

LOAD FLOW OF DISTRIBUTION SYSTEM USING GRAPH ALGORITHM

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Of

MASTER OF ENGINEERING *In* **Power Systems**

Submitted by

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DECLARATION

I hereby certify that the work which is being presented in dissertation entitled, "**Load Flow of Distribution System using Graph Algorithm**" in the partial fulfillment of the requirement for the degree of **Master of Engineering in Power Systems**, submitted in Electrical and Instrumentation Engineering Department, Thapar University, Patiala as a part of curriculum during **Master of Engineering in Power Systems**, submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Ms. Suman Bhullar**, Assistant Professor, EIED, Thapar University. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

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It is certified that the above statement made by the student is correct and true to the best of my knowledge and belief.

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"Achievement is finding out what you would be doing, what you have to do. The higher the summit higher will be the climb." It has been rightly said that we are built on the shoulders of others but the satisfaction that accompanies the successful completion of any task would be incomplete without the mention of the people who made it possible.

Gratitude is accorded to all the authorities of Thapar University, Patiala for providing the necessary facilities to complete my M.E thesis work.

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The paucity of words does not compromise to thank my parents, whose blessings have brought me this far in life.

(Tafheem Ashraf)

DEDICATED TO MY PARENTS

ABSTRACT

Load Flow analysis is significant mechanism which is used in all the aspects of designing, operation as well as expansion of distribution system. It is the study which comprises the research of foremost importance. This analysis displays capability of electrical power system as well as flow of power i.e real and reactive for specific state during the steady state operating conditions of system. A large number of methods have been developed till date for analyzing the load flow solution of distribution systems. Graph algorithms has become vital for the load flow solution of distribution network, which leads to traversal of the graph either in breadth first manner known as Breadth first search algorithm or depth first mode known as Depth first search algorithm so that each node is absolutely visited once in a precise order. In this dissertation, firstly adjacency matrix is developed from the single line diagram of distribution network in order to make a biograph. Biograph is then traversed in Breadth first search algorithm that leads to the exploration of power flow paths and two different matrices are constructed, Bus Injection to Branch Current Matrix (BIBC) and Branch Current to Bus Voltage Matrix (BCBV) for load flow solution. Secondly different types of loads are calculated at rated voltage, after which Backward/Forward sweep is employed in order to update currents and voltages at every individual bus of the distribution system. Thus completing the load flow process and the results are obtained. The results are compared with other methods and are tested on IEEE-15, 28 & 33 bus system.

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LIST OF ABBREVIATIONS

BFS	Breadth First Search
DFS	Depth First Search
BIBC	Bus Injection to Branch Current Matrix
BCBV	Branch Current to Bus Voltage Matrix
FIFO	First In First Out
RDN	Radial Distribution Network
BINP	Bus Injection to Node Power Matrix
LLNP	Line Loss to Node Power Matrix

NOMENCLATURE

P_{br} loss	Real Power loss in branch
Q_{br} loss	Reactive Power loss in branch
P_t loss	Total Real Power loss
Q_t loss	Total Reactive Power loss
V_i	Voltage at each bus in per unit
V_a	Voltage angle at each bus
N	Total nodes or buses
Z_t	Constant Impedance Type Load
I_t	Constant Current Type Load
PQ_t	Constant Real and Reactive Power Type Load
ZIP_t	Mixed Type Load
IL	Line Current
S_i	Complex Power injected at <i>ith</i> bus
I_{jk}	Current through branch-jk
I_{hj}	Current through branch-hj
V_j	Voltage of node <i>j</i>
V_h	Voltage of node <i>h</i>
Z_{hj}	Impedance of branch <i>hj</i>
I_i	Current Injected at bus- <i>i</i>

NB	Number of Branches
IBr	Branch Current
R	Resistance of Branches
X	Reactance of Branches

CHAPTER-1

INTRODUCTION

1.1 ELECTRICAL POWER SYSTEM

Electrical energy is generated in large hydro-electric, thermal and nuclear power stations. These stations are mainly located at distant places from load centers. This requires a broad power supply network between the generating stations and the consumer loads. Figure 1.1 shows the layout of power supply network. This system might be separated into two parts viz., transmission system and distribution system. The former may be divided into primary and secondary (or sub) transmission and the latter into primary and secondary distribution. Transmission lines transfer majority of electrical power from sending end stations to receiving end stations without supplying any consumers along their route: by contrast, a distribution line or distributor supplies consumers directly at short intervals along the line. The transmission system of a region (or state) is acknowledged as grid. The different grids are connected through tie lines to form a regional grid and the different regional grids are further connected to form a national grid. Each grid functions individually. Though, power can be transferred from one grid to another, over tie lines, under conditions of sudden loss of generation or increase in load. The maximum generation voltage in progressive countries is 33 kV while that in India is 11 kV. The quantity of power that has to be transferred via transmission lines is in bulk and if this power is transferred at 11 kV or 33 kV, the line current and the power loss would be huge. Consequently, this voltage is stepped up to some higher value using step up transformers placed in substations (known as sending end substations) near the generating stations. The high voltage transmission lines transfer electrical power from the sending end substations to the receiving end substations. At the receiving end substations the voltage is stepped down to a lower value. The secondary transmission system forms the link between the main receiving end substations and the secondary substations [1]. The transmission and distribution system differs in terms of their structure while former is having loop nature and later is radial in nature. Also distribution system is having high ratio of R/X as compared to transmission systems [2].

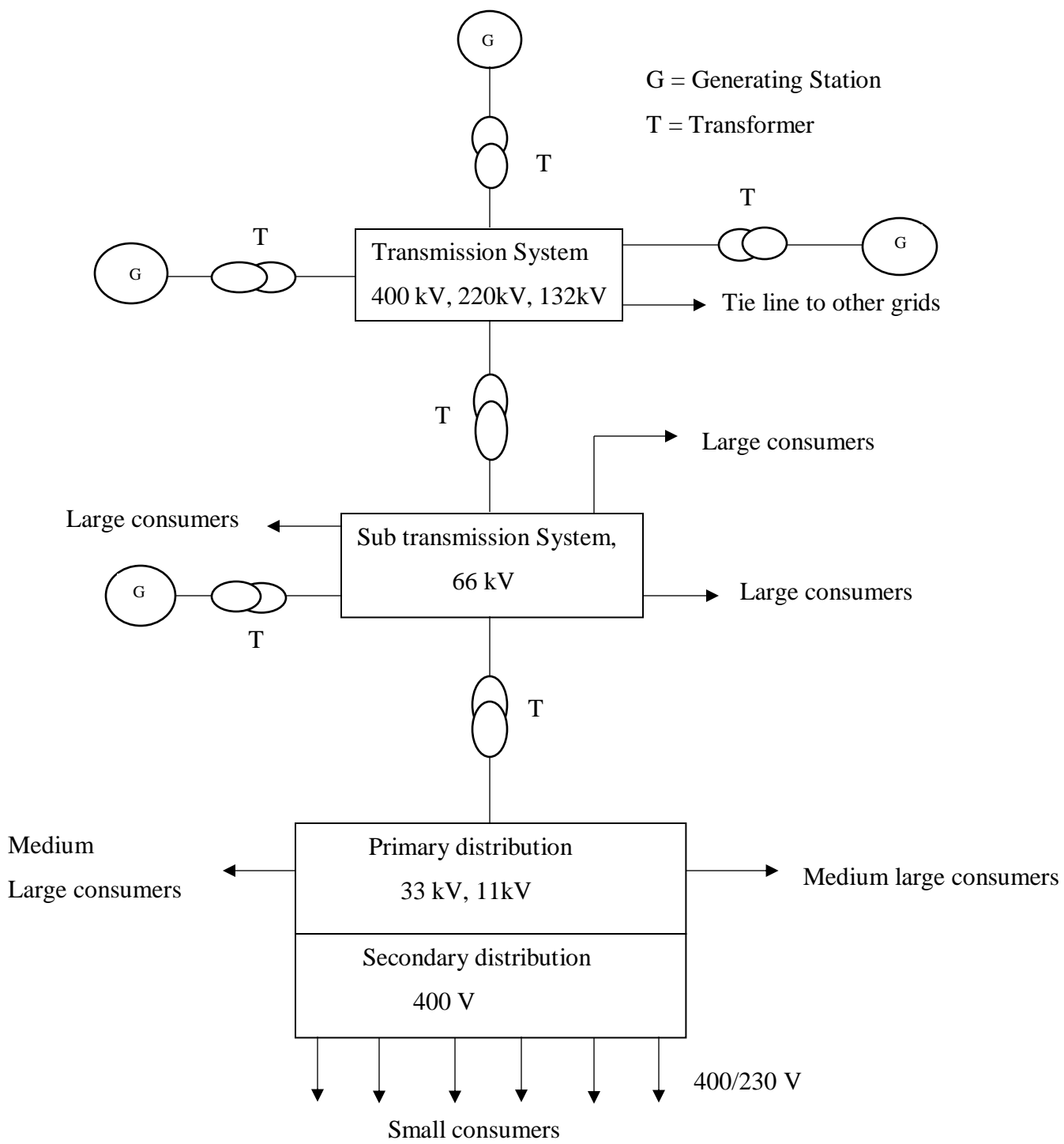


Fig 1.1 Power System Network

1.2 DISTRIBUTION SYSTEM

The generation of electrical energy at generating stations is transmitted to consumers via transmission and distribution systems. In general, distribution system is that part of power network that distributes power to the consumers for utilization. The distribution system is the electrical network between the sub –station fed by transmission network and the costumer meters. Figure 1.2 shows the main parts of distribution system viz feeders, distributors and service mains [3].

Feeders are conductors that provide connection between substations and load areas where power is to be delivered. Feeders remain same from beginning to end because connections cannot be taken from a feeder. For the design of feeder, current carrying capacity is taken into account.

Distributors are also conductors from were connections are taken in order to supply power to load. However, there is a variation of voltage at load end which is $\pm 10\%$ of rated value and hence for the design aspects of distributors, the drop in voltage is taken into account. Because of connections placed at different points on the distributor path, the flow of current is of varying nature.

Third part of distribution system i.e. service mains is a connecting wire between distributor and load terminal.

An efficient distribution system has following characteristics:

- It must have less voltage drop.
- It should have balanced three phase supply.
- There should be small disturbances during supply of power.
- Voltage flickering should be in acceptable limits.

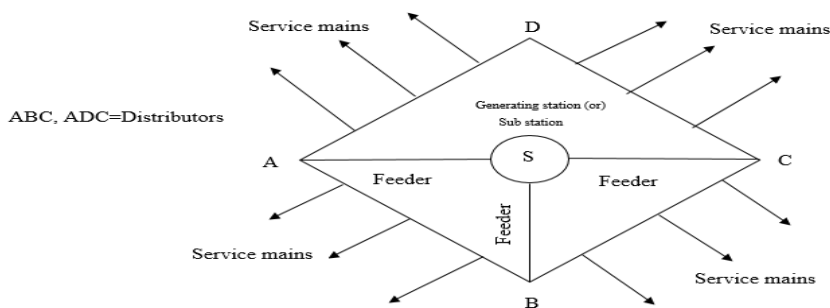


Fig 1.2 Single Line Diagram of Distribution System

1.3 CLASSIFICATION OF DISTRIBUTION SYSTEMS

Distribution systems can be categorized corresponding to [3]:

(1) Nature of current: Owing to the nature of current, distribution systems are categorized as-

(a) A.C distribution system (b) D.C distribution system

Presently the distribution of electric power is done through A.C rather than D.C, the reason being A.C distribution is easy and effective and also voltage can be stepped up and down in A.C that causes power to flow in a trouble-free manner.

(2) Type of construction: In this category, distribution systems are divided into-

(a) Overhead system

(b) Underground system

For the purpose of distribution of electric power, overhead systems are mainly commissioned because they are economical [3] than the corresponding underground systems, whereas underground system is employed at such areas where it is difficult to construct overhead system or where the public laws do not permit.

(3) Schemes of connection: In this category, distribution systems have following types-

(a) Radial system:

The radial system is that type of distribution system in which number of feeders branch out from single sub-station and these feeders are connected to different kinds of distribution centers at one end and sometimes at both ends only. There are laterals and sub-laterals in the radial distribution system. Figure 1.3 & 1.4 show the single line diagram for D.C and A.C distribution.

Benefits of Radial System:

- Construction is simple.
- It is economical.
- Because of simple construction and cheapest price, radial system is used as most common distribution system for power flow in rural India.

