MAXIMUM LOADING OF RADIAL DISTRIBUTION NETWORKS

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

Master of Engineering
in
Power Systems & Electrical Drives

Thapar University, Patiala

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JUNE, 2009
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CERTIFICATE

I hereby certify that the work is presented in the thesis entitled, "**Maximum Loading of Radial Distribution Networks**", in partial fulfilment of the requirements for the award of degree of Master of Engineering in Power Systems & Electric Drives submitted in Electrical & Instrumentation Engineering Department of Thapar University, Patiala, is authentic record of my own work carried out under the supervision of Dr. Smarajit Ghosh, Prof & Head, EIED.

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

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ACKNOWLEDGEMENTS

First of all, I thank the Almighty God, who gave me opportunity, strength and guided me to work on the right path of life. My greatest thanks are to my parents who bestowed ability to complete this work.

I would like to express thanks to **Dr. Smarajit Ghosh, Prof & Head, EIED** for the opportunity to work with him, and also for his encouragement, trust and untiring support. **Dr. Smarajit Ghosh** has been an advisor in the true sense both academically and morally throughout this project work.

Much appreciations is expressed to **Prof. Abhijit Mukherjee, Director, Thapar University, Prof. K.K. Raina, Deputy Director, Thapar University and Prof. R.K. Sharma, Dean of Academic Affairs** to provide me moral support to go ahead with my innovative M.E. Thesis work.

I thank to **Dr. Y. Singh, Associate Professor, EIED** and **Mr. Mandeep Singh, Assistant Professor, EIED** for their continuous inspiration and valuable suggestions during this thesis work.

I am also very thankful to the entire faculty and staff members of Electrical and Instrumentation Engineering Department for their direct–indirect help, cooperation, love and affection, which made my stay at Thapar University memorable. I wish to thank all my classmates for their time to time suggestions and cooperation.

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Dedicated to My Parents

ABSTRACT

In this Thesis work, an attempt has been made to determine the maximum loading of electric power distribution system. A new formula for computing the loading of any distribution network is proposed in this thesis work.. Using example of 56-node radial distribution networks, it has been shown that the node having the minimum value become most sensitive node using the proposed method which is also the end node. presents a method for obtaining the maximum allowable loading of radial distribution feeders for different types of loads without violating the maximum current carrying capacity of branch conductors. Minimum voltage of the feeders can also be maintained by allowing the feeders to take load growth up to a specific period of time. The critical values of total real power load (TPL) and total reactive power load (TQL) are derived out for the sub-station voltage of 1.0 pu. for 56-node radial distribution network. The proposed method will reduce the real and reactive power losses, improves voltage profile and enhances the loading capability of distribution network.

The proposed method to determine the loading will be very useful for distribution system planning, optimum placement of shunt capacitors, network reconfiguration, etc.

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LIST OF SYMBOLS

NB	Total no. of Nodes
LN1	Total no. of Branches
jj	Branch no. i.e., jj = 1,2,3,………,LN1
m1	I S(jj) be the Sending–end Node of Branch-jj
m2	IR(jj) be the Receiving –end Node of Branch-jj
ISS(jj)	IS(jj) for all jj
IRR(jj)	IR(jj) for all jj
V(m1)	Voltage of Sending – end Node of Branch – jj
V(m2)	Voltage of Receivng – end Node of Branch – jj
R(jj)	Resistance of Branch – jj
X(jj)	Reactance of Branch – jj
Z(jj)	Impedance of Branch – jj
I(jj)	Current through the Branch – jj
Ir(jj)	Real Component of I(jj)
Im(jj)	Imaginary Component of I(jj)
PL(m2)	Active Power Load at Node m2
QL(m2)	Reactive Power Load at Node m2
IL(m2)	Load Current at Node m2
LP(jj)	Real Power Loss of Branch – jj
LQ(jj)	Reactive Power Loss of Branch – jj
DVMAX	Maximum Voltage Difference

CHAPTER- 1

INTRODUCTION

1.1 ELECTRICAL POWER SYSTEM

The transmission system of an area is known as grid. Each grid operates independently. However, power can be transmitted from one grid to another, over tie lines, under conditions of sudden loss in generation or increase in load demand.

