LOAD–FLOW ANALYSIS OF RADIAL DISTRIBUTION NETWORKS WITH REDUCED DATA PREPARATION

Thesis submitted in partial fulfillment of the requirements for the award of degree of

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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, "**Load–flow analysis of radial distribution networks with reduced data preparation** " in partial fulfillment of the requirements for the award of degree of Master of Engineering in Power system & electric drives submitted in Electrical & Instrumentation engineering department of Thapar University, Patiala ,is an authentic record of my own work carried out under the supervision of *Dr. Smarajit Ghosh* and refers other researcher's works which are duly listed in the reference section.

The matter presented in this thesis has not been submitted anywhere for the award of any other degree**.**

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

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ABSTRACT

In this thesis, load-flow technique for solving radial distribution networks by reducing data preparation using sequential numbering scheme has been proposed. The proposed method needs only the source node and number of total node of main feeder, lateral(s) and sub lateral(s) only and does not need equivalent network. The simple algebraic equations have been considered. Effectiveness of the load–flow has been tested by two examples (33–node and 69–node radial distribution networks) with constant power (CP), constant current (CI), constant impedance (CZ), composite and exponential load modelling for each of these examples.

The superiority of the proposed method has been compared with the other methods available in literature.

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LIST OF SYMBOLS

kV- Kilo Volts

kVA- Kilo volt ampere

kVAr- Amount of reactive power

kW- kilo watts

NB - be the total no. of nodes

CHAPTER 1

INTRODUCTION

To meet the present growing domestic, industrial and commercial load day by day, effective planning of radial distribution network is required. To ensure the effective planning with load transferring, the load−flow study of radial distribution network becomes utmost important. In this chapter introduction of distribution system will be carried out at first followed by load−flow.

1.1 Power Distribution Systems

Distribution networks have typical characteristics. The aim of this article is to introduce distribution networks design and establish the distinction between country and urban distribution networks.

1.1.1 Global Design of Distribution Networks

The electric utility system is usually divided into three subsystems which are generation, transmission, and distribution. A fourth division, which sometimes is made, is sub transmission. However, the latter can really be considered as a subset of transmission since the voltage levels and protection practices are quite similar.

The distribution system is commonly broken down into three components: distribution substation, distribution primary and secondary. At the substation level, the voltage is reduced and the power is distributed in smaller amounts to the customers. Consequently, one substation will supply many customers with power. Thus, the number of transmission lines in the distribution systems is many times that of the transmission systems. Furthermore, most customers are connected to only one of the three phases in the distribution system. Therefore, the power flow on each of the lines is different and the system is typically ‘unbalanced’. This characteristic needs to be accounted for in load−flow studies related to distribution networks.

1.1.2 Distribution Substations

The distribution system is fed through distribution substations. These substations have an almost infinite number of designs based on consideration such as load density, high side and low side voltage, land availability, reliability requirements, load growth, voltage drop, cost and losses, etc.

1.1.3 Distribution Feeders

There are three basic types of distribution system designs: Radial, Loop, or Network. As one might expect, one can use combinations of these three systems, and this is frequently done. The Radial distribution system is the cheapest to build, and is widely used in sparsely populated areas. A radial system has only one power source for a group of customers. A power failure, short-circuit, or a downed power line would interrupt power in the entire line, which must be fixed before power can be restored.

A loop system, as the name implies, loops through the service area and returns to the original point. The loop is usually tied into an alternate power source. By placing switches in strategic locations, the utility can supply power to the customer from either direction. If one source of power fails, switches are thrown (automatically or manually), and power can be fed to customers from the other source. The loop system provides better continuity of service than the radial system, with only short interruptions for switching. In the event of power failures due to faults on the line, the utility has only to find the fault and switch around it to restore service. The fault itself can then be repaired with a minimum of customer interruptions. The loop system is more expensive than the radial because more switches and conductors are required, but the resultant improved system reliability is often worth the price.

Network systems are the most complicated and are interlocking loop systems. A given customer can be supplied from two, three, four, or more different power supplies. Obviously, the big advantage of such a system is added reliability. However, it is also the most expensive. For this reason it is usually used only in congested, high load density municipal or downtown areas.

1.2 Load–Flow Analysis

Load–flow analysis is concerned with describing the operating state of an entire power system, by which we mean a network of generators, transmission lines, and loads that could represent an area as small as a municipality or as large as several states. Given certain known quantities—typically, the amount of power generated and consumed at different locations— load–flow

analysis allows one to determine other quantities. The most important of these quantities are the voltages at locations throughout the transmission system, which, for alternating current (AC), consist of both a magnitude and a time element or phase angle. Once the voltages are known, the currents flowing through every transmission link can be easily calculated. Thus the name power flow or load flow, as it is often called in the industry: given the amount of power delivered and where it comes from, power flow analysis tells us how it flows to its destination. Owing mainly to the peculiarities of AC, but also to the sheer size an complexity of a real power system—its elaborate topology with many nodes and links, and the large number of generators and loads—it turns out to be no mean feat to deduce what is happening in one part of the system from what is happening elsewhere, despite the fact that these happenings are intimately related through well-understood, deterministic laws of physics Even a small network of a handful of AC power sources and loads defies our ability to write down formulas for the relationships among all the variables: as a mathematician would say, the system cannot be solved analytically; there is no closed-form solution. We can only get at a numerical answer through a process of successive approximation or iteration. In order to find out what the voltage or current at any given point will be, we must in effect simulate the entire system.

Historically, such simulations were accomplished through an actual miniature DC model of the power system in use. Generators were represented by small DC power supplies, loads by resistors, and transmission lines by appropriately sized wires. The voltages and currents could be found empirically by direct measurement. To find out how much the current on line A would increase, for example, due to Generator X taking over power production from Generator Y, one would simply adjust the values on X and Y and go read the ammeter on line A. The DC model does not exactly match the behavior of the AC system, but it gives an approximation that is close enough for most practical purposes. In the age of computers, we no longer need to physically build such models, but can create them mathematically. With plenty of computational power, we can not only represent a DC system, but the AC system itself in a way that accounts for the subtleties of AC Such a simulation constitutes load−flow analysis.

Load−flow uses a mathematical algorithm of successive approximation by iteration, or the repeated application of calculation steps. These steps represent a process of trial and error that starts with assuming one array of numbers for the entire system, comparing the relationships among the numbers to the laws of physics, and then repeatedly adjusting the numbers until the entire array is consistent with both physical law and the conditions stipulated by the user. In practice, this looks like a computer program to which the operator gives certain input information about the power system, and which then provides output that completes the picture of what is happening in the system. There are variations on what types of information are chosen as input and output, and there are also different computational techniques used by different programs to produce the output. Beyond the straightforward load−flow program that simply calculates the variables pertaining to a single, existing system condition, there are more involved programs that analyze a multitude of hypothetical situations or system conditions and rank them according to some desired criteria; such programs are known as optimal power flow (OPF).

load−flow study is instrumental in the planning, design, and operation of distribution system for industrial facilities. This study can be used to evaluate the effects of various equipment configurations, additions or modifications to generators, motors, or other electrical loads. Modern systems are complex and have many paths or branches over which power can flow. Electric power flow will divide among these branches until a balance is reached in accordance with Kirchoff's laws. The computer programs to solve load flows are divided into two types; static and dynamic. This discussion is concerned with only static network models and their analysis. As the load distribution, and possibly the network, will vary considerably during different time periods, it is necessary to obtain solutions representing the major different system conditions such as peak load, normal load, light or no load. These solutions will be used to determine either optimum operating modes for normal conditions, such as the proper setting of voltage control devices, or how the system will respond to abnormal conditions, such as outages of lines or transformers. It also serves as the basis for other types of studies such as short-circuit, stability, motor starting, and harmonic studies. It provides the network data and an initial condition for these studies.

Typically the input data is divided into

- Bus data
- Branch data
- Generator data
- Transformer data
- Load data

This data is included (or should be) with every load–flow output file in order to document the system , load configuration that the solution applies for. The load flow study should have a predefined set of criteria that the system evaluated must meet. These criteria include:

- Voltage criteria
- Power flows on cables and transformers must be within equipment ratings.
- Generator reactive outputs must be within the limits defined by the generator capability curves.