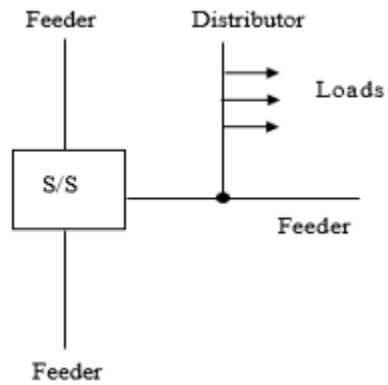


Fig 1.3 Single Line Diagram of D.C Radial Distribution System

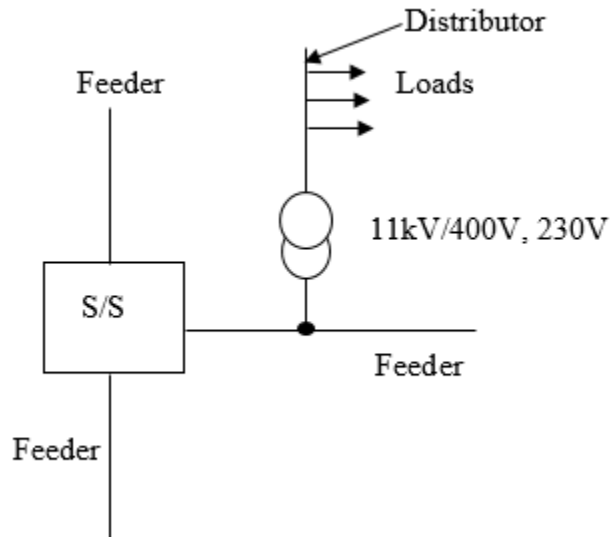


Fig 1.4 Single Line Diagram of A.C Radial Distribution System

(b) Ring main system:

In ring main system, the distribution transformer primaries form a loop. Starting from the sub-station bus-bars, the loop circuit encloses the entire serving area and comes back to sub-station. Figure 1.5 shows the single line diagram of ring main system for A.C distribution. Here the primary ring gets supply from sub-station. Tapping's of distributors is done at various positions of the feeder via distribution transformers.

Benefits of ring main system:

- At customer ends, the fluctuations in voltage are reduced.
- The system is very much reliable because of the fact that every distributor is supplied through two feeders due to which if there is fault in any one of the feeder, the supply does not get interrupted and flow is maintained.

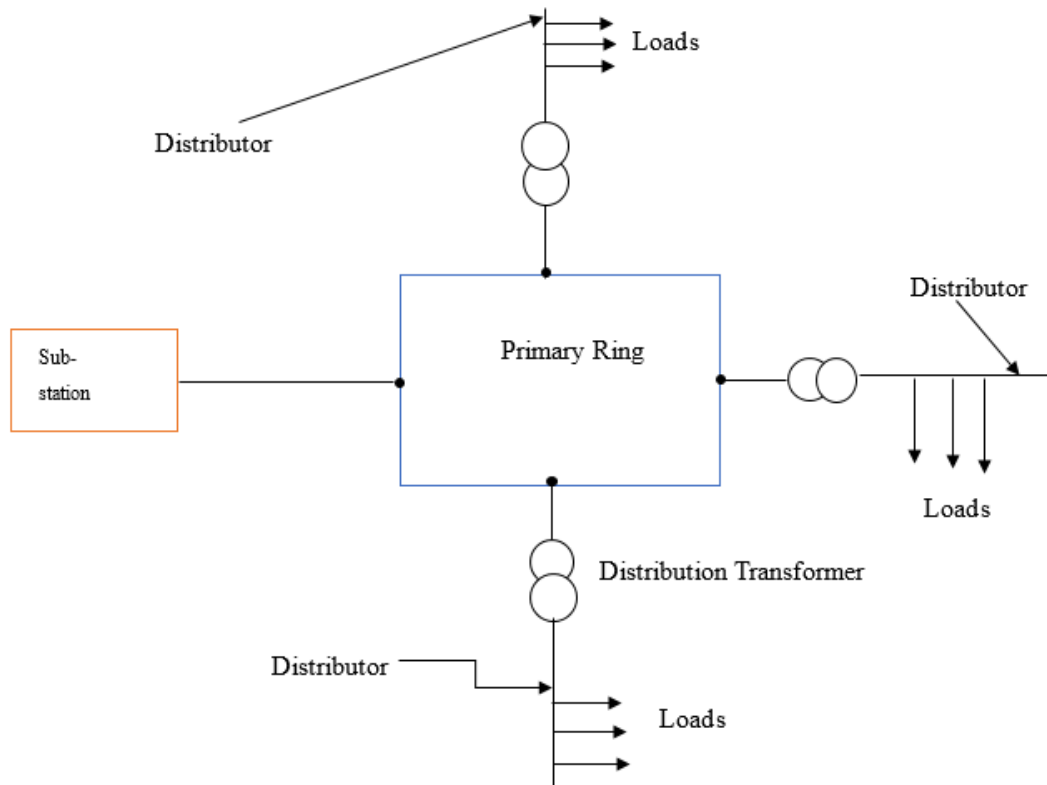


Fig 1.5 Single Line Diagram of Ring Main A.C distribution system

(c) Interconnected system:

Two or more than two sub-stations or generating stations when provide supply to feeder ring, is known as interconnected system. Figure 1.6 presents single line diagram of interconnected system. From this figure, feeder ring ABCD is energized by two sub-stations S1 and S2 located at D and C correspondingly. At positions O, P, Q and R of the feeder ring in figure 1.6, distributors are connected via distribution transformers.

This type of system has the advantages as:

- The service reliability is enhanced.
- Any area which is supplied by single sub-station can also be supplied by other sub-station during peak load hours, which will decrease the reserve power capacity and efficiency of system will be enhanced.

In order to maintain supply of the electric power as required by different types of customers, significant amount of efforts are mandatory. Distribution systems must have the capability to supply power to the customers according to their load demands. Service reliability is one of the important factor in present time. Industries, homes, business units, emergency services all require reliable service because they all are dependent on electric power for their operation.

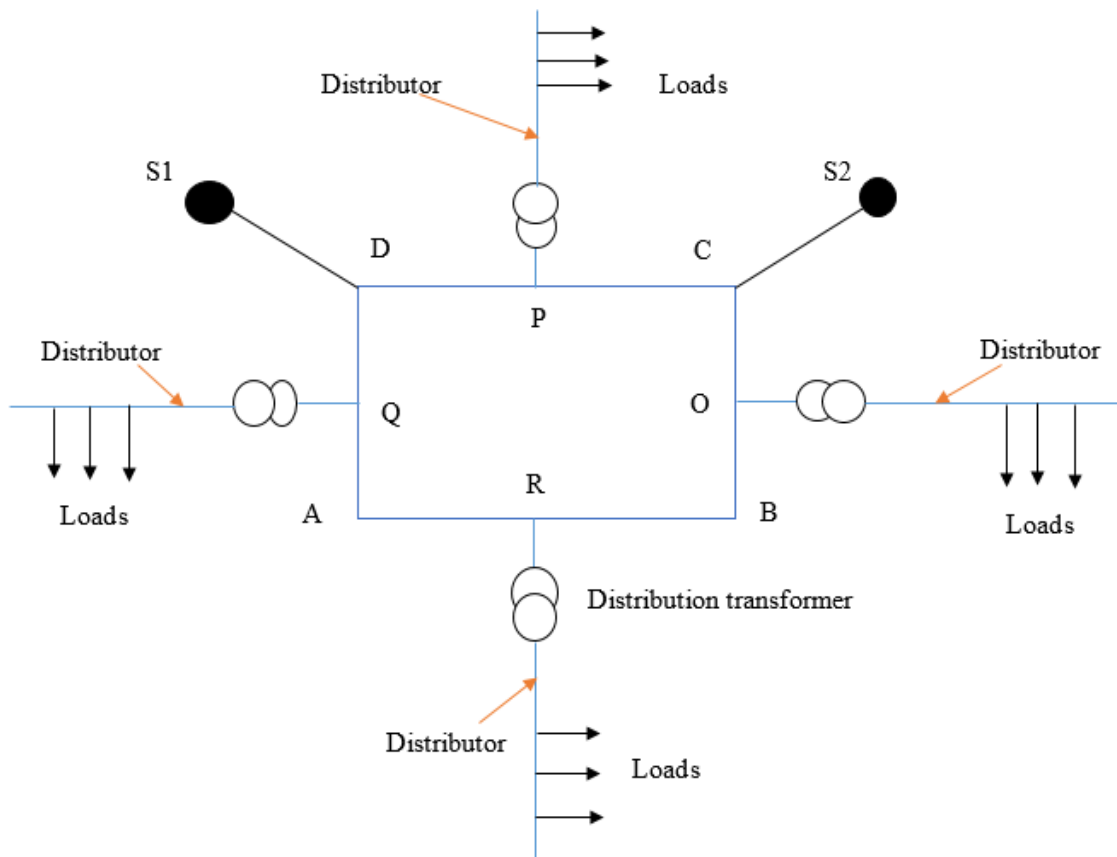


Fig 1.6 Single Line Diagram of Interconnected Distribution System

1.4 LITERATURE REVIEW

Mohanty *et al.* [2] developed a technique on radial distribution network which was depending on network topology. The proposed technique presented evaluation of stability for radial distribution system and involved use of two stable voltage indices for determination of bus which was more responsive to voltage collapse. This technique involved analysis of simple algebraic expression of voltage magnitude and trigonometric functions were not used. After performing load flow analysis, voltages at all the buses were determined. The bus which was having minimum stability index was more responsive to voltage collapse. Also responsiveness was executed to determine finest position of shunt capacitor placement. This technique entirely exploited radial characteristic of distribution system.

Shirmohammadi *et al.* [4] presented a newly load flow method in order to solve weakly meshed distribution and transmission system by utilizing multi-port compensation technique and elementary formula of Kirchhoff's laws. Branch numbering scheme was used so as to boost numerical operation for solution technique. They developed computer program in order to implement their load flow technique and victoriously their program was used in various practical distribution systems having radial and weakly meshed structure.

Baran and Wu [5] provided the solution of power flow analysis of radial distribution system using reiterative results involving elementary expressions which represented active power, reactive power and voltage magnitude.

Chiang [6] provided three different algorithms to get solution of radial distribution network on the basis of technique given in [4].

Jasmon and Lee [7] developed a technique for power-flow analysis in order to obtain the power-flow results for radial distribution system by implementing three basic equations illustrating real power, reactive power and voltage magnitude as presented in [4]. Authors presented the criteria for voltage instability. This technique compared the performance of three A.C load flow methods in terms of their capability to resolve the voltage stability issues of distribution systems.

Rahman *et al.* [8] presented novel method so as to discover static voltage stability of load buses in a power system with respect to some operational conditions. Therefore determined load buses near to breakdown voltage. The voltage stability index with respect to load bus was formulated

from voltage equations which were obtained from a two-bus system. These were evaluated with the help of thevenin equivalent circuit of power network referred to load bus. The presented method computed load flow solution of radial distribution network having reduced number of iterations.

Keresting & Mendive [9] and **Keresting** [10] developed a load flow technique for solution of radial distribution network. Keresting & Mendive [9] updated voltages and currents using ladder network theory based on backward/forward sweep.

Iwamoto and Tamura [11] developed a technique to calculate load-flow of ill conditioned power network as there had been no practical method to solve the same. The proposed technique involved no mathematical estimation, was effortless, and was entirely based on practical approach. Employing this technique, the load flow solution never got diverged. The existing solution could be easily decided from the initial approximation. The developed technique was effortlessly integrated into normal Newton-Raphson method.

Rajicic and Bose [12] developed a technique for the modification of fast decoupled method in order to handle high R/X branch ratios. This developed technique of modification was efficient and reliable as compared to series and parallel compensation methods. The technique was efficient as the fast decoupled method for marginal R/X ratios switched to modification during abnormal R/X ratios, only when fast decoupled method had failed. Therefore for the conditions where calculation time was supreme, the developed technique proved adorable.

Renato [13] developed a single technique for obtaining load flow results of radial distribution system. It was to determine electrical equivalent of every bus which was summation of all loads supplied to the system via bus which included losses. From root bus, the voltage of every individual receiving bus was determined.

Jamali et al. [14] developed a power flow method which was based on numbering of branches in sequential manner. In order to design distribution system, authors considered committed loads which included residential, commercial, public, and industrial loads. Current and demand committed loads were also put into consideration.

Chakravorty and Das [15] provided the technique of voltage stability index in order to discover the node which was more responsive to voltage collapse. After calculating parameters at all nodes,

proper position was found. Efficacy of the technique was demonstrated by performing it on 69-bus radial distribution system and was found acceptable.

Goswami and Basu [16] developed a technique based on direct power flow solution of radial distribution network by fully exploiting topological feature of distribution systems. In order to attain memory requirements and calculation performance, a distinctive branch and node numbering scheme was provided. This technique handled the mixed load modelling easily. The developed technique was also incorporated to meshed distribution networks and unbalanced networks. Results for memory requirements and calculation performance was found to be same as in balanced one.