The amount of power that has to be transmitted through transmission lines is very large and if this power is transmitted at 11kV (or 33kV) the line current and power loss would be very large. Therefore, this voltage is stepped up to a higher value by using step up transformers located at sending end sub-stations. The transmission voltages in India are 66kV, 110kV, 132kV, 220/230kV and 400kV. The high voltage transmission lines transmit electrical power from the sending end sub-stations to the receiving end substations. At the receiving end sub-stations voltage is stepped down to a lower value of 66, 33 or 11kV. The secondary transmission system forms the link between the main receiving end substations and the secondary sub-stations. At the secondary sub-stations the voltage is stepped down to 33kV, 11kV or 3.3kV and power is fed into the primary distribution system. Feeders originate from the secondary substations and terminate in distribution sub-stations.

The distribution sub-stations consist of step down transformers and various protective devices. These are placed at suitable locations in an area in which power is to be supplied. Sometimes, these distribution sub-stations consist of pole-mounted transformers located on the road side. These transformers step down the voltage to 400V. The 400V distribution lines are laid along the roads and service connections to the consumers are tapped off from the distributors. In some cases there is only one level of transmission and secondary transmission. In such cases the feeders directly take off from the main sub-stations. Some large consumers are supplied at 132kV and 66kV directly.

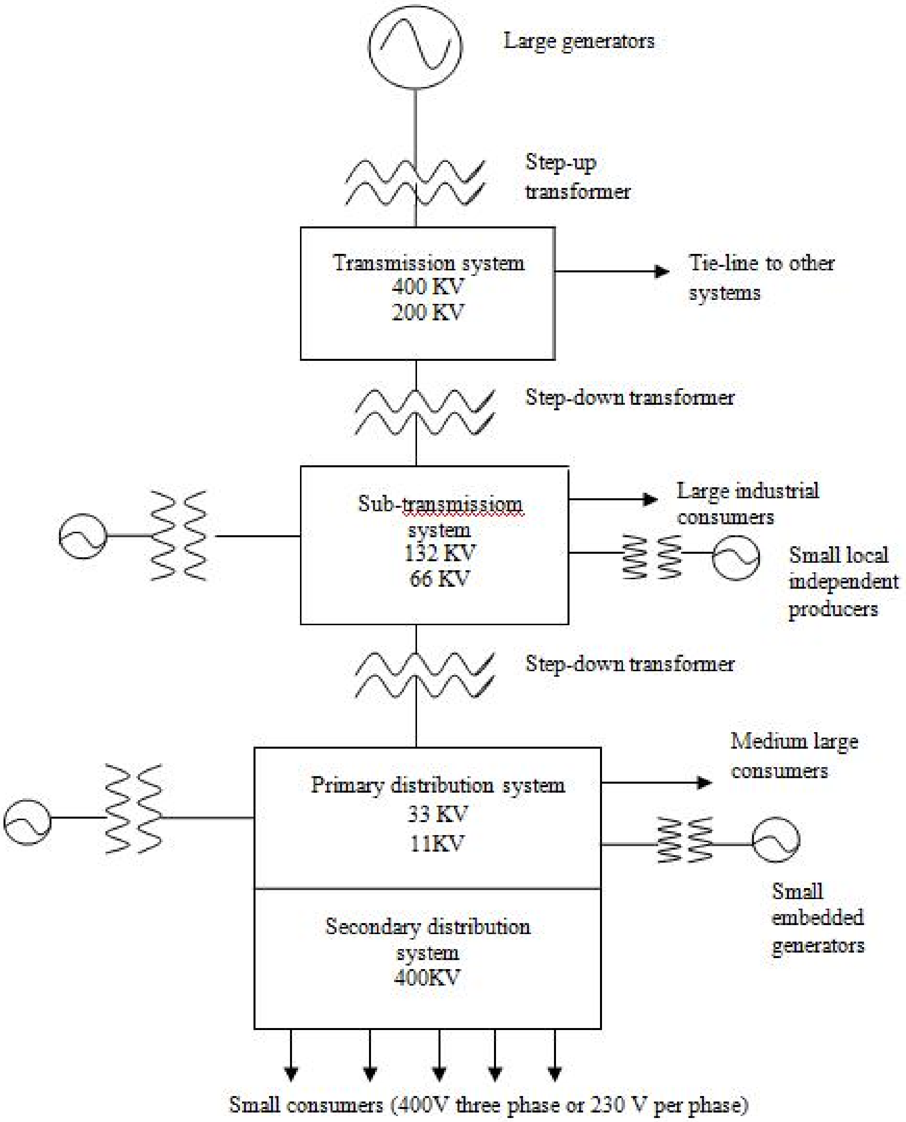

Figure 1.1 Network of Electric Supply System

1.2 Distribution System

The distribution system plays an important role in any electric power system. The effectiveness with which it achieves its objective of distributing electric energy to various consumers, is measured in terms of voltage regulation, flexibility, security of supply efficiency and cost.

