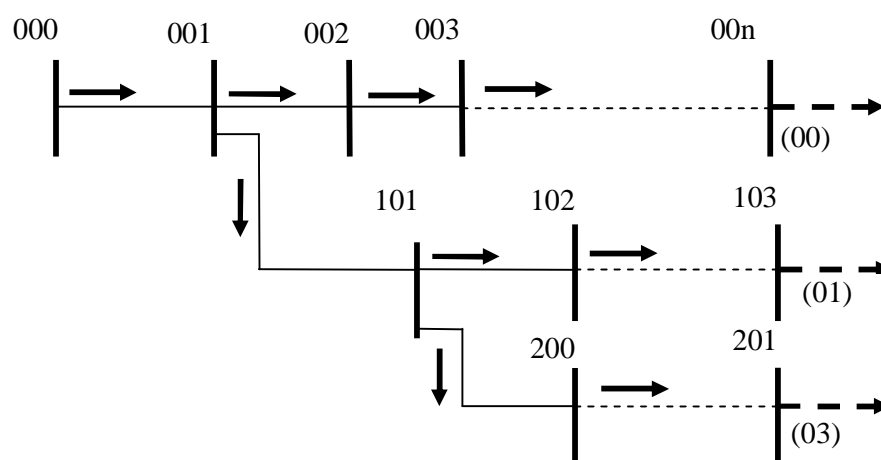
Three phase unbalanced distribution load flow solutions with minimum data preparation approach by Whie-Min Lin et al (1998) is based on the method of modified decoupling. Here for high R/X ratio networks the Jacobian formulation is used, though the formulation and analysis are complex for the large PDN.

Ghosh and Das's (1999) Method for load flow solution of radial distribution networks needs a constant current representation of the load. For voltage, this method uses the flat start assumptions but it does not guarantee the accuracy of the solution in cases of the multiple contingency. Jen-Hao (2002) presents a Novel and fast three-phase load flow for unbalanced radial distribution system which considers mutual coupling effects and employs Kron's method for the reduction of matrix size. The Jacobian matrix is built

using this reduced matrix. The complex mathematical model of this approach increases the complexity in the analysis of quick service restoration of EPDS and also needs skilled programming.

### 2.2.2 Branch Order Method

Yoshikazu Fukuyama et al (1998) present the parallel power flow calculations in electric distribution networks and use multiprocessors for fast distribution power flow studies. They use the branch order method for identification of network connectivity. In the branch order method levelization of the feeders is done as shown in the Figure 2.2. A feeder at the level  $k$  is defined as a lateral branching out from a lateral at the level  $k-1$ . The level of the main feeder, connected to secondary side of the sub-station is '0'. A route starting from the sub-station to an end node is considered as the main feeder, if it contains the largest number of nodes. The method needs renumbering of the nodes in PDN. With more number of laterals, renumbering of the nodes becomes a tedious task for electrical power distribution engineers. Hence, it is not suitable for identification of network connectivity in quick service restoration of EPDS.



**Figure 2.2 Levelization of Feeders**

A new network connectivity method for the identifying the configuration of the PDN is developed to overcome the above mentioned draw-backs of the approaches discussed. The proposed method is simple, flexible and more efficient for the network connectivity analysis of the pre/post PDN.

A new mathematical model has been formulated to analyze the network connectivity of the pre/post fault power distribution network. The model is based on node and branch connectivity matrix manipulations. The proposed mathematical model helps in the identification of nodes beyond a particular node and hence, it will provide the complete knowledge of connectivity of the pre/post fault PDN. Using the new network connectivity method the main requirement of node load identification of the forward substitution method has been obtained. Due to the simplicity of this New Network Connectivity Method, computational efficiency is greatly improved.

### **2.3 DEVELOPMENT OF NEW NETWORK CONNECTIVITY METHOD FOR THE EPDS**

The steps involved in developing the new network connectivity method are:

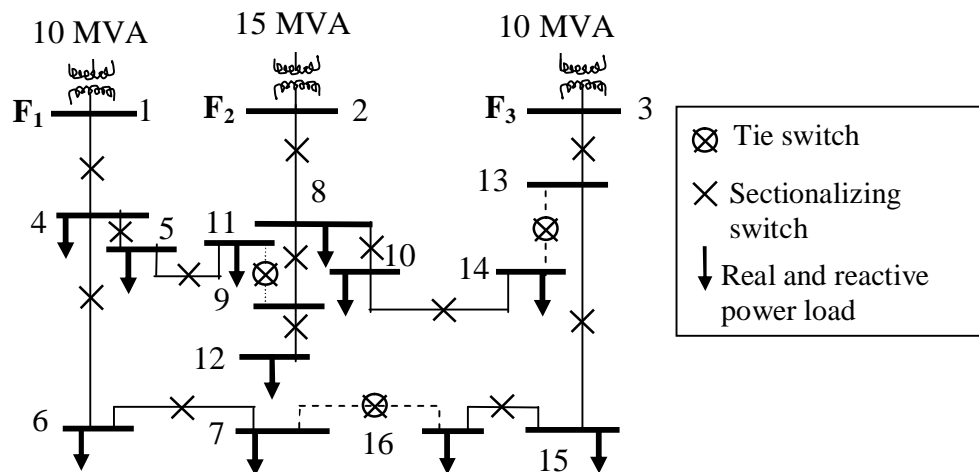
Step 1: To Identify the status of the switches

Step 2: Branch connectivity matrix formulation of the PDN

Step 3: Matrix formulation of node beyond a particular node.

Step 4: Identifying the nodes connected to particular feeder

A typical 16-Bus, three-feeder EPDS is shown in Figure 2.3. The development of the New Network Connectivity Method is explained in detail for the same.



**Figure 2.3 16-Bus, Three-feeder Practical Distribution System**

### 2.3.1 Identification of status of the Sectionalizing and Tie Switches

Based on the status of the sectionalizing and tie switches the algorithm for network connectivity is formulated for the pre/post-fault power distribution network. Initially sectionalizing switches are kept in closed position and tie switches in open position in the power distribution network. To satisfy all the operational planning problem of the EPDS the power distribution network is reconfigured and the status of these switches is changed. The following observations are made to identify the status of the switch.

- Closed Switch status (that is, Sectionalizing Switch) is considered as '1' and the Open Switch (that is, Tie switch) status is considered as '0'

- The total number of switches will be equal to the total number of branches in the PDN under consideration.
- If the Receiving End Bus Number repeats in the Receiving End bus matrix (EB), it will indicate the violation of the radiality constraint, that is, PDN is a meshed one and needs any one of the switch with repeated bus number to be opened in order to maintain the radiality structure of the EPDS.

In this example, the receiving end bus numbers corresponding to the branches 8 and 9 are the same. Hence any one of the switch corresponding to the branches 8 or 9 has to be opened in order to maintain the radial structure of feeder 1 of the PDN. Similarly any one of the switch corresponding to the branches 12 and 13, and 15 and 16 are to be opened in the order to maintain the radiality constraint of the feeders 2 and 3 of PDN. The status of the switches is given below in Table 2.1.

### **2.3.2 Formulation of the Branch Connectivity Matrix**

In the formulation of branch connectivity matrix, the SB (Sending End Bus) and EB (Receiving End Bus) are identified based on the switch status. The SB and EB matrix elements are modified in order to know the pre/post-fault PDN connectivity. The modified SB and EB matrix is given below in Table 2.2. The branches corresponding to the switch position '0' are eliminated from the SB and EB matrices, and the modified SB and EB matrices (that is,  $SB_1$  and  $EB_1$ ) are given below in Table 2.2.



**Table 2.1 Bus Connectivity Details for 16-Bus, three feeder Distribution System**

Branch Number (BN)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Sending End Bus (SB)	1	4	4	6	2	8	8	5	9	9	3	13	10	13	15	7
Receiving End Bus (EB)	4	5	6	7	8	9	10	11	11	12	13	14	14	15	16	16
Switch Status (SW)	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	0

**Table 2.2 Modified Bus Connectivity Details for 16-Bus, three feeder Distribution System**

Sending End Bus (SB <sub>1</sub> )	1	4	4	6	2	8	8	5	9	3	10	13	15
Receiving End Bus (EB <sub>1</sub> )	4	5	6	7	8	9	10	11	12	13	14	15	16
Switch Status (SW)	1	1	1	1	1	1	1	1	1	1	1	1	1

The Branch Connectivity matrix formation is done based on the following observations.



From the branch connectivity matrix it can be observed that:

- If the  $m^{\text{th}}$  row and  $n^{\text{th}}$  column element of the branch connectivity matrix is equal to the  $n^{\text{th}}$  row and  $n^{\text{th}}$  column element of the branch connectivity matrix, then it indicates the connection of the  $m^{\text{th}}$  node to  $n^{\text{th}}$  node in the  $m^{\text{th}}$  branch of the PDN.

Eg:  $nn(4, 5) = nn(5, 5)$ ,  $nn(15, 16) = nn(16, 16)$  etc.