Abul'Wafa [17] developed a technique to determine the load flow solution of radial distribution system depending on network graphical information. This technique needed statistics for arrangement of branch data just in a manner that receiving bus should have ascending order. The given technique allowed construction of two different matrices: Bus injection to branch current matrix and Branch current to bus voltage matrix for determination of load flow results. The capability to converge was determined for various conditions of load and various values of tolerance for comparison purposes. The efficacy of this technique was performed on 8-test systems.

Das et al. [18] provided easy and competent technique to solve load flow of radial distribution system having different types of load modelling. This technique was efficient and required less computer memory

Murthy et al. [19] developed a technique to determine load flow results of radial distribution system. Two matrices were constructed by employing network topology so as to calculate load flow solution. Two parts having effective load were determined from two new network matrices: Bus injection to node power matrix (BINP) and Line loss to node power matrix (LLNP). The technique involved simple algebraic equations containing magnitude of voltage.

Ghosh and Sherpa [20] provided an efficient technique so as to calculate load flow of radial distribution system having reduced data. In this technique, numbering scheme for branches and nodes need not to be sequential. The given technique used comprehensible equations for determination of voltage magnitude and had the potential of handling mixed load. Efficacy of the

given technique had been tested on 33 and 69-bus system having constant power, constant current, constant impedance, mixed and exponential loads.

Murari *et al.* [24] developed a technique to determine load-flow analysis of radial distribution system by employing matrix method. The technique involved identification of nodes beyond every branch with reduced calculation time and memory. The matrix caused the solution to be entirely Simpler and the solution converged exceptionally in short time. Efficacy of the technique was evaluated on 33-bus system having constant power, constant current, constant impedance, mixed and exponential loads.

N.Murty *et al.* [25] developed a technique to analyze power flow of radial distribution network. The motive of this method was to minimize the data composition in order to evaluate power flow solution of radial distribution network. This developed technique involved simpler expressions, needed reduced time for calculation and number of iterations. Backward/forward sweep technique was employed in this method. The developed technique did not require construction of bus injection to branch current matrix and branch current to bus voltage matrix respectively. The proposed method calculated power flow in two manners on the basis of current and power.

Ghosh and Das [26] developed a power flow technique in order to solve radial distribution system by determining the nodes after branches. They employed voltage convergence, started with flat voltage profile and proved convergence. Authors presented that by incorporating charging admittances losses were reduced and voltage profile was improved. The developed technique computed each branch current by addition of load currents of the nodes after the particular branch.

Ghosh [27] presented further technique to solve load flow. This technique helped in reduction of data preparation and handled the scheme for arbitrary numbering of nodes in a simple way.

Das *et al.* [28] developed novel based method in order to solve radial distribution system. Forward sweeping was employed to solve distribution network. This technique fully exploited the radial nature of distribution system. A special lateral node, branch numbering scheme was proposed that provided power flow solution of radial distribution system. There was guaranteed convergence for any experimental radial distribution system having R/X ratio by employing forward sweep method. The proposed technique stored all of the data in vector form therefore decreasing memory

requirements. This technique handled mixed loads in a simpler sense if break up of loads was known.

Jena *et al.* [29] provided a network topology based back/forward sweep technique so as to solve radial distribution system. This method employed matrices derived from network graphical information and equations based on Kirchhoff's current law and Kirchhoff's voltage law. The data was kept in matrix form which reduced the requirements of memory. Using backward/forward sweep, currents and voltages were updated. The technique had been evaluated on IEEE 33 and 69 test systems and results were acceptable.

Singh and Ghose [30] presented a systematic technique to solve load flow of radial distribution network. The branch flows of radial network were directly determined by employing novel transformation method. This technique caused backward/forward sweep to be fast. Exploitation of radial nature of radial distribution system and simple matrix manipulations in order to get desired transformation was provided by matrix transformation method.

Sharma *et al.* [31] developed a technique for implementation of load flow analysis algorithm by making use of graph theory and this technique was evaluated on 69-node radial distribution system. This technique made use of adjacency list in order to represent radial network and complexity of the load flow analysis algorithm was $O(n)$. Where n is order.

Teng [32] provided a technique based on network topology in order to solve three-phase distribution load flow problem. There was a full exploitation of network topology so that direct solution was possible. BIBC and BCBV matrices developed were sufficient to determine load flow solution.

Prakash and Sydulu [33] developed a technique which was completely exploiting the radial feature of system and determined power flow of distribution system directly. The practical data composition was suggested in order to recognize all the branches incident upon line which were between supply buses and any chosen buses. By employing this aforementioned idea and primitive impedance of the branches, only diagonal elements of distribution power flow matrix were evaluated and they had to be kept in single dimension vector so as to get distribution power flow solution.

1.5 RESEARCH GAP

From the above article 1.4, there is still possibility of obtaining load flow solution of radial distribution system by employing Graph algorithms with reduced number of iterations, less time, small computer memory requirements and faster rate of convergence.

1.6 OBJECTIVE OF THE DISSERTATION WORK

The motive concerning this dissertation work is to evaluate load flow analysis of radial distribution system. To achieve this objective, the following steps have been carried out using MATLAB:

- Construction of adjacency matrix so as to obtain biograph.
- Traversing the biograph in Breadth First Search algorithm so as to determine two different matrices BIBC and BCBV for power flow.
- Performing Load modelling with different types of loads at rated voltage.
- To calculate currents and voltages at each individual bus using Backward/Forward sweep.

1.7 ORGANIZATION OF THE DISSERTATION

Chapter-1 presents introduction, literature review, research gap, objective of dissertation work and organization of dissertation.

Chapter-2 presents review for Graph Algorithms.

Chapter-3 presents problem formulation, its solution methodology and technique for its evaluation.

Chapter-4 shows the results and discussions of 15, 28 and 33-bus radial distribution network and concludes the dissertation work.

Chapter-5 presents conclusions and future scope.

References show already published papers examined by the author associated with Load Flow of Distribution System.

Appendix-A displays the test data for IEEE-15 bus RDN.

Appendix-B displays test data for IEEE-28 bus RDN.

Appendix-C displays test data for IEEE-33 bus RDN.

CHAPTER-2

GRAPH ALGORITHMS

2.1 INTRODUCTION

A large number of problems are normally constructed concerning objects and the links among them. For example, in electrical circuits, the connections in between the objects play a prime role. The circuit elements such as resistors, inductors, capacitors are connected together with twisted wires. These circuits are illustrated and handled within a computer. A graph represents scientific way to model objects in such type of conditions [21].

Graph theory is a vital field of connectional mathematics that has been studied effectively for a decades now and innumerable effects of graphs have been manifested.

Graphs are mathematical structures representing association among objects. Graphs consist of two fundamental constituents:

- **Nodes**
- **Edges**

Nodes are the prime constituents in any graph. Nodes are having distinct and independent existence and their association is demonstrated with the use of edges.

Edges are the constituents employed to illustrate the association among different nodes of the graph. The edge between two nodes represents a single-path or double-path relationship among nodes.

Classification of Nodes:

- **Source node or Root node-** This node is the forebear of all other nodes of the graph. Root node itself has no forefather. Every graph has its one source node and traversing the graph must be from source node.
- **Leaf node-** The leaf nodes or end nodes in a graph don't possess descendants. These have only predecessors. Leaf nodes possess any number of incoming edges and not a single outgoing edge.

Classification of Graphs:

- **Undirected Graph-** In this graph, all the edges are bifacial i,e they don't mark any particular direction.

- Directed Graph- In this graph, all the edges are unifacial i.e they point towards single direction.
- Weighted Graph- In this graph every edge is allocated with a weight or cost.
- Cyclic- A graph is said to be cyclic if it consists a path which starts from a particular node and ends at the same node. Acyclic graph is also a graph but with no cycle.

Representation of a Graph:

A graph can be represented in numerous ways but the two prime ways of its representation is as:

- Adjacency Matrix- This is a $N \times N$ binary matrix A. The value of element $A_{i,j}$ is 1 if there exists edge between nodes i and j otherwise its value is 0. There is also possibility to modify adjacency matrix with respect to weighted graph in which element $A_{i,j}$ can accumulate weight or cost of edge instead of storing 0 or 1.

If there is undirected graph then $A_{i,j}=1$ and $A_{j,i}=1$ but in a directed graph if $A_{i,j}=1$ then $A_{j,i}$ may or may not be 1. Space complexity of the adjacency matrix is $O(V)^2$. where V represents number of nodes.

The adjacency matrix of the graph shown in Figure 2.1 is as:

$i / j:$	1	2	3	4
1:	0	1	0	1
2:	1	0	1	0
3:	0	1	0	1
4:	1	0	1	0

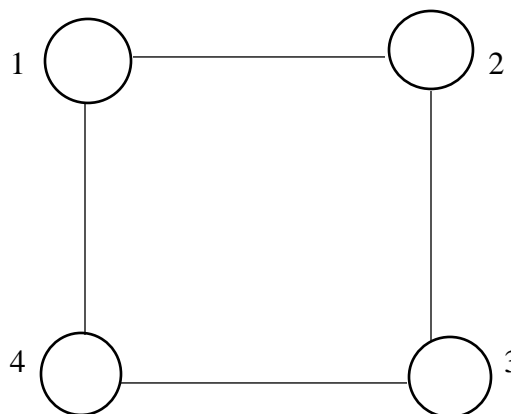


Fig 2.1 Undirected Graph-I

- Adjacency List- There can be another representation of graph also called as adjacency list. It is an array A having distinct lists. Every element of the array A_i is a list containing all the nodes that are adjacent to node i . As for as weighted graph is concerned, the weight or cost of the edge is accumulated including the node in the list using pairs. For undirected graph, if node j is in list A_i then node i will be in list A_j .

The space complexity of adjacency list is $O(V+E)$ because as far as adjacency list is concerned only those edges keep information that literally exist in the graph. Figure 2.2 shows the undirected graph for which adjacency list is as:

$A_1 \rightarrow 2 \rightarrow 4$

$A_2 \rightarrow 1 \rightarrow 3$

$A_3 \rightarrow 2 \rightarrow 4$

$A_4 \rightarrow 1 \rightarrow 3$

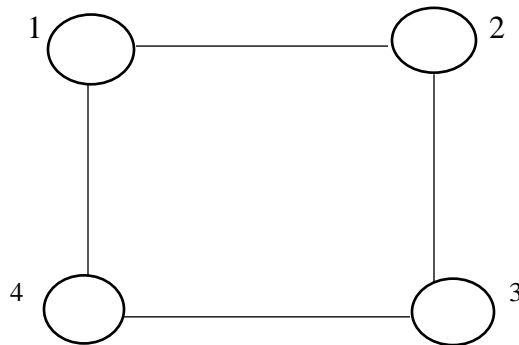


Fig 2.2 Undirected Graph-II

2.2 GRAPH TRAVERSALS

Graph traversal implies to visit each node absolutely once in a precise order. While traversing a graph it is vital to track the nodes that have been visited and to mark them is the best technique to track the nodes. While making use of some graph algorithms, every node of the graph must be visited absolutely once. The order for the visiting nodes is vital and will rely upon the algorithm while formulating for the problem evaluation. [21].

2.2.1 BREADTH FIRST SEARCH (BFS) GRAPH TRAVERSAL METHOD

Graph traversing involves innumerable techniques but breadth first search is the most frequently employed technique. In breadth first search algorithm, traversing the graph is done from any chosen node (Root or Source node) in a breadthwise or layer wise manner such that adjacent nodes are explored (Nodes that are directly connected to the particular node which is under consideration). Then traversing is continued to next layer adjacent nodes. Breadth first search

technique traverses horizontally by visiting all the nodes of particular level under consideration and then traverse to next level. From the figure 2.3 given below it is clear that the space between the nodes of layer 1 is smaller than between nodes of layer 2. So in breadth first search traverse all of the nodes in layer 1 before heading towards layer 2. [21]

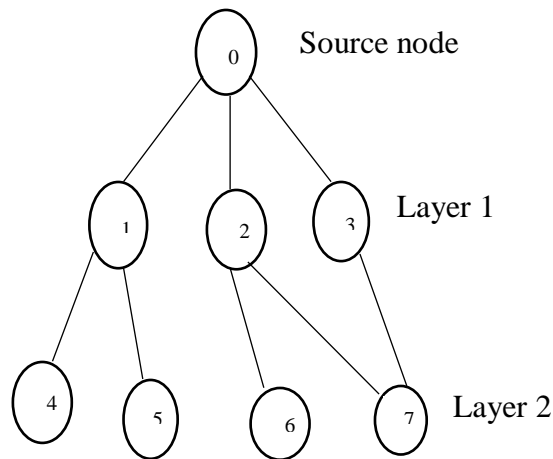


Fig 2.3 Breadth First Search Traversing Diagram-I

Traversing the child nodes:

A cyclic graph is a graph containing cycles and while traversing this graph brings us to the same node from where it had started earlier. To prevent the process of similar node again, Boolean array is employed so that the node is marked after processing. During the visit to nodes in some particular level of graph, store these nodes in such a way that the corresponding child nodes are traversed in similar order. From the figure 2.3, traversing starts from source node 0 and by visiting its child nodes 1, 2 and 3, store them in the order in which they have been visited. Due to this traversing, first child nodes of 1 will be visited i.e 4 & 5 then child nodes of 2 i.e 6 & 7 and finally child nodes of 3 i.e 7 will be visited. Making this technique simple to be processed following procedure is used:

- A queue is employed in order to store node and mark it visited till all of its adjacent nodes are marked.
- FIFO (First In First Out) queuing technique is followed by the queue so that the adjacent nodes of the particular node under consideration are visited in such an order in which they were placed in the queue i.e that node which was placed first will be visited first and so on.