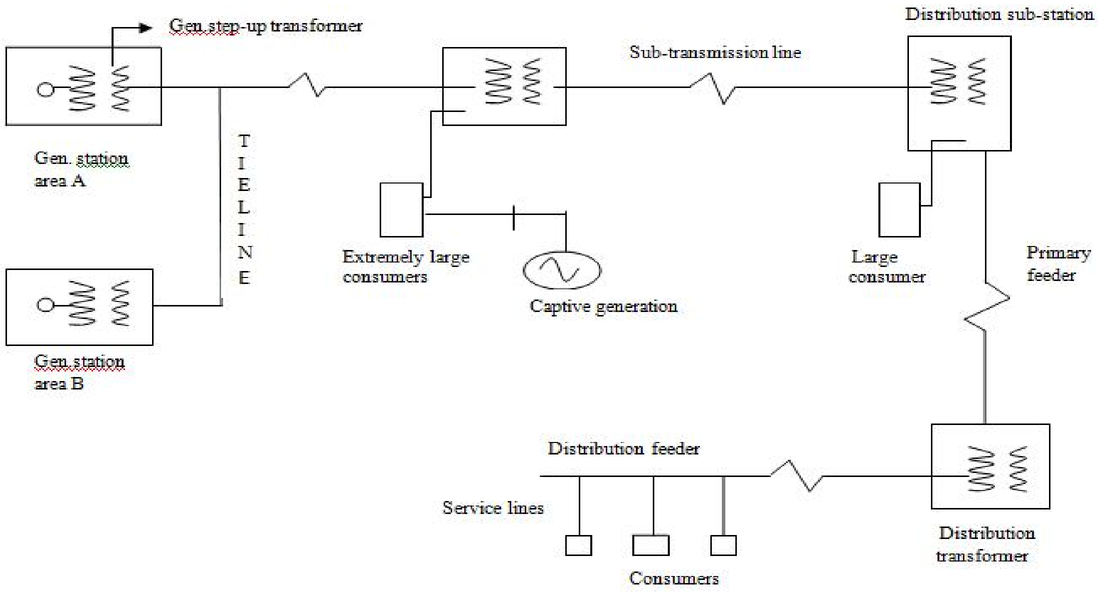

Figure 1.2 A single line diagram of typical distribution system

In general, the distribution system consists of feeders, distributors and service mains. Figure shows a single line diagram of a typical distribution system.

i) **Feeders:** A feeder is a conductor which connects the substation (or localized generating station) to the areas to be fed by those stations. Generally, no tappings are taken from feeders to the consumers. Therefore current loading of a feeder remains same along its length. It is designed mainly from the point of view of its current carrying capacity.

ii) **Distributor**: Distributors are the conductors from which numerous tappings for the supply to consumers are taken. The current loading of distributor varies along its length. Distributors are designed from the point of view of the voltage drop in them.

iii) **Service mains**: Service mains are the conductors, which connect the consumer's terminals to the distributor.

1.3 Requirements of a Distribution System

A considerable effort is mandatory to maintain the supply of electric power within the requirements of many types of consumers. The necessary requirements of a good distribution system are:-

1) **Availability of power demand**: Power should be available to the consumers in large amount as per their requirement.

2) **Reliability**: Present day industry is totally dependent on electric power for its operation. So, there is an urgent need of a reliable service. If per chance, there is a power failure, it should be for the minimum possible time at every cost. Improvement in reliability can be made upto a considerable extent by

   a) Reliable automatic control system.
   b) Providing additional reserve facilities.

3) **Proper voltage:** Most important requirement of a distribution system is that the voltage variations at the consumer terminals should be as low a possible. The main cause of changes in voltage variation is variation of load on system. Therefore, a distribution is said to be good, if it ensures that the voltage variations are within permissible limits at consumer terminals.

4) **Loading**: The transmission line should never be over loaded.

5) **Efficiency**: The efficiency of transmission lines should be maximum say about 90%.