The load–flow analysis is used to design a system that has a good voltage profile during normal operation and that will continue to operate acceptably when one or more lines become inoperative due to line damage, lightning strokes, failure of transformers, etc. In addition, the size and placement of power factor correction capacitors and the setting of generator scheduled voltages and transformer tap positions can be studied with load flows.

The great importance of load–flow studies is in the planning the future expansion of power systems as well as in determining the best operation of existing systems. The principal information obtained from the load–flow study is the magnitude and phase angle of the voltage at each bus and the real and reactive power flowing in each line.

1.3 Choice of Variables

Basically load−flow analysis deals with known real and reactive power flows at each bus, and those voltage magnitudes that are explicitly known, and from this information calculating the remaining voltage magnitudes and all the voltage angles.

We are familiar with the notion of organizing the descriptive variables of the circuit into categories of "knowns" and "unknowns," whose relationships can subsequently be expressed in terms of multiple equations. Given sufficient information, these equations can then be manipulated with various techniques so as to yield numerical results for the hitherto unknowns.

For AC circuits, because we have introduced the dimension of time: unlike in DC, where everything is essentially static(except for the instant at which a switch is thrown), with AC we are describing an ongoing oscillation or movement. Thus each of the two main variables, voltage and current, in an AC circuit really has two numerical components: a magnitude component and a time component. By convention, AC voltage and current magnitude are described in terms of root-mean-squared (r.m.s.) values and their timing in terms of a phase angle, which represents the shift of the wave with respect to a reference point in time . To fully describe the voltage at any given node in an AC circuit, we must, therefore, specify two numbers: a voltage magnitude and a voltage angle. Accordingly, when we solve for the currents in each branch, we will again obtain two numbers: a current magnitude and a current angle.

When we consider the amount of power transferred at any point of an AC circuit, we again have two numbers: a real and a reactive component. An AC circuit thus requires exactly two pieces of information per node in order to be completely determined. More than two, and they are either redundant or contradictory; fewer than two and possibilities are left open so that the system cannot be solved. Owing to the nonlinear nature of the load−flow problem, it may be impossible to find one unique solution because more than one answer is mathematically consistent with the given configuration. However, it is usually straightforward in such cases to identify the "true" solution among the mathematical possibilities based on physical plausibility and common sense. Conversely, there may be no solution at all because the given information was hypothetical and does not correspond to any situation that is physically possible. Still, it is true in principle—and most important for a general conceptual understanding that two variables per node are needed to determine everything that is happening in the system. In practice, current is not known at all; the currents through the various circuit branches turn out to be the last thing that we calculate once we have completed the load−flow analysis. Voltage, as we will see, is known explicitly for some buses but not for others. More typically, what is known is the amount of power going into or out of a bus.

load−flow analysis consists of taking all the known real and reactive power flows at each bus, and those voltage magnitudes that are explicitly known, and from this information calculating the remaining voltage magnitudes and all the voltage angles. This is the hard part. The easy part, finally, is to calculate the current magnitudes and angles from the voltages. We know how to calculate real and reactive power from voltage and current: power is basically the product of voltage and current, and the relative phase angle between voltage and current determines the respective contributions of real and reactive power. Conversely, one can deduce voltage or current magnitude and angle if real and reactive power are given, but it is far more difficult to work out mathematically in this direction. This is because each value of real and reactive power would be consistent with many different possible combinations of voltages and currents. In order to choose the correct ones, we have to check each node in relation to its neighboring nodes in the circuit and find a set of voltages and currents that are consistent all the way around the system.

1.4 Types of Buses

Previously we discussed that in load−flow analysis buses are represented as nodes.but there are many type of buses(typically 3) which should be known to us for better understanding.

Let us now articulate which variables will actually be given for each bus as inputs to the analysis. Here we must distinguish between different types of buses based on their actual, practical operating constraints. The two main types are generator buses and load buses, for each of which it is appropriate to specify different information. At the load bus, we assume that the power consumption is given—determined by the consumer—and specify two numbers, real and reactive power, for each load bus. Referring to the symbols P and Q for real and reactive power, load buses are referred to as PQ buses in load−flow analysis.

At the generator buses we could in principle also specify P and Q. Here we run into two problems. However, the first has to do with balancing the power needs of the system, and the second with the actual operational control of generators. As a result, it turns out to be convenient to specify P for all but one generator, the slack bus, and to use the generator bus voltage, V, instead of the reactive power Q as the second variable. Generator buses are therefore called PV buses.

1.4.1 Summary of Variables in load flow analysis

To summarize, our three types of buses in load flow analysis are PQ (load bus),PV (generator bus), and θ V (slack bus). Given these two input variables per bus, and knowing all the fixed properties of the system (i.e., the impedances of all the transmission links, as well as the AC frequency), we now have all the information required to completely and unambiguously determine the operating state of the system. This means that we can find values for all the variables that were not originally specified for each bus: θ and V for all the PQ buses; θ and Q for the PV buses; and P and Q for the slack bus. The known and unknown variables for each type of bus are shown in table 1.1.

Table-1.1: Variables in Power Flow Analysis

Type of Bus	Variables Given (Knowns)	Variables Found (Unknowns)
Generator	Real power (P) Voltage magnitude (V)	Voltage angle (θ) Reactive power (Q)
Load or generator	Real power (P) Reactive power (Q)	Voltage angle (θ) Voltage magnitude (V)
Slack	Voltage angle (θ) Voltage magnitude (V)	Real power (P) Reactive power (Q)

Once we know θ and V, the voltage angle and magnitude, at every bus, we can very easily find the current through every transmission link; it becomes a simple matter of applying Ohm's law to each individual link. (In fact, these currents have to be found simultaneously in order to compute the line losses, so that by the time the program announces θ' s and V's, all the hard work is done.) Depending on how the output of a load–flow program is formatted, it may state only the basic output variables, as in it may explicitly state the currents for all trans-mission links in amperes; or it may express the flow on each transmission link in terms of an amount of real and reactive power owing, in megawatts (MW) and (MVAr).

1.5 Literature Survey

In the literature, there are a number of efficient and reliable load flow solution techniques, such as; Gauss-Seidel, Newton-Raphson and Fast Decoupled Load Flow [1–8]. Hitherto they are successfully and widely used for power system operation, control and planning. However, it has repeatedly been shown that these methods may become inefficient in the analysis of distribution systems with high R/X ratios or special network structures [9–11].

Accordingly, a number of methods proposed in the literature [12-28] specially designed for the solution of power flow problem in radial distribution networks.The methods developed for the solution of ill-conditioned radial distribution systems may be divided into two categories.

The first type of methods is utilised by proper modification of existing methods such as, Newton-Raphson [2–8]. On the other hand, the second group of methods is based on forward-backward sweep processes using Kirchooff's Laws or making use of the well-known bi-quadratic equation which, for every branch, relates the voltage magnitude at the receiving end to the voltage at the sending end and the branch power flow for solution of ladder networks [12–29]. Shirmohammadi *et al.* [12] had presented a compensation-based power flow method for radial distribution networks and extended it for weakly meshed structure using a multi-port compensation technique and basic formulations of Kirchhoff's Laws. The radial part is solved by a straightforward two step procedure in which the branch currents are first computed (backward sweep) and then the bus voltages are updated (forward sweep). In the improved version [13], branch power flow was used instead of branch complex currents for weakly meshed transmission and distribution systems by Luo. Baran and Wu [14], proposed a methodology for solving the radial load−flow for analysing the optimal capacitor sizing problem. In this method, for each branch of the network three non-linear equations are written in terms of the branch power flows and bus voltages. The number of equations was subsequently reduced by using terminal conditions associated with the main feeder and its laterals, and the Newton-Raphson method is applied to this reduced set. The computational efficiency is improved by making some simplifications in the jacobian. Consequently, numerical properties and convergence rate of this algorithm have been studied using the iterative solution of three fundamental equations representing real power, reactive power and voltage magnitude by Chiang [15].

G. Renato [16] made use of well known bi-quadratic equation which, for every branch, relates the voltage magnitude at the receiving – end to the voltage at the sending –end and branch power flow. Only voltage magnitudes are computed, bus phase angles do not appear in the formulation which was also used by Das *et al.* in [17]. Jasmon [18] proposed a load flow technique which, for every branch, leads to a pair of quadratic equations relating power flows at both ends with the voltage magnitude at the sending end for the voltage stability analysis of radial networks. Haque [19] had formulated the load−flow problem of the distribution system in terms of three sets of recursive equations and analysed load−flow results for various voltage dependent load models. The effects of various load models on the convergence pattern of the method are also studied.