The start of traversal is from root node S and insert this S into the queue and mark it as visited and the traversing process of figure 2.4 goes as:

Iteration-1:

- S is pushed out from the queue
- Adjacent of S i.e 1 and 2 will be traversed
- 1 and 2 will now be traversed as they were not traversed earlier and these will be inserted into the queue and will be marked as visited.

Iteration-2:

- 1 is pushed out from the queue
- Adjacent of 1 i.e S and 3 will be traversed
- S will be disregarded as it is already visited
- 3 will be traversed as it was not traversed earlier and will be inserted into the queue and will be marked as visited.

Iteration-3:

- 2 is pushed out from the queue
- Adjacent of 2 i.e S,3 and 4 will be traversed
- 3 and S are disregarded as they are already visited
- 4 will be traversed as it was not traversed earlier and will be inserted into the queue and will be marked as visited.

Iteration-4:

- 3 will be pushed out from the queue
- Adjacent of 3 i.e 1,2 and 5 will be traversed
- 1 and 2 are disregarded as they been already visited
- 5 will be traversed as it was not traversed earlier and will be inserted into the queue and will be marked as visited.

Iteration-5:

- 4 will be pushed out from the queue

- Adjacent of 4 i.e 2 will be traversed
- 2 will be disregarded as it has been already visited

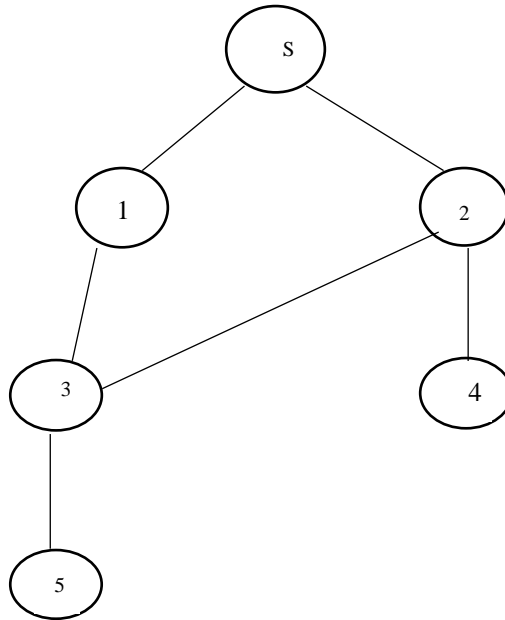


Fig 2.4 Breadth First Traversing Diagram-II

Iteration-6:

- 5 will be pushed out from the queue
- Adjacent of 5 i.e 3 will be traversed
- 3 will be disregarded as it has been already visited

The queue will now be vacant and it will come out of the loop therefore traversing all nodes employing breadth first search. Breadth first search is having time complexity of $O(N+E)$, where N is number of nodes and E number of edges.

2.2.2 DEPTH FIRST SEARCH (DFS) GRAPH TRAVERSAL METHOD

Depth first search is the repetitive technique employing the concept of reversing. It necessitates thorough searches of all the nodes by proceeding towards them, if possible else by reversing [20].

The term reversing implies that when the graph is to be traversed and by heading towards the nodes, if there are no more nodes along the path. Then traverse back along the similar path in order to explore the nodes which are to be traversed. Visit nodes along the traversing path until all

of the unvisited nodes have been traversed and select next path for traversal. This reversing technique employed by depth first search is executed by stacks as follows:

- Select a source node and insert all of its neighboring nodes into stack.
- Push out a node from the stack so that next node is selected to visit and insert all its neighboring nodes into the stack.
- This processes is repeated until the stack becomes vacant, ensuring that the nodes have been visited are marked in order to avoid visiting the similar node more than once otherwise if not doing this we will end up in an infinite loop.

Depth first search is having time complexity of $O(N+E)$, where N is number of nodes and E is number of edges.

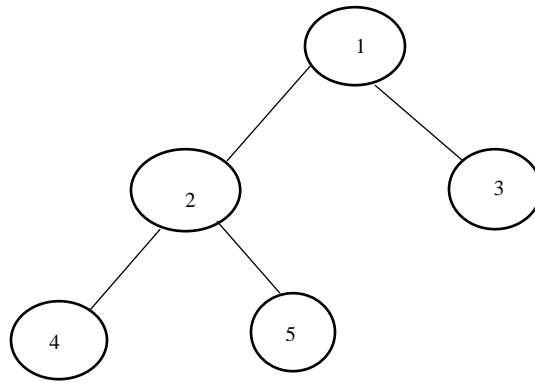


Fig 2.5 Depth First Search Traversing Diagram

The Depth First Order (DFS) of figure 2.5 can be:

$1 \rightarrow 2 \rightarrow 4 \rightarrow 5 \rightarrow 3$ or $1 \rightarrow 3 \rightarrow 2 \rightarrow 4 \rightarrow 5$ or $1 \rightarrow 3 \rightarrow 2 \rightarrow 5 \rightarrow 4$ or $1 \rightarrow 2 \rightarrow 5 \rightarrow 4 \rightarrow 3$

CHAPTER-3

LOAD FLOW OF RADIAL DISTRIBUTION NETWORK

3.1 INTRODUCTION

The study of load flow in a power network comprises the research of foremost importance. This analysis displays capability of electrical power system as well as flow of power i.e real and reactive for specific state during the steady state operating conditions of system. Furthermore, the study of power flow yields facts concerning the line and transformer loads including losses everywhere on the network as well as voltages at different points of the network for assessment and modulation of the performance of the power network under conditions known to be priori. Moreover alternative procedures are analyzed in order to meet new load demands for future development and a comprehensive data is formulated throughout the analysis.

A bus is said to be a node having single or multiple lines, single or multiple loads, and generators connected to it. It is not mandatory that all of these must be connected at each bus. The buses can be classified as: Load bus (P-Q bus), Generator or voltage controlled bus (P-V bus), and slack or swing bus (V-Q bus). The bus is designated as vertical line at which various elements are connected. In power network there are enormous buses connected with each other via transmission lines. Generators are connected at some buses while loads are connected to the remaining buses. Some buses have both generators and loads connected to them while some others may have static capacitors (or synchronous condensers) connected to them for reactive power compensation or control of voltage.

Table 3.1 Types of Buses for Load Flow Studies

Type of Bus	Quantities specified	Quantities unknown
Load bus or P-Q bus	P_i, Q_i	V_i, δ_i
Generator bus or P-V bus	P_i, V_i	Q_i, δ_i
Slack bus or Swing bus	$V_i=1, \delta_i=0$	P_i, Q_i

The most commonly buses in the power system are load buses and as far as these buses are concerned P_i, Q_i are familiar because of the fact that P_{Li}, Q_{Li} are known well from the load forecast data. Also P_{Gi}, Q_{Gi} are either zero (meaning that there is no generation at these buses) or specified. The control of governor and excitation at the generator bus enables us to designate P_{Gi} & V_i . Since P_{Li} is known (from forecast data of load) and therefore P_i is known. The requirement of one of the bus to be slack or swing is clear from the reality that at initial stage, power losses are unknown. For this reason, net flow of power into the system cannot be decided in advance. Therefore swing bus is a generator bus whose generators supply the difference of real power injected into the network and the total output of network including losses.

Furthermore the voltages through the entire network must be nearer to 1 p.u and for this reason designated voltage at slack bus is equal to 1 p.u. Also, the voltage of slack bus is chosen as reference phasor and thereby making its angle δ_i equal to 0. Normally, the bus belonging to huge generating station is selected to be the slack bus and it's numbered as bus 1.

Electrical power distribution system is having following features:

- It's having radial or weakly meshed nature.
- Enormous buses, nodes, and branches.
- Loads are distributed and operation is unbalanced.
- The values of resistance and reactance are having wide range.

3.2 PROBLEM FORMULATION

3.2.1 SOLUTION METHODOLOGY

The assumption employed is that the system is balanced and is represented by single line diagram by neglecting charging capacitances at distribution level as shown in figure 3.1.

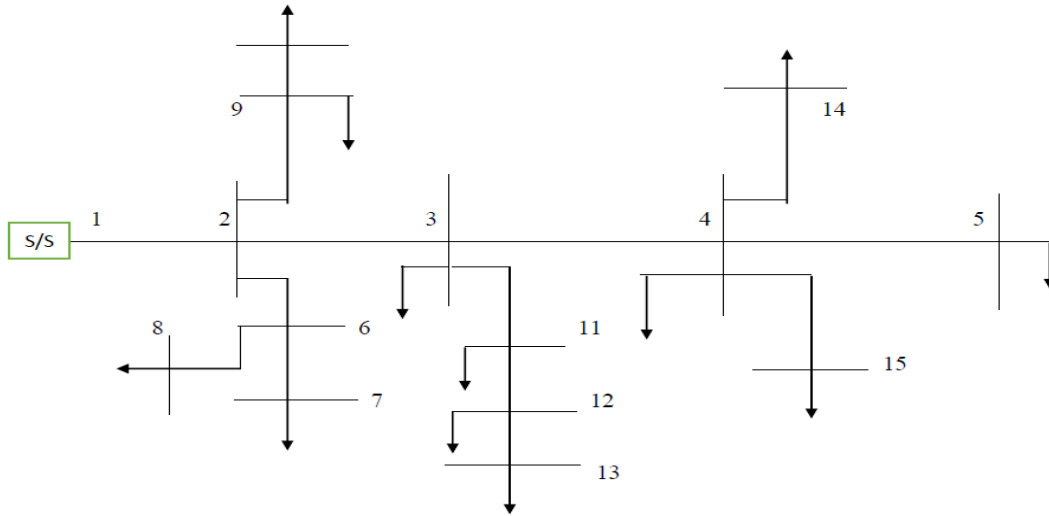


Fig 3.1 Single Line Diagram of Radial Distribution System

From this single line diagram, make a connection matrix CFT (node-node adjacency matrix) as shown below [17]:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	0	0	1	0	0	1	0	0	0	0	0	0
3	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0
4	0	0	1	1	1	0	0	0	0	0	0	0	0	1	1
5	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
7	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
8	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
9	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0
10	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
11	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0
12	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0
13	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
14	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
15	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1

The adjacency matrix given above is graphed as biograph as shown in figure 3.2.

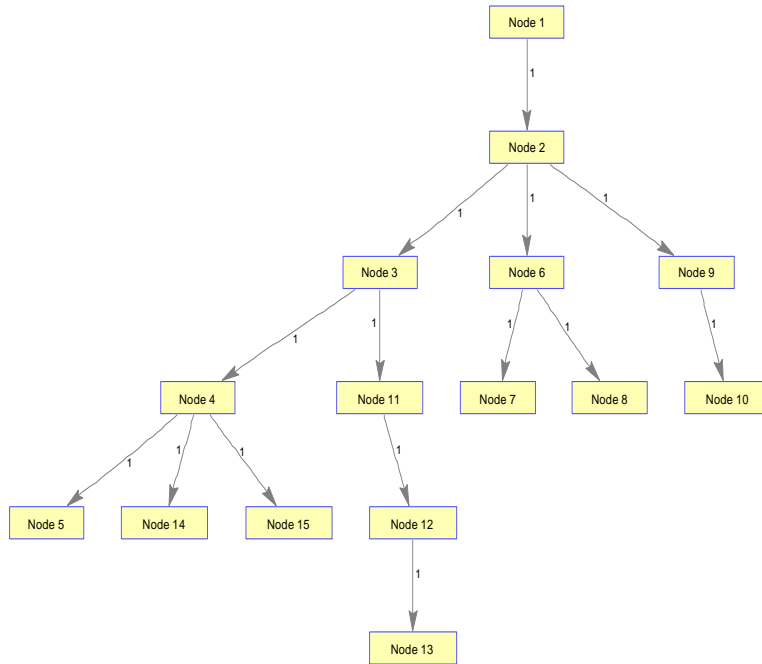


Fig 3.2 Biograph of Single Line Diagram

This graph is traversed using one of the graph traversing technique known as breadth first search (BFS) algorithm by the help of which nodes beyond a particular branch are explored [21]. In other words bus injection to branch current (BIBC) matrix is constructed and power flow paths are discovered. Travelling the directed graph in breadth first search, the flow of power through the paths starting from the node under consideration can be determined.