- If the  $m^{\text{th}}$  row has 'k' number of elements, then 'k-1' branches (that is, sub-laterals) are emanating from that node.

Eg: if  $m = 2$ , then  $k = 2$ ;  $k-1 = 1$ ; that is, the node 8 is emanating from the node 2.

If  $m = 4$ , then  $k = 3$ ;  $k-1 = 2$ ; that is, the node 5 and 6 are emanating from the node 4.

- If the  $n^{\text{th}}$  row and  $(n+1)^{\text{th}}$  column elements of the branch connectivity matrix is zero, then it indicates the tail end of feeder or the lateral/ sub-lateral under consideration. Other way of identifying the tail end of the feeder is that, if the  $m^{\text{th}}$  row in the branch connectivity matrix consists of only one non-zero element, then it indicates that the tail end of feeder or the lateral/ sub-lateral is under consideration.

### 2.3.3 Formulation of the matrix of nodes beyond a particular node

For the forward substitution method, knowledge of the node load is essential. The matrix of nodes beyond a particular node helps in calculating the total load connected to each node of the power distribution network. In order to identify the nodes connected to a particular node, matrix

manipulations are done. The nodes connected to a particular node are first identified and then the overall connectivity of nodes connected to a particular feeder is found. For all remaining feeders in the power distribution network the procedure is repeated. The feeder connected to the root node is identified after identifying the nodes connected to the feeder.

### 2.3.3.1 Union of Branch Connectivity Matrix elements

For a distribution system shown in Figure 2.3, the nodes connected to a particular node are identified using the following steps. Here initially all the elements of the Branch Connectivity Matrix is considered. The nodes connected to a particular node '1' are identified as follows.

For the node, say  $m = 1$ ,

$$nn(1,:) = \text{First elements of the matrix 'nn'} = [1, 4, 0, 0, \dots, 0]$$

$$nn(4,:) = \text{First elements of the matrix 'nn'} = [4, 5, 6, 0, 0, \dots, 0]$$

Similarly

$$nn(5,:) = [5, 11, 0, 0, 0, \dots, 0]$$

$$nn(6,:) = [6, 7, 0, 0, 0, \dots, 0]$$

$$nn(7,:) = [7, 0, 0, 0, 0, \dots, 0]$$

$$nn(11,:) = [11, 0, 0, 0, 0, \dots, 0]$$

The matrix of nodes beyond a particular node (nbe) is identified as follows:

$$nbe(1, :) = \text{Nodes beyond the node '1'}$$

$$nbe(1, :) = nn(1,:) \cup [ nn(4, :) \cup [nn(5, :) \cup [nn(6, :) \cup [nn(7, :) \cup [nn(11, :) ]]]]]$$

$$= [ 1, 4, 5, 6, 7, 11, 0 ]$$

Similarly for the nodes 2, 3, .....16, the nodes beyond those nodes is given by

$$\begin{aligned} \text{nbe}(2, :) &= \text{nn}(2,:) \cup [\text{nn}(8, :) \cup [\text{nn}(9, :) \cup [\text{nn}(10, :) \cup [\text{nn}(12,:) \cup [\text{nn}(14,:)]]]]] \\ &= [2, 8, 9, 10, 12, 14, 0] \end{aligned}$$

$$\begin{aligned} \text{nbe}(3, :) &= \text{nn}(3,:) \cup [\text{nn}(13, :) \cup [\text{nn}(15, :) \cup [\text{nn}(16, :)]]] \\ &= [3, 13, 15, 16, 0] \end{aligned}$$

$$\begin{aligned} \text{nbe}(4, :) &= \text{nn}(4,:) \cup [\text{nn}(5, :) \cup [\text{nn}(6, :) \cup [\text{nn}(7,:) \cup [\text{nn}(11,:)]]]] \\ &= [4, 5, 6, 7, 11, 0] \end{aligned}$$

$$\begin{aligned} \text{nbe}(5, :) &= \text{nn}(5,:) \cup [\text{nn}(11,:)] \\ &= [5, 11, 0] \end{aligned}$$

$$\begin{aligned} \text{nbe}(6, :) &= \text{nn}(6,:) \cup [\text{nn}(7,:)] \\ &= [6, 7, 0] \end{aligned}$$

.....  
 .....

$$\begin{aligned} \text{nbe}(16, :) &= \text{nn}(16,:) \\ &= [16, 0] \end{aligned}$$

‘nbe’ cannot be treated as a matrix, as we can observe that, the matrix ‘nbe’ consists of unequal number of non-zero elements. Additional number of zeros is added in each row of the nbe to overcome this problem.