The effect of voltage-dependency of load on the results and convergence characteristics of power flow solution were also analysed [20], where the proposed method was also based on Kirchoff's Laws. Liu *et al.*[21] had proposed Ratio-Flow method which is based on forward-backward ladder equation for complex distribution system by using voltage ratio for convergence control. This method were applied with standard Newton-Raphson method for complex distribution systems, which have multiple sources or relatively strong connected loops with extended long radial feeders including laterals, to solve the load−flow problem.

R. Ranjan *et al.* [22] had proposed a new method to solve radial distribution networks. They had used simple algebraic recursive expression of voltage magnitude and the proposed algorithm used the basic principle of circuit theory. D. Zimmerman and H. D. Chiang [23] formulated load–flow problem as a function of the bus voltages and equations are solved by Newton's method. The method has been compared with classical Newton-Raphson and Forward-Backward sweep methods by using a number of test cases. Although required iteration number considerable favoured from classical methods for small tolerances, no results has been provided on the accuracy of the solution in terms of bus voltage magnitudes or angles. The results provided in [23] suggest that undertaken comparisons only cover network structures which are inherently convergent ie. solutions can also be obtained using classical Newton-Raphson method. J.Jerome *et al.*[25],had proposed forward-backward substitution method which is based on the Kirchhoff's Laws. In backward substitution, each branch current is calculated by Kirchhoff's current law (KCL). Using these currents, the node voltages are calculated by Kirchhoff's Voltage Law in forward substitution at each iteration. The voltage magnitudes at each bus in an iteration are compared with their values in the previous iteration. If the error is within the tolerance limits, the procedure is stopped. Ladder network theory shown in ref. [26] is similar to the Forward-Backward Substitution method. In Ladder network theory, the currents in each branch are computed by KCL. In addition to the branch currents, the node voltages are also computed by KVL in each iteration. Thus magnitude of the swing bus voltage is also determined. The calculated value of swing bus is compared with its specified value. If the error is within the limit, the procedure is stopped. Otherwise, the forward and backward calculations are repeated as in forward-backward substitution method. The aim of this paper is to compare the convergence ability of distribution system load–flow methods which are widely used for distribution systems analysis. The method, analysed in this section, are classical Newton- Raphson method [2], Ratio-Flow [21], Forward Backward Substitution method [25] and Ladder Network Theory [26], The convergence ability of methods were also evaluated for different tolerance values, different voltage levels, different loading conditions and different R/X ratios, under the wide range exponents of loads. Algorithms had been implemented with Matlab codes.

A few researchers [29–32] had tried to incorporate composite load model in their algorithms. The most recent of these is the work of Mok et al. [33], which included composite loads and solves the networks by ladder network theory. However, their convergence was not efficient and takes a high number of iterations.

Chiang [34] had also proposed three different algorithms for solving radial distribution networks based on the method proposed by Baran and Wu .He had proposed decoupled, fast decoupled & very fast decoupled distribution load-flow algorithms. In fact decoupled and fast decoupled distribution load-flow algorithms proposed by Chiang [34] were similar to that of Baran and Wu [l4]. However, the very fast decoupled distribution load flow proposed by Chiang [16] was very attractive because it did not require any Jacobian matrix construction and factorisation. Renato [12] had proposed one method for obtaining a load-flow solution of radial distribution networks. He has calculated the electrical equivalent for each node summing all the loads of the network fed through the node including losses and then, starting from the source node, the receiving-end voltages of all the nodes are calculated. Goswami and Basu [35] had presented a direct method for solving radial and meshed distribution networks. However, the main limitation of their method is that no node in the network is the junction of more than three branches, i.e. one incoming and two outgoing branches. Jasmon and Lee [18] had proposed a new load-flow method for obtaining the solution of radial distribution networks. They have used the three fundamental equations representing real power, reactive power and voltage magnitude derived in [35]. They have solved the radial distribution network using these three equations by reducing the whole network into a single he equivalent.

Das et al. [36] had proposed a load-flow technique for solving radial distribution networks by calculating the total real and reactive power fed through any node. They have proposed a unique node, branch and lateral numbering scheme which helps to evaluate exact real and reactive power loads fed through any node. Accordingly, there are a number of reported studies in the literature [17–28] specially designed for solution of power flow problem in radial distribution systems (RDS). Methods developed for the solution of ill-conditioned radial distribution systems may be divided into two categories. The first group of methods is based on the forward-backward sweep process for solution of ladder networks. On the other hand, the second group of methods is utilized by proper modification of existing methods such as Newton-Raphson.

1.6 Objectives of the Research

The thesis work endeavours to propose a new a new technique for load–flow analysis. The objectives are divided into the following:

- To use sequential numbering scheme.
- To reduce data preparation using the radial feature of distribution networks using only the source node of the feeder, lateral(s) and sublateral(s).
- To check the loads–flow results using the constant power, constant current, constant impedance, composite as well as exponential load modelling

1.7 Scope of the Research

The methods proposed in literature till date could not reduce the data preparation even using the radial features of the distribution networks. Data preparation for branch number, sending–end node, receiving–end node is a rigorous task and also time consuming. The aim of this thesis work is to reduce the data preparation using the sequential numbering scheme and the radial feature of distribution networks. The proposed method not only reduces the data preparation but also increases the efficiency of the load–flow. The simple algebraic equations are used to solve the load–flow.

1.8 Organization of Thesis Work

Chapter 1 presents the introduction of distribution system, load–flow, literature survey on load–flow, objectives of the research, scope of the research and organization of the research.

Chapter 2 presents the load–flow analysis of radial distribution networks. The assumption, solution methodology, load modelling, algorithms, examples and results and the conclusion.

Chapter 3 presents the summary of conclusion and the future scope of further research work.

References present the list of previous papers published by researchers in load flow, voltage stability analysis and planning of power distribution system that have been surveyed by the author and also the books in this area.

Appendix – A shows the line data and load data of 33 node radial distribution network available in [39].

Appendix – B shows the line data and load data of 69 node radial distribution network available in [14].

Appendix-C Biography

CHAPTER-2

LOAD–FLOW ANALYSIS WITH REDUCED DATA PREPARATION

2.1 Proposed method

The load–flow of distribution system is different from that of transmission system because it is radial in nature and has high R/X ratio. Convergence of load flow is utmost important. Literature survey shows that the following works had been carried out on load flow studies of electric power distribution systems. The literature survey of radial distribution networks has already been presented in Chapter–1 (**Art. 1.5**).

In this method of load flow analysis the main aim is to reduce the data preparation and to assure computation for any type of numbering scheme for node and branch. If the nodes and branch numbers are sequential, the proposed method needs only the starting node of feeder ,lateral(s) and sub lateral(s) only. The proposed method needs only the set of nodes and branch numbers of each feeder ,lateral(s) and sub-lateral(s) only when node and branch numbers are not sequential. The proposed method computes branch power flow most efficiently and does not need to store nodes beyond each branch.

The voltage of each node is calculated by using a simple algebraic equation. Although the present method is based on forward sweep ,it computes load flow of any complicated radial distribution networks very efficiently even when branch and node numbering scheme are not sequential.

A 33-node and 69-node radial distribution networks with constant power(CP),constant current (CC),constant impedance (CZ),composite and exponential load modelling are considered .

2.2 Assumption

It is assumed that three-phase radial distribution networks are balanced and represented by their single line diagrams and charging capacitances are neglected at the distribution voltage level.