3.2.2 BREADTH FIRST SEARCH (BFS) ALGORITHM

The BFS traversal algorithm is based on queue data structure. In this traversal mechanism, the data elements/nodes are traversed by first in first out order (FIFO). The algorithm starts from any arbitrary initial node at a particular level, which becomes the current node. Then all the adjacent nodes of the current node on that given level are inserted into the queue in any random order. The node at the front is removed from the queue and the algorithmic steps mentioned in 2.2.1 are repeated until queue becomes empty and all nodes are processed [21].

The BFS traversal procedure is given as:

1. Input the directed graph.
2. Label each node as -1 i.e all nodes are unvisited.
3. Visit nodes one by one.

4. Process the node under consideration. Put this node in unprocessed queue, label it 0 and at the same time, find all its adjacent or neighboring nodes.
5. Put all the adjacent nodes of the particular node which is under consideration in the unprocessed queue in any order in that corresponding level.
6. Change those adjacent nodes as 0. Change the label of particular node under consideration to 1 and put this node in processed queue.
7. Remove nodes from unprocessed queue one by one by processing those using steps (5&6).
8. Once unprocessed queue is empty and all nodes are in processed queue then STOP.
9. Finally display the order of nodes as in processed queue which is BFS order.

Implementing this procedure to figure 3.2, BFS order is as:

[1 2 3 6 9 4 11 7 8 10 5 14 15 12 13]

From this order, nodes beyond branch matrix and power flow equations are determined.

Branches	Nodes →														
	1	2	3	6	9	4	11	7	8	10	5	14	15	12	13
1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	0	0	1	0	0	1	1	0	0	0	1	1	1	1	1
3	0	0	0	0	0	1	0	0	0	0	1	1	1	0	0
4	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
5	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0
6	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
8	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
10	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1
11	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
13	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

From this BIBC matrix, BCBV matrix is constructed using the following equation:

$$BCBV = BIBC' \times \text{diag}(Z) \quad (3.1)$$

Where $\text{diag}(Z)$ represents diagonal elements of impedance matrix Z , $BIBC'$ represents transpose of BIBC matrix.

3.2.3 LOAD MODELLING

The distribution network loads are generally specified by the complex power they consume. The voltage specified will always be the voltage of the distribution substation at the low Voltage bus. Thus creating a problem because the load current requirement cannot be determined without knowing the voltage. So for this reason, backward/forward sweep iterative technique is generally employed which is explained in next section [22].

Loads on the distribution feeder can be modelled as:

1. Constant impedance type load (Z_t)
2. Constant current type load (I_t)
3. Constant real and reactive power type load (PQ_t)
4. Any combination of the above i.e composite or mixed type load load(ZIP_t).

The above developed load models are employed in the backward/forward iterative technique where initially flat voltage is assumed. Then the assumed load voltage is updated by the actual operating load voltage. All loads require the branch current in order to perform load flow analysis. This branch current is determined in backward sweep technique.

Constant Real and Reactive Power Loads-

The branch current for PQ_t type loads is given as:

$$IL(PQ_t) = \left(\frac{S}{V}\right)^* \quad (3.2)$$

Where S is complex power and V is voltage, IL is the line current for constant PQ -type loads.

Constant Impedance Loads-

Initially determine the constant impedance (Z_t) loads from complex power as:

$$Z_t = \frac{|V|^2}{S^*} \quad (3.3)$$

The load currents which is function of above equation 3.3 is given as:

$$IL(Z_t) = \frac{V}{Z_t} \quad (3.4)$$

Where IL is line current of constant Z_t -type loads.

Constant Current Loads-

In these load models, the magnitude of current is calculated in accordance to equation 3.2

$$IL (I_t) = |IL| \quad (3.5)$$

Where IL is line current of constant I_t-type loads.

Mixed Loads or Composite Loads-

Mixed loads can be modelled by allocating a percentage of the total load of the three above mentioned load models. The total branch current which enters the load is the sum of three components.

$$I (ZIP_t) = IL (PQ_t) + IL (I_t) + IL (Z_t) \quad (3.6)$$

3.2.4 BACKWARD/FORWARD SWEEP METHOD

Backward sweep:

The motive of backward sweep is to update the branch currents in every portion of the network by taking into consideration the past iteration voltages at every bus. Meanwhile in backward sweep, the values of the voltage is kept constant with updated branch currents transmitted towards the network involving backward path. The backward sweep starts from the end or leaf node and moves towards the root or source node [29].

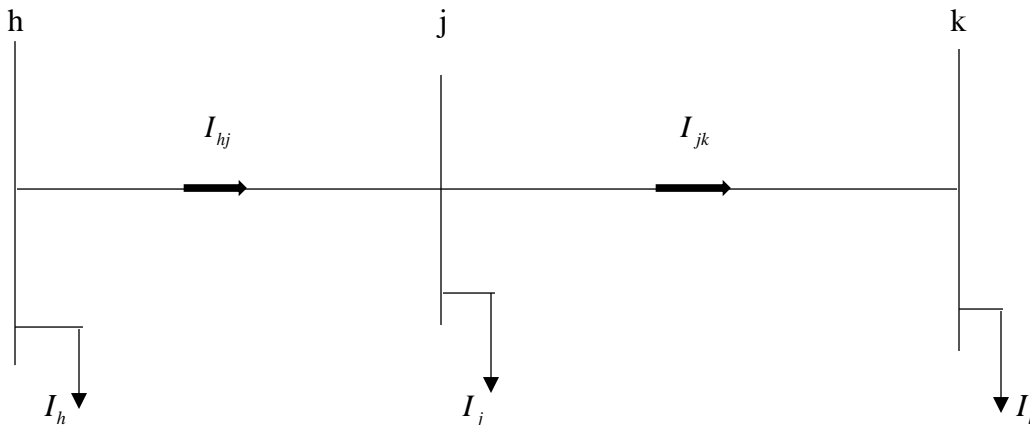


Fig 3.3 Single Line Section of Radial Network

The branch currents which are antecedent to the leaf nodes, the equation employed is shown as:

$$I_{jk} = I_k \quad (3.7)$$

The above equation 3.7 represents the current in branch j-k antecedent to leaf node k respectively.

The equation employed for intermediate node is as:

$$I_{hj} = I_{jk} + I_j \quad (3.8)$$

Where I_{hj} represents branch current between nodes h and j,

I_{jk} represents branch current between j and k

Forward sweep:

The motive of the forward sweep is to evaluate the voltages at every node while starting from source or root node [29]. By assuming flat voltage of 1 p.u throughout the system i.e

$V_i = 1 \text{ p.u } \forall i=1 \text{ to } N$, we have

$$V_j = V_h - I_{hj} \times Z_{hj} \quad (3.9)$$

Where, V_j indicates voltage of j node, V_h is the voltage of h node and Z_{hj} denotes the drop of the branch h-j respectively [29].

ALGORITHM:

Step-1: Read input data (bus and branch data).

Step-2: Assume flat voltage of 1 p.u throughout the buses.

Step-3: Set iter=1 (iteration counter).

Step-4: Determine injected current as:

$$I_i = \left(\frac{S_i}{V_i} \right)^*, \text{ for } i=2 \text{ to } i=N \quad (3.10)$$

Where, I_i is the injected current at *ith* bus, S_i is the complex power at *ith* bus and V_i is the voltage at *ith* bus respectively.

Step-5: In order to update branch currents, perform backward sweep from bus $i=N$ using BIBC matrix as

$$\text{IBr} = \text{BIBC} \times I_i \quad (3.11)$$

Where, IBr represents branch current of the system.

Step-6: Set $i=2$.

Step-7: Perform forward sweep in order to update the bus voltage magnitude and angles as given in eqn. 3.9.

Step-8: Set $i=i+1$.

Step-9: Check for $i=N$, If yes then step-10 is followed else step-7 is followed.

Step-10: Check convergence for magnitude of bus voltage at every bus by comparing it with the previous iteration. If convergence is attained then go to step-12 else go to step-11.

Step-11: $iter = iter+1$.

Step-12: Display magnitude of voltage in per unit and angle in radians at every bus.

By completion of backward/forward sweep, compute the real and reactive power losses of the branches as well as total power loss as:

$$P_{br,loss} = \frac{(P_i^2 + Q_i^2)}{V_i^2} \times R \quad (3.12)$$

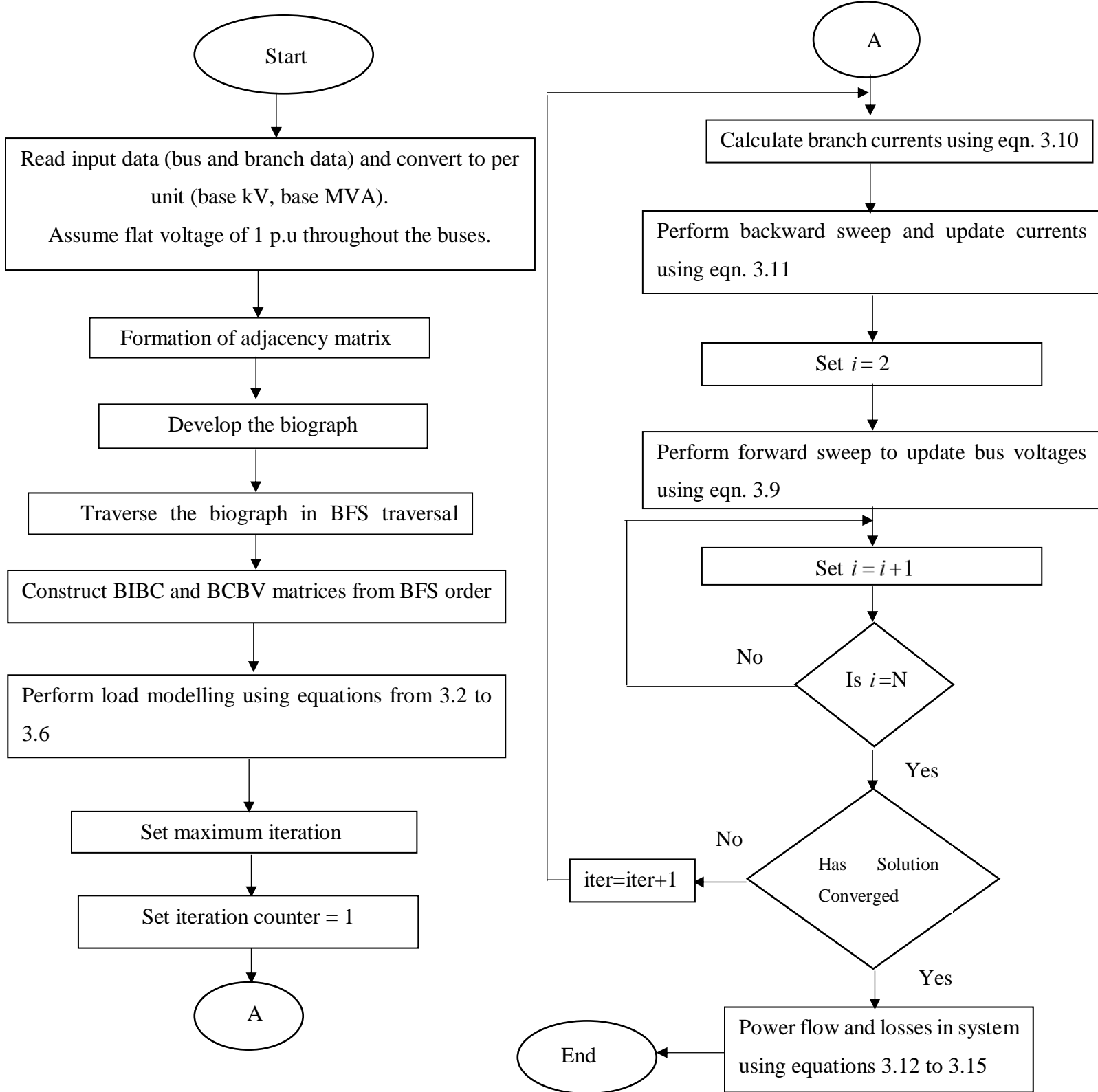
$$Q_{br,loss} = \frac{(P_i^2 + Q_i^2)}{V_i^2} \times X \quad (3.13)$$

$$P_t,loss = \sum_{i=1}^{NB} P_{br,loss} \quad (3.14)$$

$$Q_t,loss = \sum_{i=1}^{NB} Q_{br,loss} \quad (3.15)$$

Where, P_i and Q_i are the real and reactive power demand at i th bus, R and X are the resistance and reactance of the branches, NB is the total number of branches.

3.2.5 FLOW CHART FOR LOAD FLOW OF RADIAL DISTRIBUTION SYSTEM



CHAPTER-4

RESULTS AND DISCUSSIONS

This chapter presents the results which have emerged after the solution methodology (available in chapter-3) is implemented using MATLAB, R2014a, 64-bit. The proposed algorithm discussed in previous chapter is implemented on IEEE-15, 28 and 33- node radial bus network for which the single line diagrams are shown in figure 4.1, 4.3 and 4.6 respectively.