Eg: 10 zeros are to be added, in the first row of the ‘nbe’

10 zeros are to be added, in the second row of the ‘nbe’, etc.,

In the next section of this chapter the calculation of number of zeros to be added to resize it as a matrix, in each row of the 'nbe' is explained.

### 2.3.3.2 Horizontal concatenation of the matrix elements

The following procedure is used to horizontally concatenate each row of the 'nbe' so that 'nbe' can be resized to convert it as a matrix,

- i) The length of each row of the 'nbe' is computed and then the number of zeros to be added in each row of the 'nbe' is calculated

Length of the vector nbe (1, :) = 7

Number of zeros to be added = (nbch +1) – 7 = 17 – 7 = 10

Length of the vector nbe (2, :) = 7

Number of zeros to be added = (nbch +1) – 7 = 17 – 7 = 10

.....

.....

Length of the vector nbe (16, :) = 2

Number of zeros to be added = (nbch +1) – 7 = 17 – 2 = 15

- ii) Horizontal concatenation is used to form the matrix 'nbe'.

- nbe (1, :) = Horizontal concatenate (1, :), zeros (1, 10)

= [ 1, 4, 5, 6, 7, 11, 0, 0,0, 0, 0, 0, 0, 0, 0, 0 ]

- nbe (2, :) = Horizontal concatenate (2, :), zeros (1, 10)

= [2, 8, 9, 10, 12, 14, 0 , 0, 0, 0, 0, 0, 0, 0, 0, 0 ]

.....

.....

- $nbe(16, :) = \text{Horizontal concatenate}(16, :), \text{zeros}(1, 15)$   
 $= [16, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]$

Now the matrix 'nbe' is of size  $[(nbch+1) \times (nbch+1)]$ .

- The additional row and column of the matrix 'nbe' is eliminated.

Using the nodes beyond a particular node (nbe) of the matrix, pre/post fault PDN can be analyzed.

### 2.3.3.3 Identification of the nodes connected to a particular feeder

Identifying the nodes connected to a feeder helps in the analysis of feeder loading. The nodes connected to the feeders 1, 2 and 3 are obtained as follows:

Eg: In 16-Bus distribution system the number of feeders is three, viz.,  $F_1$ ,  $F_2$  and  $F_3$ . Root nodes of the feeders are 1, 2 and 3. Only non-zero elements are considered.

Feeder 1, Nodes connected are =  $nbe(1, :)$  = [1, 4, 5, 6, 7, 11]

Feeder 2, Nodes connected are =  $nbe(2, :)$  = [2, 8, 9, 10, 12, 14]

Feeder 3, Nodes connected are =  $nbe(3, :)$  = [3, 13, 15, 16]

In the pre/post-fault power distribution network, the knowledge of the nodes connected to a particular node helps in calculating the connected load at different nodes. Due to single or multiple line outages, if the configuration of the power distribution network changes, this change can be easily incorporated by changing the status of the switch. The modification in switch status 'SW' changes the connected bus details and complete

knowledge of the network connectivity can be obtained from the matrix 'nbe'. The matrix of nodes beyond a particular node 'nbe' for the 16-Bus, three - feeder distribution system is given below.

$$\text{nbe} = \begin{bmatrix} 1 & 4 & 5 & 6 & 7 & 11 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 8 & 9 & 10 & 12 & 14 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 3 & 13 & 15 & 16 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 5 & 6 & 7 & 11 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 5 & 11 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 6 & 7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 8 & 9 & 10 & 12 & 14 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 9 & 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 10 & 14 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 11 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 13 & 15 & 16 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 14 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 15 & 16 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 16 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