1.4 Classification of Distribution System

A distribution system may be classified as:-

i) **Nature of current**: According to nature of current, distribution system can be classified as

   a) AC distribution system.
   b) DC distribution system.

ii) **Type of construction**: According to type of construction, distribution system is classified as

   a) Overhead system

    - b) Underground system

- iii) **Scheme of operation**: According to scheme of operation, distribution system may be classified as:
    - a) Radial system
    - b) Ring main system
    - c) Interconnected system

1.5 D.C. Distribution

The electric power is almost exclusively generated, transmitted and distributed as AC. However for certain applications dc supply is mandatory such as for operation of variable speed machinery for electromechanical work etc. for this purpose ac power is converted into dc at substation by using converting machinery e.g mercury arc rectifiers.

1.6 A.C. Distribution

Nowadays, electrical energy is generated, transmitted and distributed in form of alternating current. One major use of ac in comparison to dc is the fact that alternating voltage can be stepped up or stepped down conveniently. This is possible only through a transformer. It can transmit high voltage and that too at a safe potential. High transmission and distribution voltages have greatly reduced current in conductors and the resulting line losses. The ac distribution system is further classified as: a) Primary distribution system and b) Secondary distribution system.

a) **Primary distribution system**: It is that part of ac distribution system which operate at voltage somewhat higher than the general utilization. It can handle large blocks of electrical energy. The voltage used for primary distribution depends upon the amount of power to be conveyed and the total distance of substation required to be fed. The most commonly used primary distribution voltages are 11KV, 3.3KV, 6.6KV. Due to economic considerations, primary distribution is carried by 3-phase, 3-wire system. The system consists of number of number of interconnected feeders. Two or more sub-transmission circuits supply two or more secondary substations from which feeders take off. Because the feeders are interconnected, power is supplied to all the distribution transformers. Even though a part of network may be out of service.

Each secondary substation consists of a transformer (to step down the sub transmission voltage to the primary feeder voltage) and the necessary switchgear to isolate the faulty feeder and to control the feeders. This system provides good reliability and flexibility and is used in large metrolpolitan area where the continuity of supply is essential. The primary distribution system may consist of radial feeders, parallel feeders, ring feeders or a network. A radial feeder is the simplest and the most commonly used. It is used extensively to supply small, medium residential and non-critical loads. The distribution transformers are connected to the primary feeders, sub-feeders and laterals, usually through fused cutouts. A parallel feeder consists of duplicate feed system having two radial feeders running in parallel. Each feeder supplies about half of the total load area but has a capability to supply the entire load in the event of outage on the other feeder. Loss of either feeder will result in interruption of service until load normally supplied by the faulted feeder is transferred to the other feeder by automatic or manually controlled switches. Parallel feeders cost more than the radial feeders but substantially reduce the frequency and duration of outages.

A system of two or more radial feeders originating from same or different secondary substations and separately routed through load areas results into a loop feeder system. If the ends of two feeders are tied together through normally open switching devices, the resulting arrangement is known as open loop system. If the ends are tied together by means of a normally closed switching device, the result is a ring loop or simply ring feeder. The loop feeder provides a good continuity of service. Feeder and loop components must have sufficient reserve capacity to serve the load that may be transferred under emergency conditions. Loop feeder system is the most practical for providing reasonable reliability with nearly full utilization of facilities.