2.3 Solution Methodology

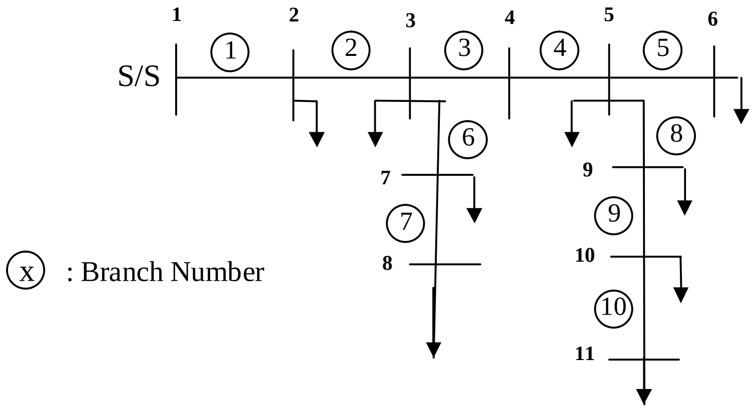

Figure 2.1: Single-line diagram of a radial distribution network

Figure 2.1 shows single-line diagram of a radial distribution network. The proposed method does not need the rigorous data preparation for branch numbers, sending–end nodes and receiving–end nodes respectively. The proposed method needs only the following:

(i) Source node of feeder, lateral(s) and sub lateral(s) and their total number of nodes,

(ii) branch resistance and reactance and

(iii) real and reactive power load at each node

In Figure 2.1, the source node of feeder, lateral(s) are 1, 3 and 5 and their total nodes are 6, 3 and 4 respectively.

The proposed software will immediately generate and store the node numbers of feeder, lateral(s) of Figure 2.1 in the array FN(i,j).

For feeder,

F(1,1) = 1, F(1,2) = 2, F(1,3) = 3, F(1,4) = 4, F(1,5) = 5 and F(1,6) = 6.

For lateral 1,

F(2,1) = 3, F(2,2) = 7 and F(2,3) = 8

For lateral 2,

F(3,1) = 5, F(3,2) = 9, F(3,3) = 10 and F(3,4) = 11

If the sub lateral exists, it can also be handled. The total branch numbers in each case will be one less than the total number of nodes in each case. The last node is the end nodes.

The proposed logic will find the common nodes of lateral(s) and feeder of Figure 2.1. To do this the proposed logic will check the node numbers of feeder with that of lateral(s). The common nodes in this case are 3 and 5 respectively of lateral 1 and lateral 2 with the feeder respectively. These nodes are stored in the array CN where CN means the common nodes and the number of lateral are stored in the array LN where LN means lateral number.

Here CN(1) = 3 and CN(2) = 5.

LN(1) = 2 and LN(2) = 3.

Current of each branch of the network must be calculated at first. To calculate the current of each branch, the proposed software starts from the last lateral or last sub lateral if sub lateral exists.

For lateral 2:

$$I(FB(3,10)) = IL(FN(3,11)) = IL(FN(3,10+1)) \quad (2.1)$$

$$I(FB(3,9)) = I(FB(3,10)) + IL(FN(3,10)) = I(FB(3,9+1)) + IL(FN(3,9+1)) \quad (2.2)$$

$$I(FB(3,8)) = I(FB(3,9)) + IL(FN(3,9)) = I(FB(3,8+1)) + IL(FN(3,8+1)) \quad (2.3)$$

For lateral 1:

$$I(FB(2,7)) = IL(FN(2,8)) = IL(FN(2,7+1)) \quad (2.4)$$

$$I(FB(2,6)) = I(FB(2,7)) + IL(FN(2,7)) = I(FB(2,6+1)) + IL(FN(2,6+1)) \quad (2.5)$$

For Feeder:

$$I(FB(1,5)) = IL(FN(1,6)) = IL(FN(1,5+1)) \quad (2.6)$$

$$I(FB(1,4)) = I(FB(1,5)) + IL(FN(1,4)) + I(FB(LN(2),1))$$
$$= I(FB(1,4+1)) + IL(FN(1,4+1)) + I(FB(LN(2),1)) \quad (2.7)$$

$$I(FB(1,3)) = I(FB(1,4)) + IL(FN(1,4)) = I(FB(1,3+1)) + IL(FN(1,3+1)) \quad (2.8)$$

$$I(FB(1,2)) = I(FB(1,3)) + IL(FN(1,3)) + I(FB(LN(1),1))$$
$$= I(FB(1,2+1)) + IL(FN(1,2+1)) + I(FB(LN(1),1)) \quad (2.9)$$

$$I(FB(1,1)) = I(FB(1,2)) + IL(FN(1,2)) = I(FB(1,1+1)) + IL(FN(1,1+1)) \quad (2.10)$$

From above expressions, we can conclude that

$$I(FB(i,j)) = IL(FN(i,j+1)) \text{ for end nodes} \quad (2.11)$$

and $$I(FB(i,j)) = I(FB(i,j+1)) + IL(FN(i,j+1)) \text{ for other nodes} \quad (2.12)$$

While calculating the branch currents, the proposed software checks the node numbers with the nodes stored in the array. If it matches, the equation (2.12) is modified as follows:

$$I(FB(i,j)) = I(FB(i,j+1)) + IL(FN(i,j+1)) + I(FB(LN(k),1)) \quad (2.13)$$

for nodes when node FN(i,j+1)) is common to the source node of any lateral.

For branch FB(1,1), voltage of node FN(1,2) can be expressed as

$$V(FN(1,2)) = V(FN(1,1)) - I(FB(1,1))Z(FB(1,1)) \quad (2.14)$$

Similarly for branch FB(1,2),

$$V(FN(1,3)) = V(FN(1,2)) - I(FB(1,2))Z(FB(1,2)) \quad (2.15)$$

In general we have

$$V(FN(i,j)) = V(FN(i,j-1)) - I(FB(i,j-1))Z(FB(i,j-1)) \quad (2.16)$$

The load current of node FN(i,j) is

$$IL(FN(i,j)) = \frac{PL(FN(i,j)) - jQL(FN(i,j))}{V^{*}(FN(i,j))} \quad (2.17)$$

and the charging current at a node m2 is shown below

$$IC(FN(i,j)) = y_o(FN(i,j))\, V(FN(i,j)) \quad (2.18)$$

If charging currents are present at any particular receiving end node FN(i,j+1) of branch j, the expression for branch current becomes

$$I(FB(i,j)) = I(FB(i,j+1)) + IL(FN(i,j+1)) + IC(FN(i,j+1)) \text{ for other nodes} \quad (2.19)$$

i.e., $I(FB(i,j)) = I(FB(i,j+1)) + IL(FN(i,j+1)) + I(FB(LN(k),1)) + IC(FN(i,j+1))$ (2.20)

for nodes when node FN(i,j+1)) is common to the source node of any lateral for feeder or any sub lateral for lateral.

Real and reactive power losses of each branch are

$$LP(FB(i,j)) = |I(FB(i,j))|^2 R(FB(i,j)) \quad (2.21)$$

and $$LQ(FB(i,j)) = |I(FB(i,j))|^2 X(FB(i,j)) \quad (2.22)$$

respectively for i =1,2,..,TN and j = 1,2,3,…,N(i) −1.

After computing the voltages at all nodes, convergence of the solution is checked.

As per the method proposed in this paper, the solution converges after successive iterations if the maximum difference in voltage magnitude (ΔVmax) is equal to 0.00001.

2.4 Load Modelling

Load modelling has a crucial role in voltage stability analysis of a distribution network system. Every load depends upon the voltage and frequency in the distribution system.

A balanced load is being considered in this paper that can be represented either as constant power, constant current, constant impedance or as an exponential load. The method of load–flow analysis must have the capability to handle all types of load modelling. Equation (2.23) and (2.24) shows the load modelling.

$$P(FN(i,j)) = P_n\,[a_0 + a_1V(FN(i,j)) + a_2V^2(FN(i,j)) + a_3V^{e1}(FN(i,j))] \qquad (2.23)$$

$$Q(FN(i,j))= Q_n[b_0 + b_1V(FN(i,j)) + b_2V^2(FN(i,j)) + b_3V^{e1}(FN(i,j))] \qquad (2.24)$$

where, P_n and Q_n are nominal real and reactive power respectively and V(FN(i,j)) is the voltage at node m2.

For all the loads, Equation 2.23 and Equation 2.24 are modeled as

$$a_0 + a_1 + a_2 + a_3 = 1.0 \qquad (2.25)$$

$$b_0 + b_1 + b_2 + b_3 = 1.0 \qquad (2.26)$$

For constant power (CP) load $a_0 = b_0 = 1$ and $a_i = b_i = 0$ for i = 1, 2, 3. For constant current (CI) load $a_1 = b_1 = 1$ and $a_i = b_i = 0$ for i = 0, 2, 3. For constant impedance (CZ) load $a_2 = b_2 = 1$ and $a_i = b_i = 0$ for i = 0, 1, 3. Composite load modelling is combination of CP, CI and CZ. For composite load $a_3 = b_3 = 0$ and $a_i = b_i = 1$ for i = 0, 1, 2. For exponential load $a_3 = b_3 = 1$ and $a_i = b_i = 0$ for i = 0, 1, 2 and e1 and e2 are 1.38 and 3.22 respectively.