## 2.4 FLOW CHART OF NEW NETWORK CONNECTIVITY METHOD

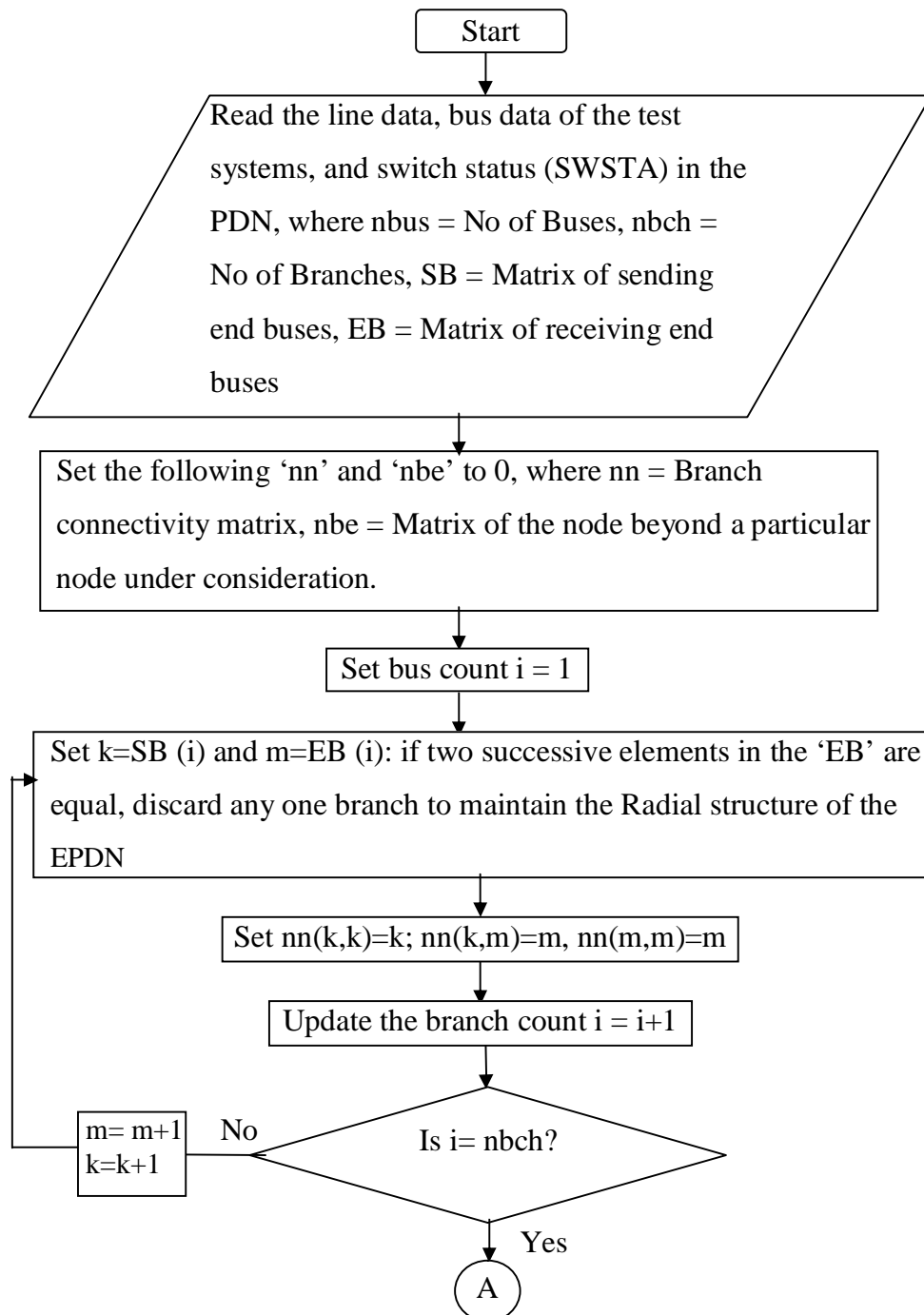
For the analysis of pre/post fault PDN, the following steps are considered in developing the flow chart for the new network connectivity method.