4.1: IEEE-15 bus network-

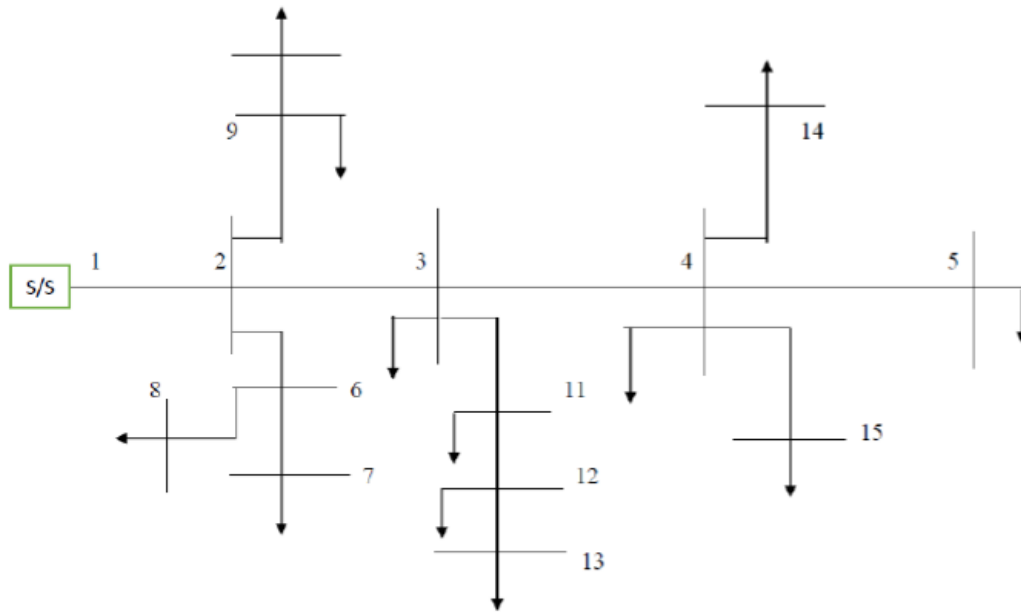


Fig 4.1 Single Line Diagram of 15-Bus Radial Distribution System

For IEEE-15 bus system, total number of buses are 15 and total number of branches are 14, base voltage is 11 kV and base MVA as 100 MVA, total real power load is 1226.4 kW and total reactive power load is 1251.179 kVAr.

The branch and bus data employed for the system is acquired from [17] for which the results are presented.

Bus-1 is swing bus, rest all other buses are load buses.

Table 4.1: Node Voltages for IEEE-15 Bus System employing Constant Real and Reactive Power Type Load

Node	Magnitude of Voltage in per unit	Angle of Voltage in radians
1	1	0
2	0.9713	0.0339
3	0.9547	-0.0603
4	0.9489	-0.0531
5	0.9479	-0.0409
6	0.9582	0.1913
7	0.9560	0.2185
8	0.9569	0.2070
9	0.9679	0.0739
10	0.9669	0.0869
11	0.9480	0.0222
12	0.9438	0.0734
13	0.9425	0.0897
14	0.9466	-0.0246
15	0.9469	-0.0225

Here, node 13 is having minimum voltage of 0.9425 p.u and its angle is 0.0897 respectively. Real and reactive power loss, minimum voltage, CPU time, number of iterations for different load models of IEEE-15 Bus System are shown in table 4.2 respectively.

Table 4.2: Real and Reactive Power Loss, Minimum Voltage, CPU Time, Number of Iterations for Different Load Models of IEEE-15 Bus System

Load Model	Power Loss		Minimum Voltage (p.u)	CPU Time (sec)	Number of Iterations
	Real (kW)	Reactive (kVAr)			
Constant Power(PQ_t)	61.963	55.381	$V_{13}=0.9425$	0.012	2
Constant Impedance(Z_t)	51.339	46.970	$V_{13}=0.9479$	0.023	2
Constant Current(I_t)	56.142	50.675	$V_{13}=0.9454$	0.026	2
Mixed Type(ZIP_t)	53.253	51.845	$V_{13}=0.9469$	0.01	2

The sensitivity of IEEE-15 bus system with respect to different load models is shown in figure 4.2 respectively.

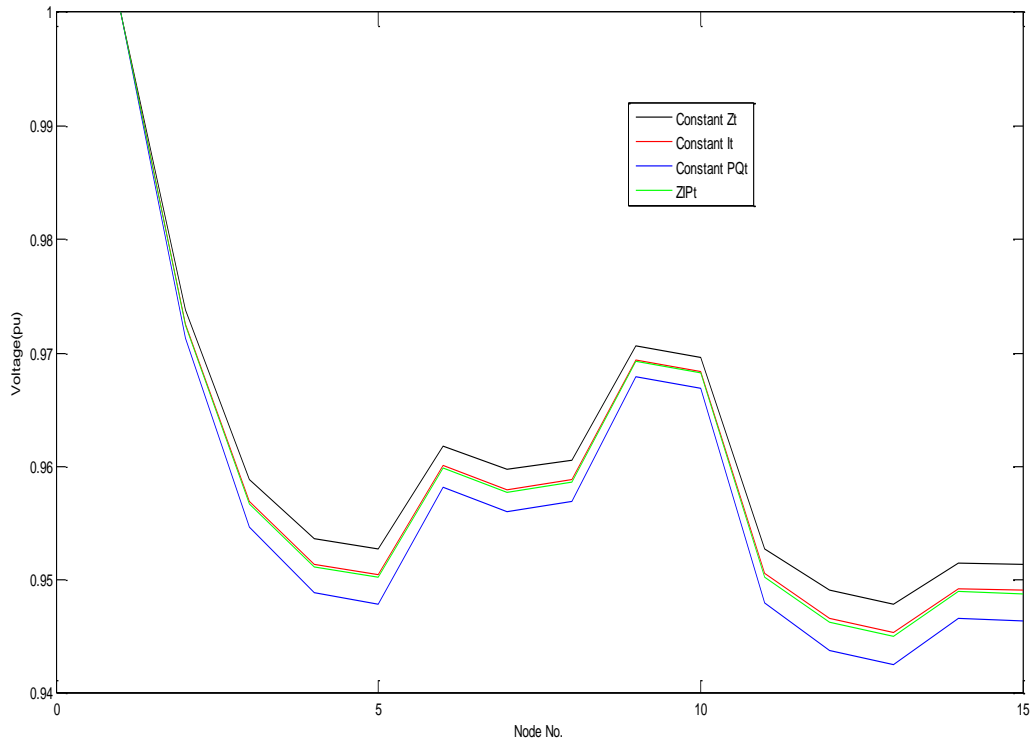


Fig 4.2 Sensitivity of IEEE-15 Bus System with Different Load Modelling.

The plot in figure 4.2 shows how voltage profile gets effected with different types of load models. From the plot, black, red, blue and green lines indicate the variation of voltage with constant impedance type load, constant current type load, constant real and reactive power type load and mixed type load. The Comparison of proposed method with other methods in terms of CPU time and number of iterations for IEEE-15 bus system is given in table 4.3 as:

Table 4.3: Comparison of proposed method with other methods in terms of CPU time and Number of iterations

Methods	CPU time (Sec)	Number of iterations
Ghosh and Sherpa [19]	1	3
Das <i>et al</i> [27]	2.23	3
Proposed Method	0.01	2

4.2: IEEE-28 bus network-

For IEEE-28 bus system, total number of buses are 28 and total number of branches are 27, base voltage is 12.66 kV and base MVA as 100 MVA, total real power load is 1900kW and total reactive power load is 1070 kVAr.

The branch and bus data employed for the system is acquired from [28] for which the results are presented.

Bus-1 is Sub-Station, rest all other buses are load buses.

Figure 4.3 and 4.4 below show the single-line diagram of IEEE-28 bus system and its biograph

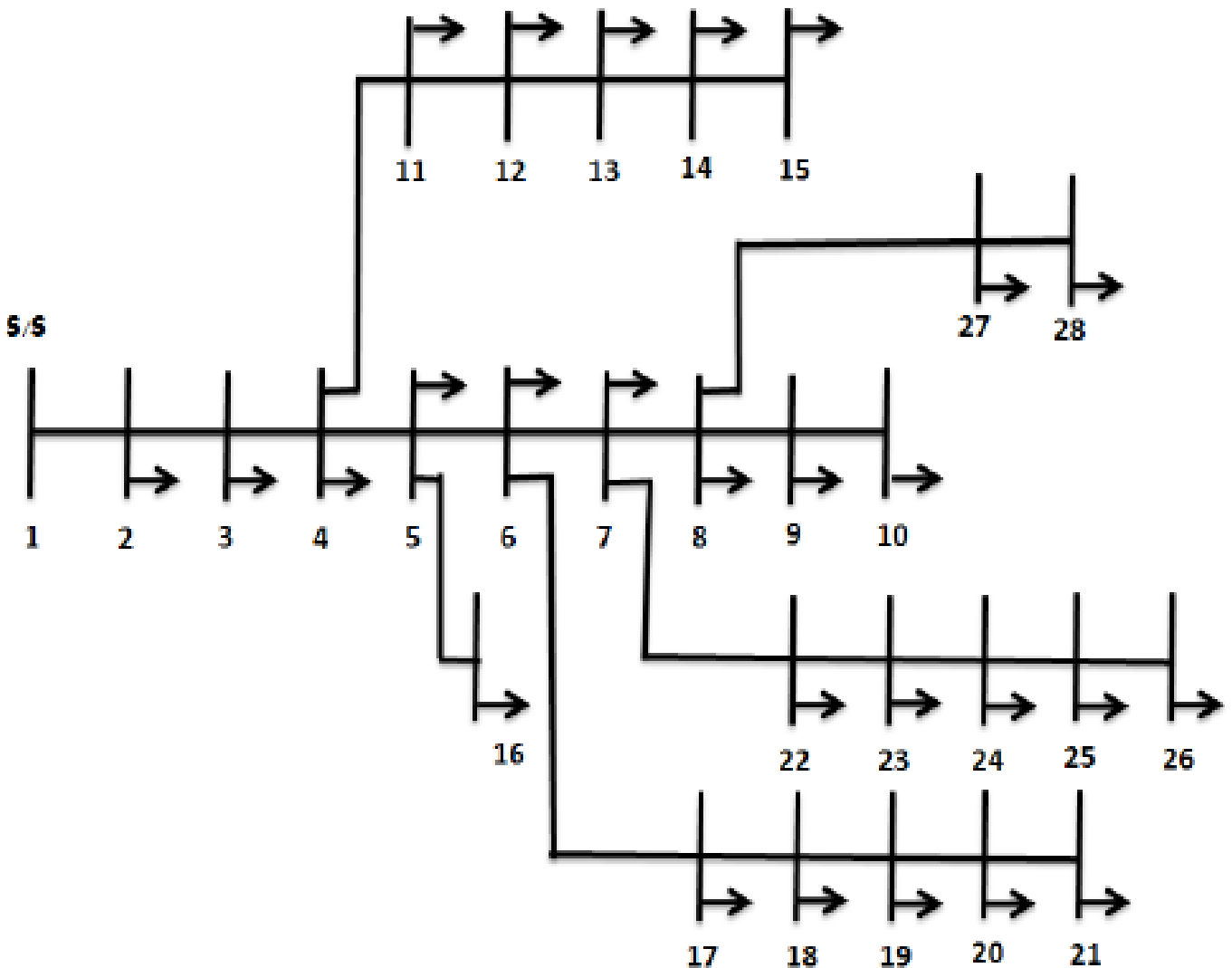


Fig 4.3 Single Line Diagram of 28-Bus Radial Distribution System

For this IEEE-28 bus system, its biograph is shown in figure 4.4 below as:

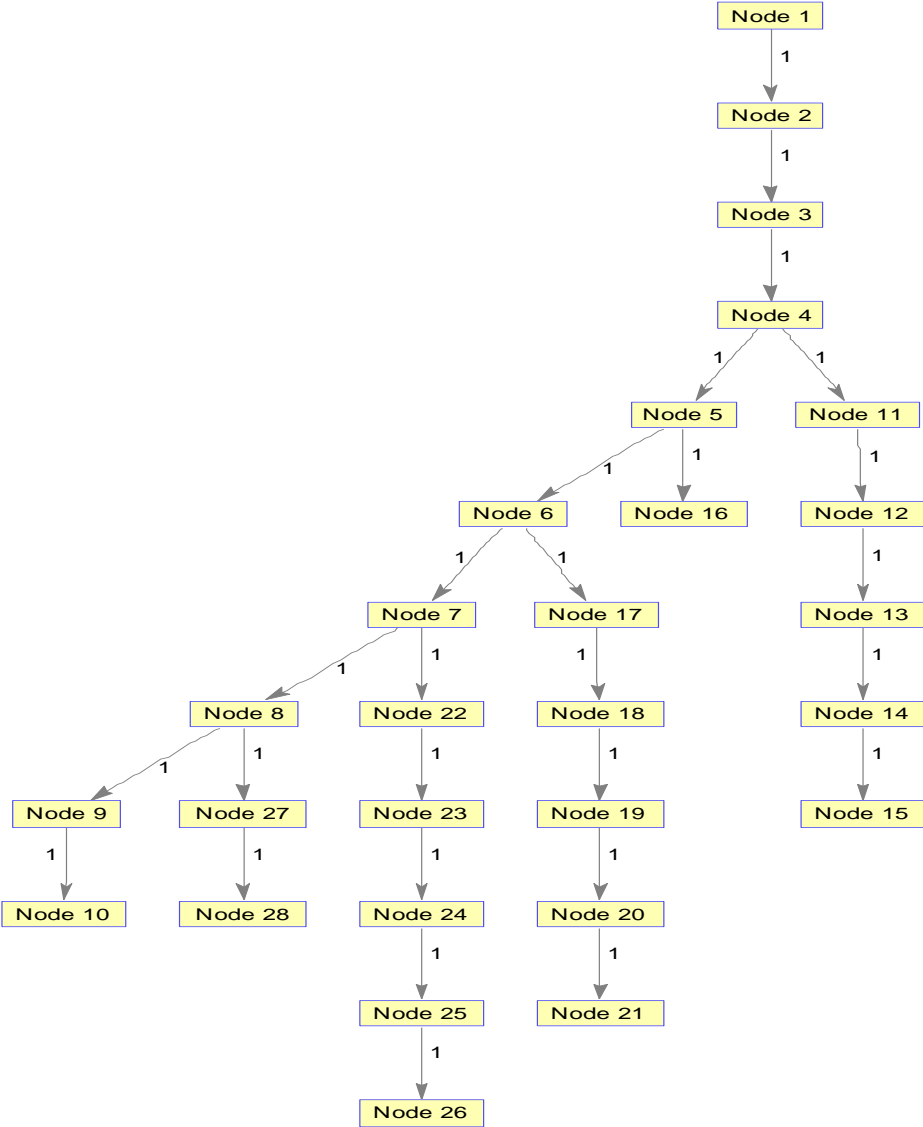


Fig 4.4 Biograph of IEEE-28 Bus System.

The biograph of IEEE-28 bus system is traversed in breadth first search algorithm to construct two matrices, bus injection to branch current matrix and branch current to bus voltage matrix. The former matrix is used to determine branch currents by employing backward sweep method and latter matrix for calculation of voltage drop by using forward sweep method.

. Real and reactive power loss, minimum voltage, CPU time, number of iterations for different load models of IEEE-28 Bus System are shown in table 4.4 respectively.

Table 4.4: Real and Reactive Power Loss, Minimum Voltage, CPU Time, Number of Iterations for Different Load Models of IEEE-28 Bus System

Load Model	Power Loss		Minimum Voltage (p.u)	CPU Time (sec)	Number of Iterations
	Real (kW)	Reactive (kVAr)			
Constant Power (PQ_t)	46.447	28.263	$V_{18}=0.9243$	0.02	2
Constant Impedance (Z_t)	37.113	22.678	$V_{18}=0.9329$	0.02	2
Constant Current (I_t)	41.502	25.308	$V_{18}=0.9288$	0.03	2
Mixed Type (ZIP_t)	42.070	25.647	$V_{18}=0.9282$	0.03	2

The sensitivity of IEEE-28 bus system with respect to different load models is shown in figure 4.5 respectively.

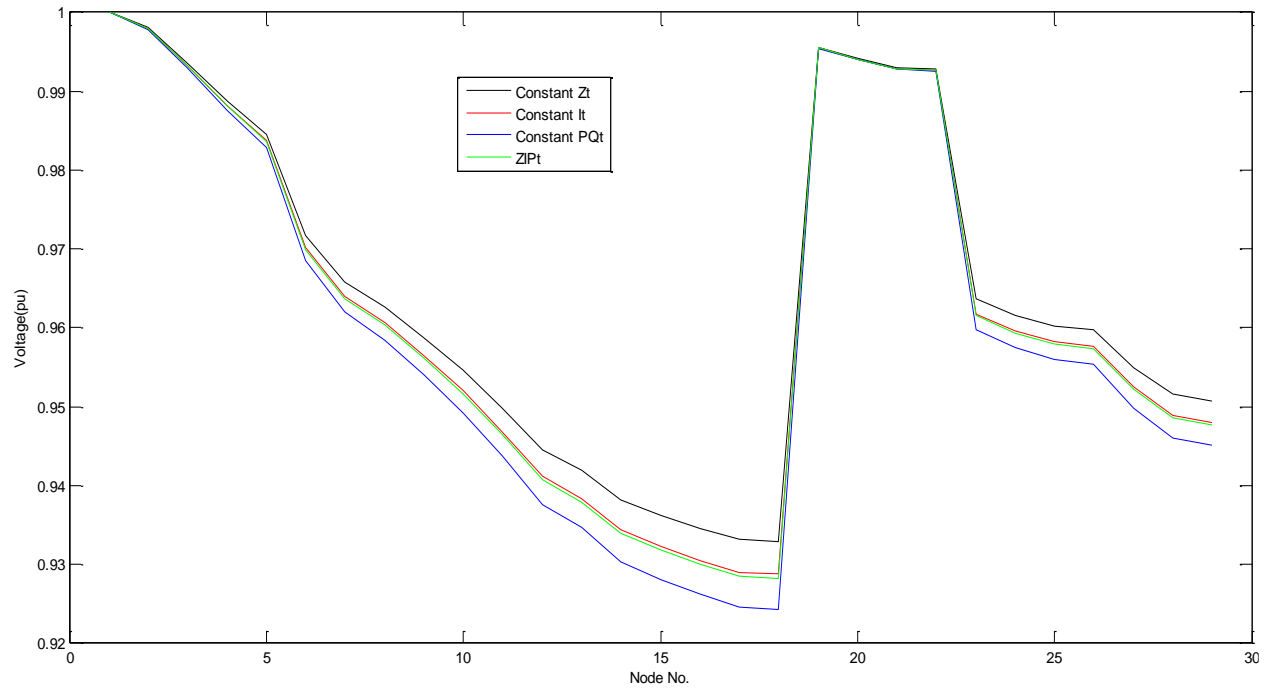


Fig 4.5 Sensitivity of IEEE-28 Bus System with Different Load Modelling.

The plot in figure 4.5 shows how voltage profile gets effected with different types of load models. From the plot, black, red, blue and green lines indicate the variation of voltage with constant impedance type load, constant current type load, constant real and reactive power type load and mixed type load. The Comparison of proposed method with other methods in terms of CPU time and number of iterations for IEEE-28 bus system is given in table 4.5 as:

Table 4.5: Comparison of proposed method with other methods in terms of CPU time and Number of iterations

Methods	CPU time (Sec)	Number of iterations
Abul'Wafa [16]	0.05	3
Das <i>et al</i> [27]	2.23	3
Proposed Method	0.02	2

4.3: IEEE-33 bus network-

For IEEE-33 bus network, total number of buses are 33, total number of branches are 32, base voltage is 12.66 kV, and base MVA is 100 MVA, total real power load is 3685kW and total reactive power load is 2300 kVAr.

The branch and bus data employed for the system is acquired from [26] for which the results are presented.

Bus-1 is swing bus, rest all other buses are load buses.

The single line diagram of IEEE-33 bus system is shown in figure 4.6 as:

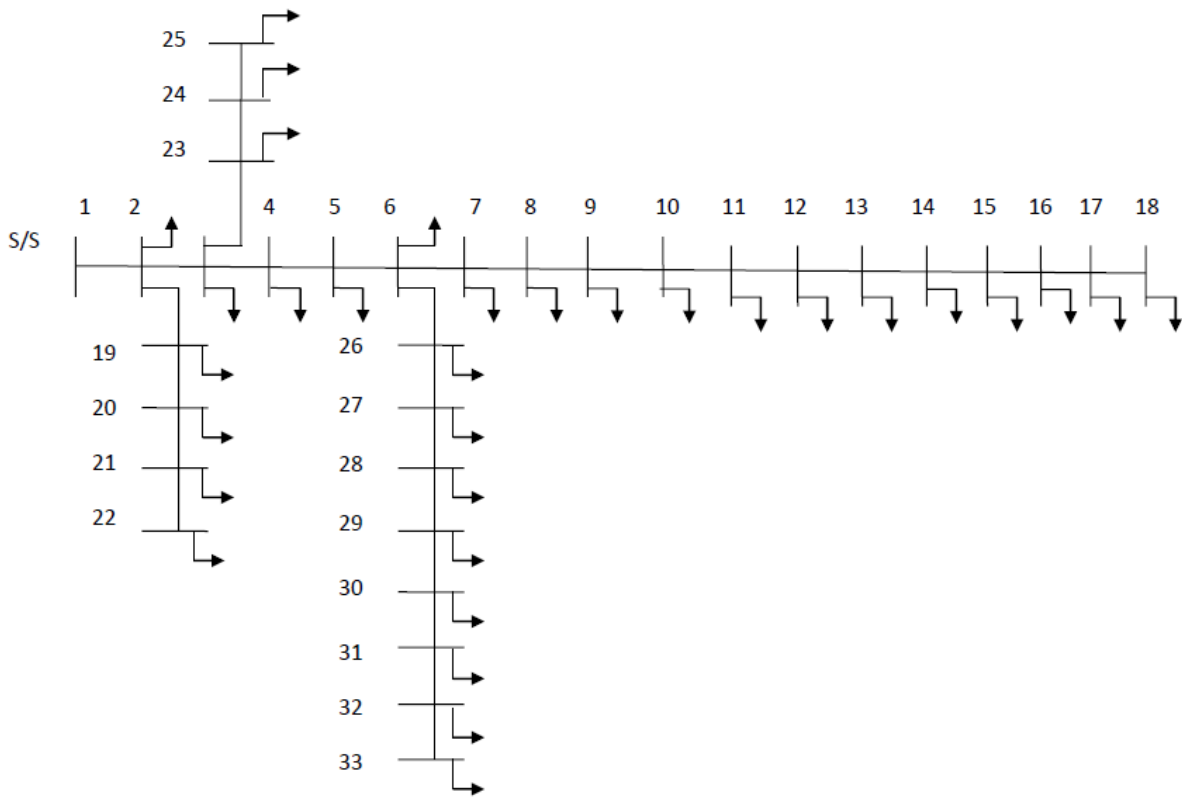


Fig 4.6 Single Line Diagram of 33-Bus Radial Distribution System.

For this IEEE-33 bus system, its biograph is shown in figure 4.7 below as:

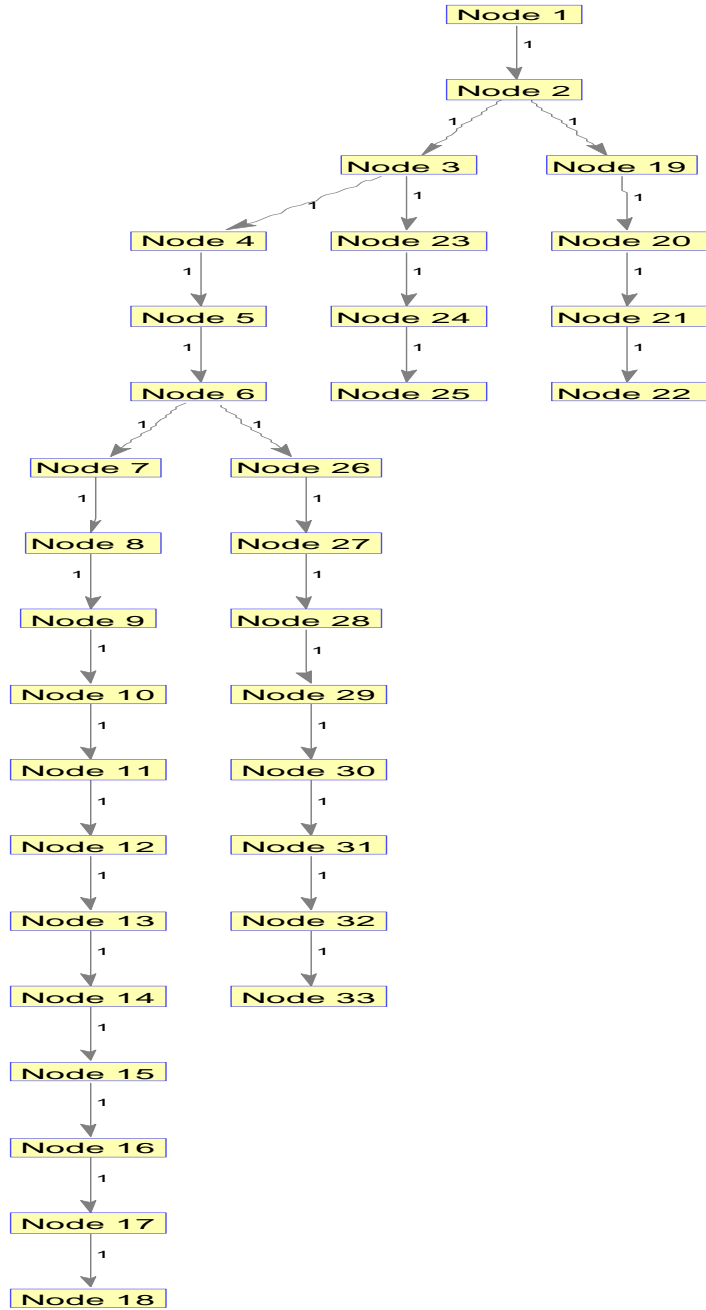


Fig 4.7 Biograph of IEEE-33 Bus System

The biograph of IEEE-33 bus system is traversed in breadth first search algorithm to construct two matrices, bus injection to branch current matrix and branch current to bus voltage matrix. The former matrix is used to determine branch currents by employing backward sweep method and latter matrix for calculation of voltage drop by using forward sweep method.