2.5 Algorithm for Load–flow Computation

The complete algorithm for load flow calculation of radial distribution network is shown below.

Step 1 **:** Get the number of Feeder(A), lateral(s) (B) and sub lateral(s) (C).

Step 2 **:** TN = A + B + C

Step 3 **:** Read the source node and total number of nodes i.e., N(i) of feeder, lateral(s) and sub lateral(s) for i = 1,2,…,TN

Step 4 **:** Read real and reactive power load at each node i.e., PL[FN(i,j)] and QL[FN(i,j)] for j = 2,3,..,N(i) and i = 1,2,..,TN.

Step 5	:	Total number of branches B(i) = N(i) − 1 of feeder, lateral(s) and sub lateral(s) for i = 1,2,…,TN and store them in FB(i,j).
Step 6	:	Read resistance and reactance of each branch i.e., R[FB(i,j)] and X[FB(i,j)] for j = 2,3,..,N(i) −1 and i = 1,2,..,TN.
Step 7	:	Read base kV and base MVA, Total number of iteration (ITMAX), ε (0.00001)
Step 8	:	Initialize PL[FN(1,1)] = 0.0 and QL[FN(1,1)] = 0.0
Step 9	:	Set V[FN(i,j)] = 1.0 + j0.0 for j =1,2,…,N(i) and i = 1,2,….,TN and also set V1[FN(i,j)] = V[FN(i,j)] for j =1,2,…,N(i) and i = 1,2,….,TN.
Step 10	:	Set IT (iteration count) = 1
Step 11	:	Compute the per unit values of PL[FN(i,j)] and QL[FN(i,j)] for j = 2,3,..,N(i) and i = 1,2,..,TN as well as R[FB(i,j)] and X[FB(i,j)] for j = 1,2,3,..,N(i) −1 and i = 1,2,..,TN.
Step 12	:	Set PL1[FN(i,j)] = PL[FN(i,j)] and QL1[FN(i,j)] = QL[FN(i,j)] for j = 2,3,..,N(i) and i = 1,2,..,TN
Step 13	:	Set LP[FB(i,j)] = 0.0 and LQ[FB(I,j)] = 0.0 for all j = 1,2,…,N(i) −1 and i = 1,2,….,TN.
Step 14	:	Set V[FN(i,j)] = 1.0 + j0.0 for j =1,2,…,N(i) and i = 1,2,….,TN and set V1[FN(i,j)] = V[FN(i,j)] for j =1,2,…,N(i) and i = 1,2,….,TN.
Step 15	:	Use proper load modeling using Equations (2.23) and (2.24).
Step 16	:	Calculate the current of each node IL(FN(i,j)) using Equation (2.17).
Step 17	:	Calculate current through each branch i.e., I[FB(i,j)] for for all j = 1,2,…,N(i) −1 and i = 1,2,….,TN using Equations (2.11),(2.12) or (2.13) when charging capacitors are absent or Equation (2.19) or (2.20) when charging capacitors are present.
Step 18	:	Compute voltage |V[FN(i,j)]| using Equation (2.16) for j = 2,3,..,N(i) and i = 1,2,..,TN.
Step 19	:	Compute |ΔV[FN(i,j)]| = |V1[FN(i,j)]| − |V[FN(i,j)]| for j = 2,3,..,N(i) and i = 1,2,..,TN.
Step 20	:	Set |V1[FN(i,j)]| = |V[FN(i,j)]| for j = 1,2,3,..,N(i) and i = 1,2,..,TN.
Step 21	:	Compute LP[FB(i,j)] and LQ[FB(i,j)] for all j = 1,2,…,N(i)−1 and

i = 1,2,….,TN using Equations (2.22) and (2.23) respectively.

Step 22 : Find ΔV_{max} from $|\Delta V[FN(i,j)]|$ for j = 2,3,..,N(i) and i = 1,2,..,TN.

Step 23 : Set PL[FN(i,j)] = PL1[FN(i,j)] and QL[FN(i,j)] = QL1[FN(i,j)] for j = 2,3,..,N(i) and i = 1,2,..,TN

Step 24 : If $\Delta V_{min} \leq 0.00001$ go to Step 27 else go to Step 25.

Step 25 : IT = IT + 1

Step 26 : If IT ≤ ITMAX go to Step 16 else write "NOT CONVERGED" and go to Step 28.

Step 27 : Write " CONVERGED" and display the results

Step 28 : Stop

2.6 Examples

Two examples have been considered to demonstrate the effectiveness of the proposed method. The first example is **33–node** radial distribution network (nodes have been renumbered with Substation as node 1) shown in Figure 2.2. Data for this system are available in [9] shown in Appendix–A. Real and reactive power losses of this system for CP, CI, CZ, Composite load **(40% CP + 30% CI + 30% CZ)** and Exponential load modelling is shown in Table 2.1. The minimum voltage occurs at node number 18 in all cases. Base values for this system are **12.66 kV and 100 MVA** respectively.

The second example is **69–node** radial distribution network (nodes have been renumbered with Substation as node 1) shown in Figure 2.3. Data for this system are available in [5] shown in Appendix–B. Real and reactive power losses of this system for CP, CI, CZ, Composite load **(40% CP + 30% CI + 30% CZ)** and Exponential load modelling is shown in Table 2.2. Table 2.3, Table 2.4,Table 2.5 and Table 2.6 respectively. Table 2.7 shows the total load of 33-node and 69-node radial distribution networks for CP, CI, CZ, composite and exponential load modeling. Table 2.8 shows the comparison of results for 33-node and 69-node radial distribution networks. The minimum voltage occurs at node number 65 in all cases. Base values for this system are **12.66 kV and 100 MVA** respectively.

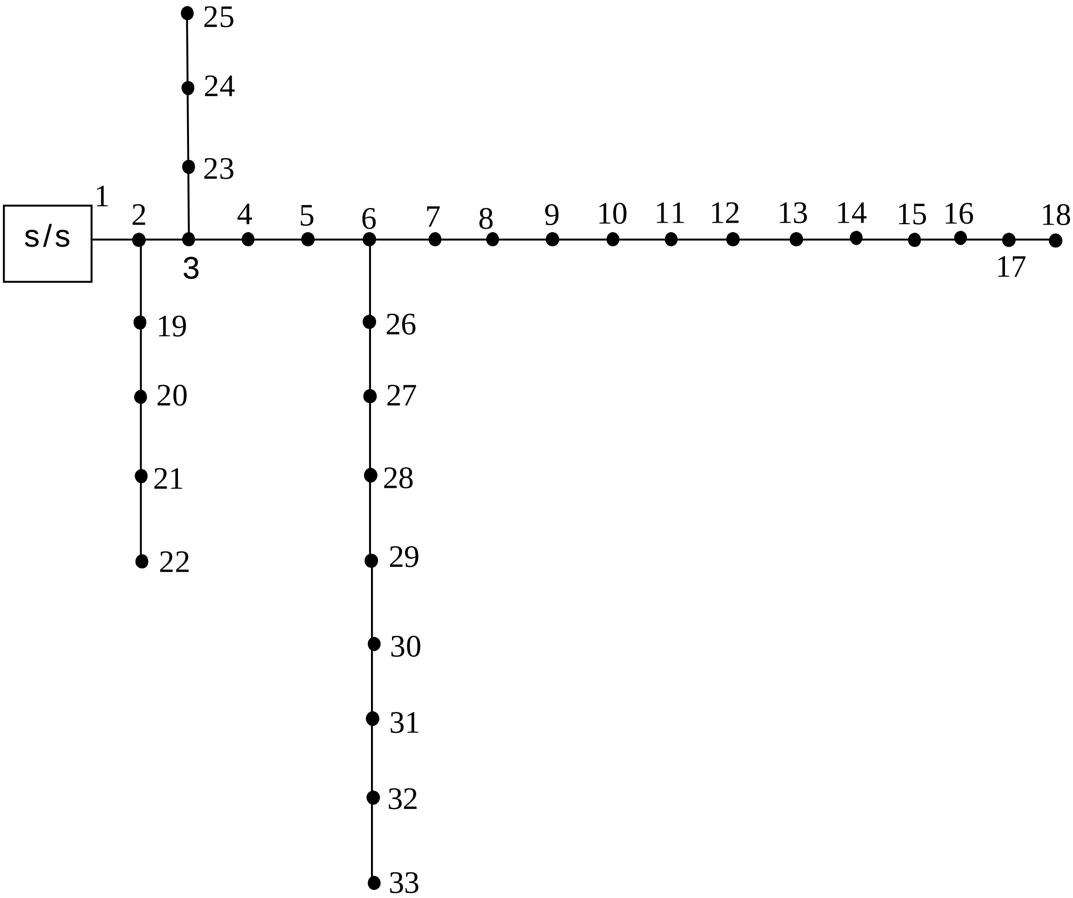

Figure 2.2: 33 Node Radial Distribution Network [39]