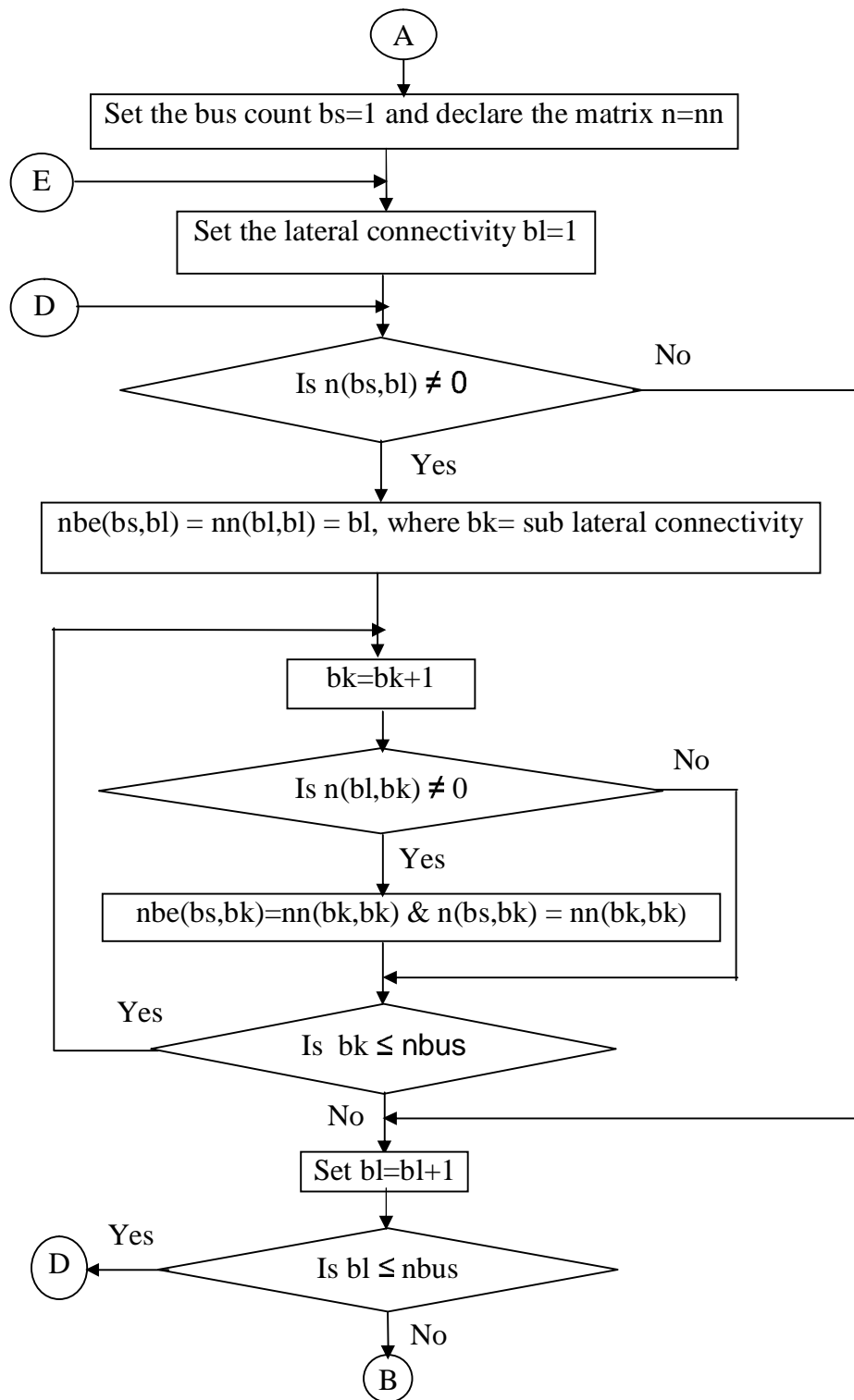
- First read the number of branches and buses connected to the PDN and then formulate the line data of the EPDS and branch connectivity matrix (nn).
- If the number of receiving end bus repeats, in the receiving end bus matrix (EB), then it indicates the violation of radiality constraint. Any one branch of the receiving end bus is hence