Table 4.6: Node Voltages for IEEE-33 Bus System employing Constant Real and Reactive Power Type Load

Node	Magnitude of Voltage in per unit	Angle of Voltage in radians
1	1	0
2	0.9970	0.0135
3	0.9830	0.0953
4	0.9755	0.1610
5	0.9681	0.2277
6	0.9498	0.1342
7	0.9463	-0.0960
8	0.9327	-0.2486
9	0.9264	-0.3227
10	0.9208	-0.3910
11	0.9199	-0.3837
12	0.9184	-0.3721
13	0.9123	-0.4646
14	0.9100	-0.5443
15	0.9086	-0.5824
16	0.9072	-0.6060
17	0.9052	-0.6842
18	0.9046	-0.6939

Table 4.6: Continued

Node	Magnitude of Voltage in per unit	Angle of Voltage in radians
19	0.9965	0.0027
20	0.9929	-0.0643
21	0.9922	-0.0836
22	0.9916	-0.1040
23	0.9794	0.0644
24	0.9727	-0.0242
25	0.9694	-0.0679
26	0.9478	0.1734
27	0.9453	0.2293
28	0.9339	0.3120
29	0.9258	0.3896
30	0.9222	0.4943
31	0.9181	0.4105
32	0.9172	0.3877
33	0.9169	0.3800

Here, node 18 is having minimum voltage of 0.9046 p.u and its angle is -0.6939 respectively.

Table 4.7: Real and Reactive Power Loss, Minimum Voltage, CPU Time, Number of Iterations for Different Load Models of IEEE-33 Bus System

Load Model	Power Loss		Minimum Voltage (p.u)	CPU Time (sec)	Number of Iterations
	Real (kW)	Reactive (kVAr)			
Constant Power (PQ _t)	208.456	141.458	$V_{18}=0.9046$	0.023	2
Constant Impedance (Z _t)	159.788	107.882	$V_{18}=0.9179$	0.023	2
Constant Current (I _t)	182.383	123.453	$V_{18}=0.9115$	0.032	2
Mixed Type (ZIP _t)	185.450	125.572	$V_{18}=0.9106$	0.030	2

The sensitivity of IEEE-33 bus system with respect to different load models is shown in figure 4.8 respectively.

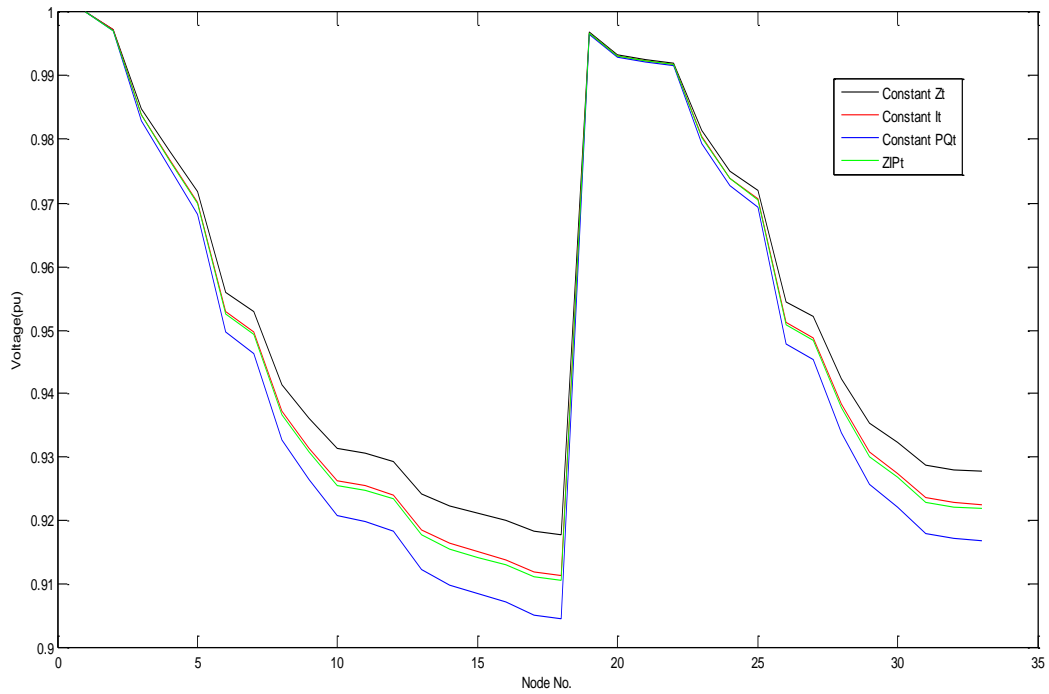


Fig 4.8 Sensitivity of IEEE-33 Bus System with Different Load Modelling

The plot in figure 4.8 shows how voltage profile gets effected with different types of load models. From the plot, black, red, blue and green lines indicate the variation of voltage with constant impedance type load, constant current type load, constant real and reactive power type load and mixed type load. The Comparison of proposed method with other methods in terms of CPU time and number of iterations for IEEE-33 bus system is given in table 4.8 as:

Table 4.8: Comparison of proposed method with other methods in terms of CPU time and Number of iterations

Methods	CPU Time (sec)	Number of Iterations
Ghosh and Sherpa [19]	1	3
Murari <i>et al</i> [23]	1	3
Ghosh and Das [23]	1.2	3
Singh and Ghose [29]	1.5	5
Proposed method	0.02	2

CHAPTER-5

CONCLUSIONS AND FUTURE SCOPE

5.1 CONCLUSION

The dissertation work is carried out in order to determine Load Flow Solution of Radial Distribution Network on three IEEE- test systems using MATLAB, R2014a, 64-bit. The objective is achieved and the solution is found in three steps. First is construction of two different matrices- BIBC and BCBV. Secondly, it is to determine real and reactive power loss, magnitude of voltage and its angle at different loads and finally it determines currents and voltages at each bus of the network. BIBC and BCBV matrices are constructed by traversing the graph in Breadth First Search Algorithm. Load modelling is performed with different types of loads at rated voltage. Currents and Voltages are updated at each bus by using Backward/Forward sweep method. The results are obtained by the proposed method. The comparison of its computational performance in terms of execution time, number of iterations, and convergence with previous published methods provides confirmation concerning the efficacy of proposed method.

5.2 FUTURE SCOPE

The complexity of power systems is increasing day by day. Therefore, efficient operation and automation are significantly required in every aspect of power system.

The algorithm proposed in this dissertation can further be extended to:-

- Complex Distribution Systems.
- Large number of buses in Distribution System.

Also, to maximize the benefits of the Graph Algorithms, more studies are required in near future.

The key references provided can encourage researchers for future studies.

LIST OF PUBLICATIONS

Tafheem Ashraf and Suman Bhullar, “Power Flow of Radial Distribution Network using Breadth First Search Algorithm”, published in *International Journal of Engineering Technology, Management and Applied Sciences*, Vol. 5, Issue 5, ISSN 2349-4476, pp. 455-461, May 2017.

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APPENDIX-A

Table A.1 Test data for 15 node RDN [16]

Branch number	Send Bus	End Bus	Resistance	Reactance	P(kW)	Q(kVAr)
1	1	2	1.35309	1.32349	44.1000	44.9910
2	2	3	1.17024	1.14464	70.0000	71.4143
3	3	4	0.84111	0.82271	140.0000	142.8286
4	4	5	1.52348	1.02760	44.1000	44.9910
5	2	6	2.55727	1.72490	140.0000	142.8286
6	6	7	1.08820	0.73400	140.0000	142.8286
7	6	8	1.25143	0.84410	70.0000	71.4143
8	2	9	2.01317	1.35790	70.0000	71.4143
9	9	10	1.68671	1.13770	44.1000	44.9910
10	3	11	1.79553	1.2110	140.0000	142.8286
11	11	12	2.44845	1.65150	70.0000	71.4143
12	12	13	2.01317	1.35790	44.1000	44.9910
13	4	14	2.23081	1.50470	70.0000	71.4143
14	4	15	1.19702	0.80740	140.0000	142.8286

APPENDIX-B

Table B.1 Test data for 28 node RDN [28]

Branch number	Send Bus	End Bus	Resistance	Reactance	P(kW)	Q(kVAr)
1	1	2	0.12648	0.05263	140	90
2	2	3	0.15463	0.06579	80	50
3	3	4	0.09486	0.03947	80	60
4	4	5	0.06374	0.02632	100	60
5	5	6	0.25296	0.10526	80	50
6	6	7	0.18972	0.07895	90	40
7	7	8	0.10119	0.04211	90	40
8	8	9	0.18972	0.07895	80	50
9	9	10	0.25296	0.10526	90	50
10	4	11	0.19108	0.05402	80	50
11	11	12	0.09554	0.02701	80	40
12	12	13	0.28663	0.08103	90	50
13	13	14	0.28663	0.05942	70	40
14	14	15	0.21019	0.05402	70	40
15	5	16	0.19108	0.08103	70	40
16	6	17	0.28663	0.05402	60	30
17	17	18	0.19108	0.05402	60	30
18	18	19	0.19108	0.06753	70	40
19	19	20	0.09554	0.02701	50	30
20	20	21	0.19108	0.05402	50	30

21	7	22	0.34395	0.09724	40	20
22	22	23	0.37339	0.07023	50	30
23	23	24	0.21019	0.05942	50	20
24	24	25	0.38217	0.10804	60	30
25	25	26	0.38217	0.05402	40	20
26	8	27	0.09554	0.02701	40	20
27	27	28	0.09554	0.02701	40	20

APPENDIX C

Table C.1 Test data for 33 node RDN [26]

Branch number	Send Bus	End Bus	Resistance	Reactance	P(kW)	Q(kVAr)
1	1	2	0.0922	0.0477	100.0	60.0
2	2	3	0.4930	0.2511	90.0	40.0
3	3	4	0.3660	0.1864	120.0	80.0
4	4	5	0.3811	0.1941	60.0	30.0
5	5	6	0.8190	0.7070	60.0	20.0
6	6	7	0.1872	0.6188	200.0	100.0
7	7	8	1.7114	1.2351	200.0	100.0
8	8	9	1.0300	0.7400	60.0	20.0
9	9	10	1.0040	0.7400	60.0	20.0
10	10	11	0.1966	0.0650	45.0	30.0
11	11	12	0.3744	0.1238	60.0	35.0
12	12	13	1.4680	1.1550	60.0	35.0
13	13	14	0.5416	0.7129	120.0	80.0
14	14	15	0.5910	0.5260	60.0	10.0
15	15	16	0.7463	0.5450	60.0	20.0
16	16	17	1.2890	1.7210	60.0	20.0
17	17	18	0.7320	0.5740	60.0	40.0
18	2	19	0.1640	0.1565	90.0	40.0
19	19	20	1.5042	1.3554	90.0	40.0
20	20	21	0.4095	0.4784	90.0	40.0
21	21	22	0.7089	0.9373	90.0	40.0
22	3	23	0.4512	0.3083	90.0	50.0
23	23	24	0.8980	0.7091	420.0	200.0
24	24	25	0.8960	0.7011	420.0	200.0
25	6	26	0.2030	0.1034	60.0	25.0
26	26	27	0.2842	0.1447	60.0	25.0
27	27	28	1.0590	0.9337	60.0	20.0
28	28	29	0.8042	0.7006	120.0	70.0

29	29	30	0.5075	0.2585	200.0	600.0
30	30	31	0.9744	0.9630	150.0	70.0
31	31	32	0.3105	0.3619	210.0	100.0
32	32	33	0.3410	0.5302	60.0	40.0