Table 2.1 Voltage magnitude (p.u.) of each node for 33–node radial distribution network for CP, CI, CZ, Composite and Exponential load modeling

Node Number	Voltage magnitude (p.u.) of each node for				
	Constant Power (CP) load modeling	Constant Current (CI) load modeling	Constant Impedance (CZ) load modeling	Composite load modelling	Exponential Modeling
1	1.000000	1.000000	1.000000	1.000000	1.000000
2	0.997032	0.997186	0.997312	0.997169	0.997294
3	0.982939	0.983904	0.984695	0.983796	0.984578
4	0.975457	0.976943	0.978156	0.976777	0.977985
5	0.968061	0.970079	0.971723	0.969853	0.971495
6	0.949661	0.953028	0.955760	0.952650	0.955603
7	0.946175	0.949789	0.952720	0.949383	0.952650
8	0.941332	0.945305	0.948526	0.944858	0.948347
9	0.935064	0.939532	0.943150	0.939029	0.942898
10	0.929416	0.934337	0.938317	0.933782	0.938006
11	0.928557	0.933547	0.937583	0.932984	0.937251
12	0.927057	0.932170	0.936305	0.931594	0.935936
13	0.920945	0.926567	0.931108	0.925932	0.930677
14	0.918679	0.924491	0.929183	0.923834	0.928756
15	0.917267	0.923199	0.927987	0.922529	0.927540
16	0.915899	0.921949	0.926830	0.921265	0.926361
17	0.913873	0.920098	0.925118	0.919393	0.924649
18	0.913266	0.919543	0.924606	0.918833	0.924130
19	0.996504	0.996661	0.996791	0.996644	0.996772
20	0.992926	0.993111	0.993267	0.993091	0.993246
21	0.992222	0.992413	0.992574	0.992392	0.992553
22	0.991584	0.991781	0.991947	0.991759	0.991926
23	0.979353	0.980419	0.981300	0.980301	0.981168
24	0.972682	0.973941	0.974995	0.973803	0.974842
25	0.969357	0.970718	0.971862	0.970569	0.971698
26	0.947731	0.951247	0.954097	0.950852	0.953941
27	0.945167	0.948882	0.951893	0.948465	0.951739
28	0.933728	0.938346	0.942081	0.937826	0.942110
29	0.925510	0.930782	0.935042	0.930187	0.935209
30	0.921952	0.927511	0.932000	0.926884	0.932184
31	0.917791	0.923695	0.928459	0.923028	0.928631
32	0.916876	0.922856	0.927681	0.922180	0.927855
33	0.916592	0.922596	0.927440	0.921917	0.927619

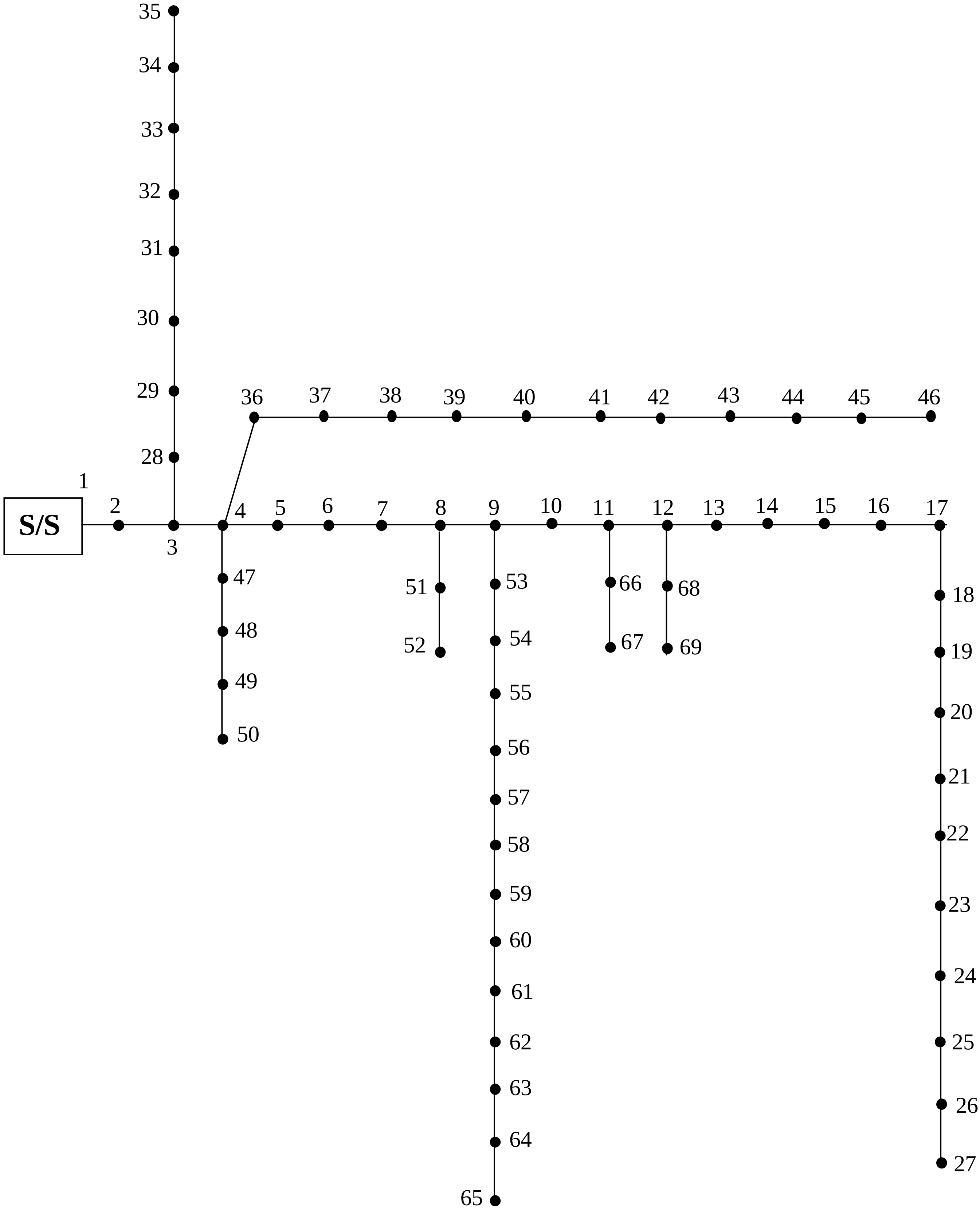

Figure 2.3: 69 node radial distribution network

Table 2.2 Voltage magnitude (p.u.) of each node for 69–node radial distribution network for CP load modeling

Node Number	Voltage magnitude (p.u.)	Node Number	Voltage magnitude (p.u.)
1	1.000000	36	0.999919
2	0.999967	37	0.999747
3	0.999933	38	0.999589
4	0.999839	39	0.999543
5	0.999021	40	0.999541
6	0.990087	41	0.998843
7	0.980796	42	0.998551
8	0.978580	43	0.998512
9	0.977447	44	0.998504
10	0.972450	45	0.998405
11	0.971349	46	0.998405
12	0.968191	47	0.999789
13	0.965269	48	0.998545
14	0.962373	49	0.994704
15	0.959505	50	0.994160
16	0.958972	51	0.978545
17	0.958093	52	0.978535
18	0.958084	53	0.974660
19	0.957619	54	0.971418
20	0.957321	55	0.966944
21	0.956839	56	0.962576
22	0.956833	57	0.940102
23	0.956761	58	0.929042
24	0.956604	59	0.924765
25	0.956435	60	0.919740
26	0.956365	61	0.912343
27	0.956346	62	0.912054
28	0.999926	63	0.911666
29	0.999854	64	0.909766
30	0.999733	65	0.909191
31	0.999712	66	0.971293
32	0.999605	67	0.971292
33	0.999349	68	0.967861
34	0.999013	69	0.967860
35	0.998946		