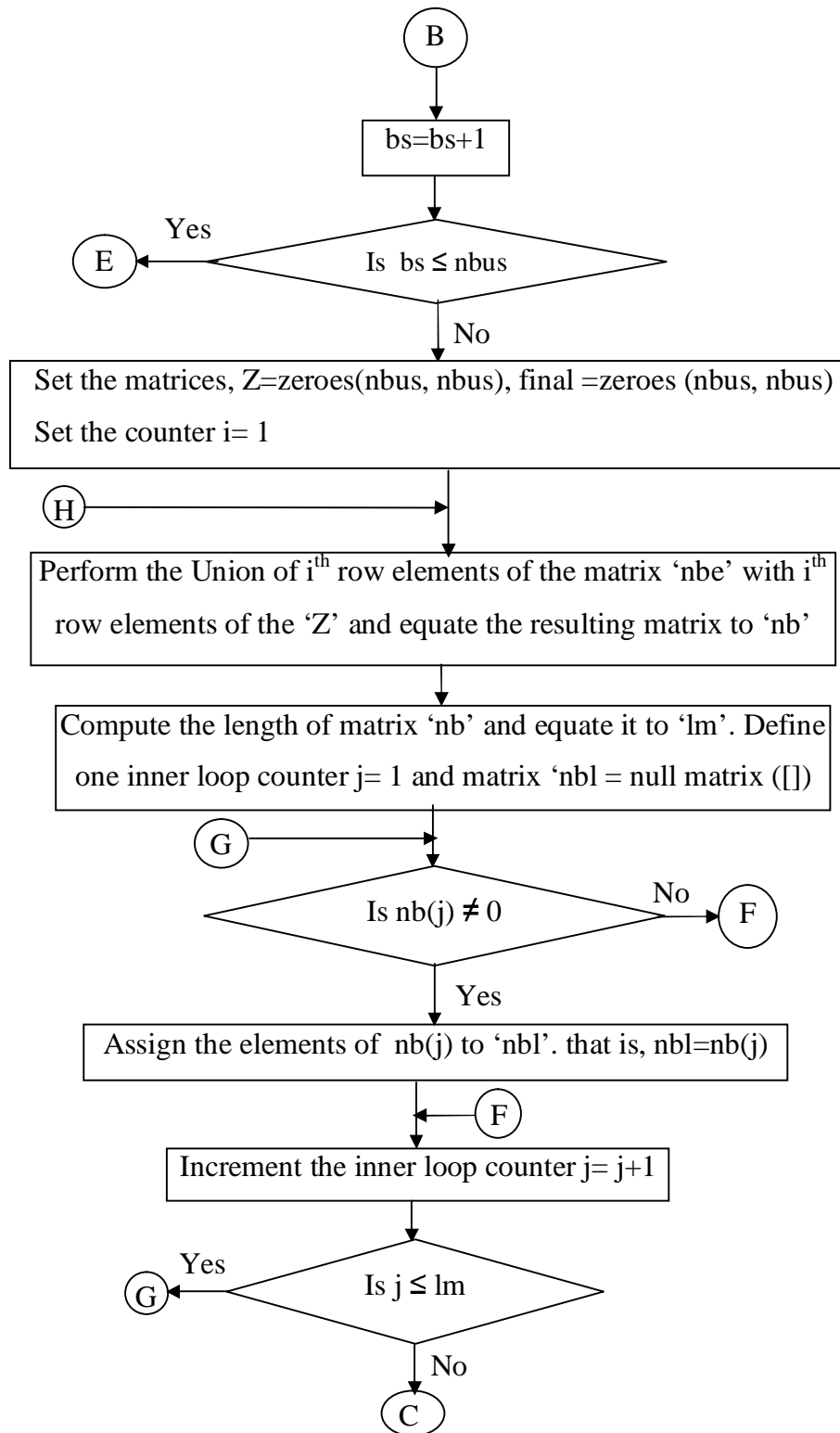


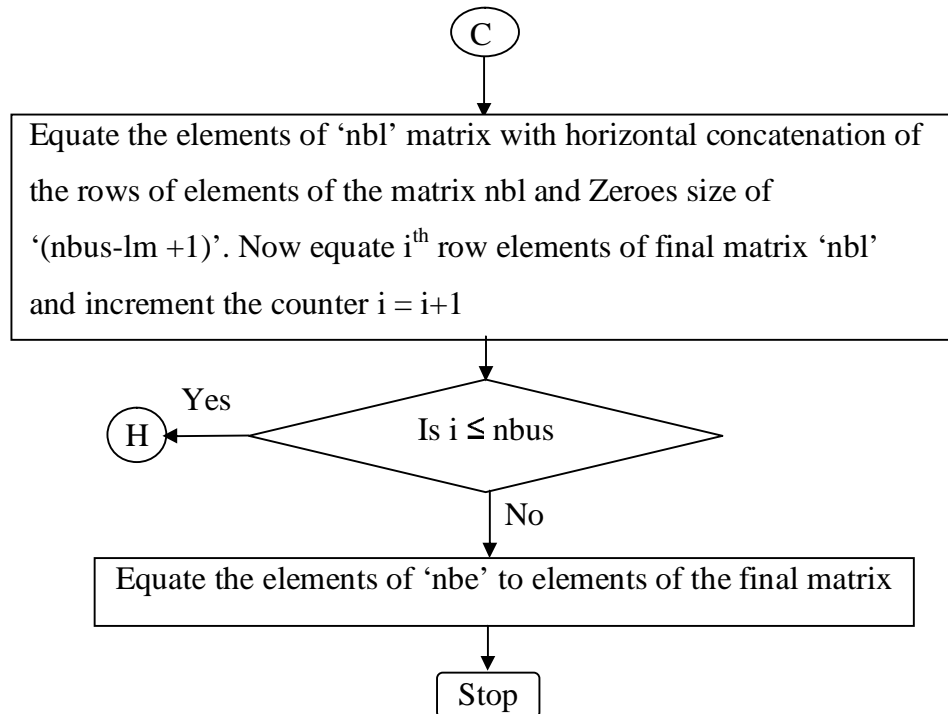
omitted from the receiving end bus matrix that results in reduction of one branch from the pre-fault PDN.