Table 2.3 Voltage magnitude (p.u.) of each node for 69–node radial distribution network for CI load modeling

Node Number	Voltage magnitude (p.u.)	Node Number	Voltage magnitude (p.u.)
1	1.00000	36	0.999923
2	0.999968	37	0.999751
3	0.999936	38	0.999593
4	0.999848	39	0.999547
5	0.999084	40	0.999545
6	0.990754	41	0.998848
7	0.982090	42	0.998556
8	0.980026	43	0.998518
9	0.978972	44	0.998509
10	0.974154	45	0.998411
11	0.973093	46	0.998410
12	0.970055	47	0.999798
13	0.967257	48	0.998560
14	0.964483	49	0.994741
15	0.961737	50	0.994200
16	0.961227	51	0.979991
17	0.960384	52	0.979982
18	0.960376	53	0.976424
19	0.959931	54	0.973460
20	0.959646	55	0.969374
21	0.959185	56	0.965387
22	0.959179	57	0.944874
23	0.959110	58	0.934779
24	0.958960	59	0.930873
25	0.958799	60	0.926290
26	0.958732	61	0.919543
27	0.958713	62	0.919280
28	0.999929	63	0.918927
29	0.999858	64	0.917198
30	0.999737	65	0.916676
31	0.999715	66	0.973037
32	0.999609	67	0.973037
33	0.999353	68	0.969736
34	0.999018	69	0.969735
35	0.998950		

Table 2.4 Voltage magnitude (p.u.) of each node for 69–node radial distribution network for CZ load modeling

Node Number	Voltage magnitude (p.u.)	Node Number	Voltage magnitude (p.u.)
1	1.00000	36	0.999925
2	0.999969	37	0.999754
3	0.999939	38	0.999596
4	0.999854	39	0.999550
5	0.999134	40	0.999548
6	0.991284	41	0.998852
7	0.983120	42	0.998561
8	0.981176	43	0.998522
9	0.980186	44	0.998514
10	0.975523	45	0.998416
11	0.974496	46	0.998415
12	0.971564	47	0.999805
13	0.968873	48	0.998573
14	0.966206	49	0.994775
15	0.963565	50	0.994237
16	0.963074	51	0.981142
17	0.962264	52	0.981133
18	0.962256	53	0.977825
19	0.961829	54	0.975078
20	0.961555	55	0.971296
21	0.961112	56	0.967607
22	0.961106	57	0.948637
23	0.961040	58	0.939299
24	0.960896	59	0.935687
25	0.960741	60	0.931450
26	0.960677	61	0.925213
27	0.960659	62	0.924969
28	0.999932	63	0.924644
29	0.999860	64	0.923049
30	0.999740	65	0.922567
31	0.999718	66	0.974443
32	0.999611	67	0.974442
33	0.999356	68	0.971254
34	0.999021	69	0.971253
35	0.998954		

Table 2.5 Voltage magnitude (p.u.) of each node for 69–node radial distribution network for Composite load modeling

Node Number	Voltage magnitude (p.u.)	Node Number	Voltage magnitude (p.u.)
1	1.00000	36	0.999922
2	0.999968	37	0.999751
3	0.999936	38	0.999592
4	0.999847	39	0.999546
5	0.999077	40	0.999544
6	0.990680	41	0.998848
7	0.981946	42	0.998556
8	0.979865	43	0.998517
9	0.978803	44	0.998509
10	0.973966	45	0.998410
11	0.972901	46	0.998410
12	0.969851	47	0.999797
13	0.967040	48	0.998558
14	0.964254	49	0.994737
15	0.961495	50	0.994196
16	0.960983	51	0.979830
17	0.960136	52	0.979821
18	0.960128	53	0.976228
19	0.959681	54	0.973232
20	0.959395	55	0.969103
21	0.958932	56	0.965073
22	0.958925	57	0.944345
23	0.958856	58	0.934143
24	0.958706	59	0.930197
25	0.958543	60	0.925565
26	0.958476	61	0.918746
27	0.958457	62	0.918479
28	0.999929	63	0.918122
29	0.999857	64	0.916374
30	0.999736	65	0.915846
31	0.999715	66	0.972846
32	0.999608	67	0.972845
33	0.999352	68	0.969531
34	0.999017	69	0.969530
35	0.998950		

Table 2.6 Voltage magnitude (p.u.) of each node for 69–node radial distribution network for Exponential load modeling

Node Number	Voltage magnitude (p.u.)	Node Number	Voltage magnitude (p.u.)
1	1.00000	36	0.999926
2	0.999970	37	0.999755
3	0.999940	38	0.999597
4	0.999857	39	0.999551
5	0.999146	40	0.999549
6	0.991237	41	0.998854
7	0.983011	42	0.998562
8	0.981052	43	0.998524
9	0.980054	44	0.998516
10	0.975348	45	0.998417
11	0.974312	46	0.998417
12	0.971351	47	0.999808
13	0.968629	48	0.998580
14	0.965931	49	0.994793
15	0.963260	50	0.994256
16	0.962764	51	0.981018
17	0.961945	52	0.981009
18	0.961936	53	0.977671
19	0.961505	54	0.974897
20	0.961227	55	0.971077
21	0.960780	56	0.967352
22	0.960773	57	0.947998
23	0.960707	58	0.938466
24	0.960561	59	0.934777
25	0.960404	60	0.930440
26	0.960339	61	0.924133
27	0.960321	62	0.923887
28	0.999933	63	0.923558
29	0.999862	64	0.921944
30	0.999741	65	0.921457
31	0.999719	66	0.974258
32	0.999613	67	0.974258
33	0.999357	68	0.971039
34	0.999022	69	0.971038
35	0.998955		

Table 2.7 shows total real and reactive power load of 33–node and 69–node radial distribution networks for constant power, constant current, constant impedance, composite and exponential load modelling for sub-station voltage.

Table 2.8 shows comparison of results of 33–node and 69–node radial distribution networks for constant power, constant current, constant impedance, composite and exponential load modelling for sub-station voltage.

Table 2.9 shows the comparison of relative speed of the proposed method with the other existing methods for constant power load modelling. All simulation works have been done in **Celeron Processor 1GHz**.

Table 2.7 Total Real power load and Reactive Power Load of 33–node and 69–node radial distribution networks for CP, CI, CZ, Composite and Exponential load modelling for substation voltage 1.0 p.u.

Type of load modelling	33–node radial distribution network		69–node radial distribution network	
	Real power load (kW)	Reactive power load (kVAr)	Real power load (kW)	Reactive power load (kVAr)
Constant Power	3714.99	2300.00	3801.89	2692.59
Constant Current	3543.34	2181.05	3633.45	2573.05
Constant Impedance	3400.46	2082.75	3495.96	2475.52
Composite load	3562.45	2194.40	3651.92	2586.17
Exponential load	3493.52	1962.48	3583.79	2352.71

Table 2.8 Comparison of results for 33–node and 69–node radial distribution network

Example	Type of Load	Power Loss		Iteration Number	Minimum Voltage (p.u.)
		Real (kW)	Reactive (kVAr)		
33–node radial distribution network Baran and Wu	CP	202.52	135.13	**5**	V_{18} = 0.913266
	CI	176.51	117.51	**3**	V_{18} = 0.919543
	CZ	156.78	104.18	**4**	V_{18} = 0.924606
	Composite	179.35	119.43	**3**	V_{18} = 0.918833
	Exponential	157.33	104.56	**4**	V_{18} = 0.924130
69–node radial distribution network Baran and Wu	CP	224.93	102.13	**5**	V_{65} = 0.909191
	CI	191.45	87.77	**2**	V_{65} = 0.916676
	CZ	167.11	77.30	**5**	V_{65} = 0.922567
	Composite	195.11	89.34	**3**	V_{65} = 0.915846
	Exponential	168.05	77.70	**4**	V_{65} = 0.921457

Table 2.9 Comparison of relative speed of the proposed method with other existing methods [22,32] for constant power load modelling.