- The bus count is initially set to 1.
- Until the maximum bus number in the EPDS is reached the lateral and sub-lateral count is increased at each node (i.e. bus). The count for the lateral or sub-lateral is incremented or not depending on if there exists connectivity or not.
- For all the nodes the above steps are repeated to know the number of laterals and sub-laterals in the EPDS. This helps in analyzing overall connectivity of the PDN. The flow chart of the new network connectivity method for the analysis of pre/post fault power distribution network is shown in Figure 2.4.









**Figure 2.4 Flow Chart of the New Network Connectivity method**

The matrix 'nn' will give the Branch Connectivity matrix of the PDN and the matrix 'nbe' will give the nodes beyond a particular node in PDN.

This approach does not require the entire knowledge of the number of lateral or sub lateral in the PDN. The only data required is that the details of sending and receiving end buses. The sum of loads of the nodes in each row of the matrix 'nbe' will give node load of respective node corresponding to that row.

To analyze the post fault state of PDN, the details of the post fault network connectivity are used. The simulation of disconnected faulty branches is done by setting the respective tie/sectionalizing switch status to zero in each configuration of the PDN.

## **2.5 NUMERICAL EXAMPLES AND IMPLEMENTATION OF NEW NETWORK CONNECTIVITY METHOD FOR THE ANALYSIS OF VARIOUS EPDS**

The developed algorithm for New Network Connectivity Method has been tested and demonstrated under normal and faulty conditions on various distribution systems viz., 12-Bus, 16-Bus, 26-Bus, 29-Bus, 33-Bus, 69-Bus, 79-Bus, 133-Bus. Matrix formulation for branch connectivity and the nodes beyond a particular node along with identification of nodes connected to a particular feeder are presented and illustrated below for 12-bus system.

### **2.5.1 Formulation of Network Connectivity Matrices for the 12-Bus Radial distribution system**

Under pre and post fault conditions of the EPDS, for the 12-Bus Distribution System, formulation of Network connectivity Matrices is



nn= Branch Connectivity Matrix

$$nn = \begin{bmatrix} 1 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 3 & 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 4 & 5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 5 & 6 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 6 & 7 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 7 & 8 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8 & 9 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 9 & 10 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 10 & 11 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 12 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 12 \end{bmatrix}$$

nbe= Matrix of nodes beyond a particular node

$$nbe = \begin{bmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 \\ 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 0 \\ 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 0 & 0 \\ 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 0 & 0 & 0 \\ 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 0 & 0 & 0 & 0 \\ 6 & 7 & 8 & 9 & 10 & 11 & 12 & 0 & 0 & 0 & 0 & 0 \\ 7 & 8 & 9 & 10 & 11 & 12 & 0 & 0 & 0 & 0 & 0 & 0 \\ 8 & 9 & 10 & 11 & 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 9 & 10 & 11 & 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 10 & 11 & 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 11 & 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

### 2.5.1.2 Formulation of Network Connectivity Matrices for the 12-Bus Radial Distribution System with Single Line to Ground Fault at bus No.6.

The 12-Bus distribution system and data are presented in Appendix 1. The bus connectivity details are given below in Table 2.4. The formulation of branch connectivity matrix and the matrix of nodes beyond a





$nbe_1 =$  Modified Matrix of nodes beyond a particular node

$$nbe_1 = \begin{bmatrix} 1 & 2 & 3 & 4 & 5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 3 & 4 & 5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 3 & 4 & 5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 6 & 7 & 8 & 9 & 10 & 11 & 12 & 0 & 0 & 0 & 0 & 0 \\ 7 & 8 & 9 & 10 & 11 & 12 & 0 & 0 & 0 & 0 & 0 & 0 \\ 8 & 9 & 10 & 11 & 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 9 & 10 & 11 & 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 10 & 11 & 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 11 & 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

## 2.6 SUMMARY

For identifying the connectivity of pre-fault/ post-fault power distribution network a New Network Connectivity Method is presented. The method needs only the line data consisting of sending end bus numbers and receiving end bus numbers which is its simplicity. The change in configuration of the post fault PDN is sensed by the breaker status in the faulty section of the line and its status is read as '0' (open). It is not a system dependent method. It is a generalized tool with minimum input data requirement for the network connectivity analysis of pre/post fault PDN. In the efficient operational planning of the EPDS the knowledge of pre/post fault distribution network helps in the connectivity identification.