Examples / Methods	Example 1 33–node radial distribution network	Example 2 69–node radial distribution network
	Speed	Speed
Proposed method	1.0	1.0
Ranjan and D.Das [22]	2.95	3.45
S.Ghosh and D.Das [32]	2.44	2.95

CHAPTER 3

SUMMARY & FUTURE SCOPE OF WORK

3.1 Conclusions

In this thesis work a method of load−flow analysis has been proposed for radial distribution networks based on the new method to identify the set of branches for every feeder, lateral and sub lateral without any repetitive search for computation of each branch current. Also this method has shown the relation of branch−number with its receiving end node and the next branch if the sequential branch−numbering as well as node−numbering is adopted. Effectiveness of the proposed method has been tested by two examples 33−node and 69− node radial distribution networks with constant power load, constant current load, constant impedance load, composite and exponential load for each of these examples. The voltage convergence has assured the satisfactory convergence in all these cases. The superiority of the proposed method in terms of speed has been checked by comparing with the other existing methods. The proposed method consumes less amount of memory compared to the other due to reduction of data preparation.

3.2 Future Scope of Work

The following are the scopes of future work

(i) Fuzzy load−flow analysis

(ii) Load−flow analysis using Genetic Algorithms

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APPENDIX A

Table A.1 Line Data of 33 Node Radial Distribution Network

Branch Number	Sending–end Node	Receiving–end Node	Branch resistance (Ω)	Branch reactance (Ω)
1	1	2	0.0922	0.0470
2	2	3	0.4930	0.2511
3	3	4	0.3660	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.8190	0.7070
6	6	7	0.1872	0.6188
7	7	8	0.7114	0.2351
8	8	9	1.0300	0.7400
9	9	10	1.0040	0.7400
10	10	11	0.1996	0.0650
11	11	12	0.3744	0.1238
12	12	13	1.4680	1.1550
13	13	14	0.5416	0.7129
14	14	15	0.5910	0.5260
15	15	16	0.7463	0.5450
16	16	17	1.2890	1.7210
17	17	18	0.7320	0.5740
18	2	19	0.1640	0.1565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.8980	0.7091
24	24	25	0.8960	0.7011
25	6	26	0.2030	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.0590	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.9630
31	31	32	0.3105	0.3619
32	32	33	0.3410	0.5302

Table A.2 Load Data of 33 Node Radial Distribution Network

Node Number	PL (kW)	QL (kVAr)
1(S/S)	0.0	0.0
2	100.0	60.0
3	90.0	40.0
4	120.0	80.0
5	60.0	30.0
6	60.0	20.0
7	200.0	100.0
8	200.0	100.0
9	60.0	20.0
10	60.0	20.0
11	45.0	30.0
12	60.0	35.0
13	60.0	35.0
14	120.0	80.0
15	60.0	10.0
16	60.0	20.0
17	60.0	20.0
18	90.0	40.0
19	90.0	40.0
20	90.0	40.0
21	90.0	40.0
22	90.0	40.0
23	90.0	50.0
24	420.0	200.0
25	420.0	200.0
26	60.0	25.0
27	60.0	25.0
28	60.0	20.0
29	120.0	70.0
30	200.0	600.0
31	150.0	70.0
32	210.0	100.0
33	60.0	40.0

BASE kV = 12.66 and BASE MVA = 100

APPENDIX B

Table B.1 Line Data of 69 Node Radial Distribution Network

Branch Number	Sending–end	Receiving–end	Branch Resistance (Ω)	Branch Reactance (Ω)
1	1	2	0.0005	0.0012
2	2	3	0.0005	0.0012
3	3	4	0.0015	0.0036
4	4	5	0.0251	0.0294
5	5	6	0.3660	0.1864
6	6	7	0.3811	0.1941
7	7	8	0.0922	0.0470
8	8	9	0.0493	0.0257
9	9	10	0.8190	0.2707
10	10	11	0.1872	0.0619
11	11	12	0.7114	0.2351
12	12	13	1.0300	0.3400
13	13	14	1.0440	0.3450
14	14	15	1.0580	0.3496
15	15	16	0.1966	0.0650
16	16	17	0.3744	0.1238
17	17	18	0.0047	0.0016
18	18	19	0.3276	0.1083
19	19	20	0.2106	0.0696
20	20	21	0.3416	0.1129
21	21	22	0.0140	0.0046
22	22	23	0.1591	0.0526
23	23	24	0.3463	0.1145
24	24	25	0.7488	0.2475
25	25	26	0.3089	0.1021
26	26	27	0.1732	0.0572
27	3	28	0.0044	0.0108
28	28	29	0.0640	0.1565
29	29	30	0.3978	0.1315
30	30	31	0.0702	0.0232
31	31	32	0.3510	0.1160
32	32	33	0.8390	0.2816
33	33	34	1.7080	0.5646
34	34	35	1.4740	0.4873
35	3	36	0.0044	0.0108
36	36	37	0.0640	0.1565
37	37	38	0.1053	0.1230

38	38	39	0.0304	0.0355
39	39	40	0.0018	0.0021
40	40	41	0.7283	0.8509
41	41	42	0.3100	0.3623
42	42	43	0.0410	0.0478
43	43	44	0.0092	0.0116
44	44	45	0.1089	0.1373
45	45	46	0.0009	0..0012
46	4	47	0.0034	0.0084
47	47	48	0.0851	0.2083
48	48	49	0.2898	0.7091
49	49	50	0.0822	0.2011
50	8	51	0.0928	0.0473
51	51	52	0.3319	0.1114
52	9	53	0.1740	0.0886
56	53	54	0.2030	0.1034
53	54	55	0.2842	0.1447
54	55	56	0.2813	0.1433
55	56	57	1.5900	0.5337
56	57	58	0.7837	0.2630
57	58	59	0.3042	0.1006
58	59	60	0.3861	0.1172
59	60	61	0.5075	0.2585
60	61	62	0.0974	0.0496
61	62	63	0.1450	0.0738
62	63	64	0.7105	0.3619
63	64	65	1.0410	0.5302
64	11	66	0.2012	0.0611
65	66	67	0.0047	0.0014
67	12	68	0.7394	0.2444
68	68	69	0.0047	0.0016

Table B.2 Load Data of 69 Node Radial Distribution Network

Node Number	PL(kW)	QL(kVAr)	Node Number	PL(kW)	QL(kVAr)
1	00.00	00.00	36	26.00	18.55
2	00.00	00.00	37	26.00	18.55
3	00.00	00.00	38	00.00	00.00
4	00.00	00.00	39	24.00	17.00
5	00.00	00.00	40	24.00	17.00
6	2.600	2.200	41	1.200	1.000
7	40.40	30.00	42	00.00	00.00
8	75.00	54.00	43	6.000	4.300
9	30.00	22.00	44	00.00	00.00
10	28.00	19.00	45	39.22	26.30
11	145.0	104.0	46	39.22	26.30
12	145.0	104.0	47	00.00	00.00
13	8.000	5.000	48	79.00	56.40
14	8.000	5.500	49	384.7	274.0
15	00.00	00.00	50	384.7	274.0
16	45.50	30.00	51	40.50	28.30
17	60.00	35.00	52	3.600	2.700
18	60.00	35.00	53	4.350	3.500
19	00.00	00.00	54	26.40	19.00
20	1.000	00.60	55	26.00	17.20
21	114.0	81.00	56	00.00	00.00
22	5.000	3.500	57	00.00	00.00
23	00.00	00.00	58	00.00	00.00
24	28.00	20.00	59	100.0	72.00
25	00.00	00.00	60	00.00	00.00
26	14.00	10.00	61	1244.0	888.0
27	14.00	10.00	62	32.00	23.00
28	26.00	18.60	63	00.00	00.00
29	26.00	18.60	64	227.0	162.0
30	00.00	00.00	65	59.00	42.00
31	00.00	00.00	66	18.00	13.00
32	00.00	00.00	67	18.00	13.00
33	14.00	10.00	68	28.00	20.00
34	19.50	14.00	69	28.00	20.00
35	6.000	4.000			

BASE kV = 12.66 and BASE MVA = 100

APPENDIX C

BIOGRAPHY

PERSONAL INFORMATION

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Higher Secondary . from C.B.S.E Board Securing 75 %.(with distinction)
High School from C.B.S.E. securing 81.2%(with distinction)

CAMPUS PLACEMENTS

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