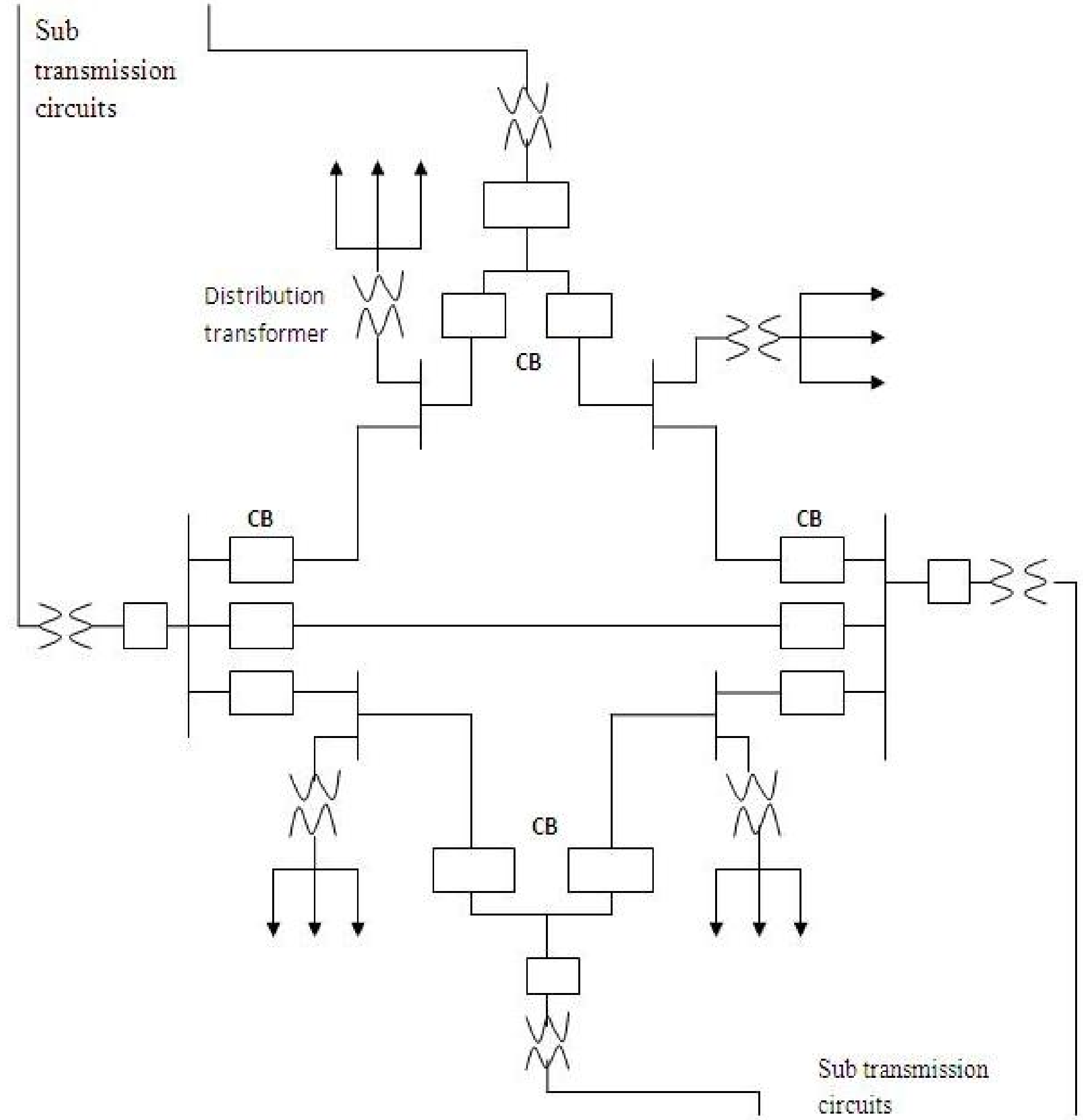

Figure 1.3 Primary distribution network

b) **Secondary distribution system**: It is that part of ac distribution system which includes the range of voltages at which the ultimate consumer utilizes electrical energy. The secondary distribution system is commonly employed for 230/400V 3-phase, 4-wire system. In this system service connections to the consumers are tapped off the distributors at convenient points. The service connections mat be single phase two-wire circuits or three phase two-wire circuits. An attempt is made to divide the single phase loads equally on the three phases.

The secondary distribution systems generally used are: radial, open-loop and network distribution. A radial distributor takes off from the distribution transformer and runs through the area served by it. This is the simplest and the least expensive system but has the poorest reliability. An open system consists of two distributors taking off from the same distribution transformer and running in different directions and supplying different areas. An open loop system consists of two distributors taking off from the same distribution transformer and running in different directions and supplying different areas. The far ends of two distributors are tied together by a normally open switching device. In the event of fault on one of the distributors, power can be supplied, though partially, from the other distributor. Thus an open loop distributor system provides better continuity of service, and its cost is marginally higher than that of radial system. The medium and high density areas are generally supplied through open loop feeders.

The secondary distribution system may be overhead or underground or partly overhead or underground. An underground system has greater reliability but is more costly than the overhead system. The distribution system in high load density and congested areas is usually underground. The selection of the type of distributor is governed by available investment and the degree of reliability of supply. Preliminary requirement of a distributor is the maximum current in each distributor. This is done from the values of connected loads of consumers to be fed from the distributor. In the design of secondary distribution system, conductor size of distributor is assumed. Since the current in a distributor decreases, as its distance from the transformer increase, the size of the distributor should be continuously decreased. For residential and commercial loads, unity power factor is assumed.

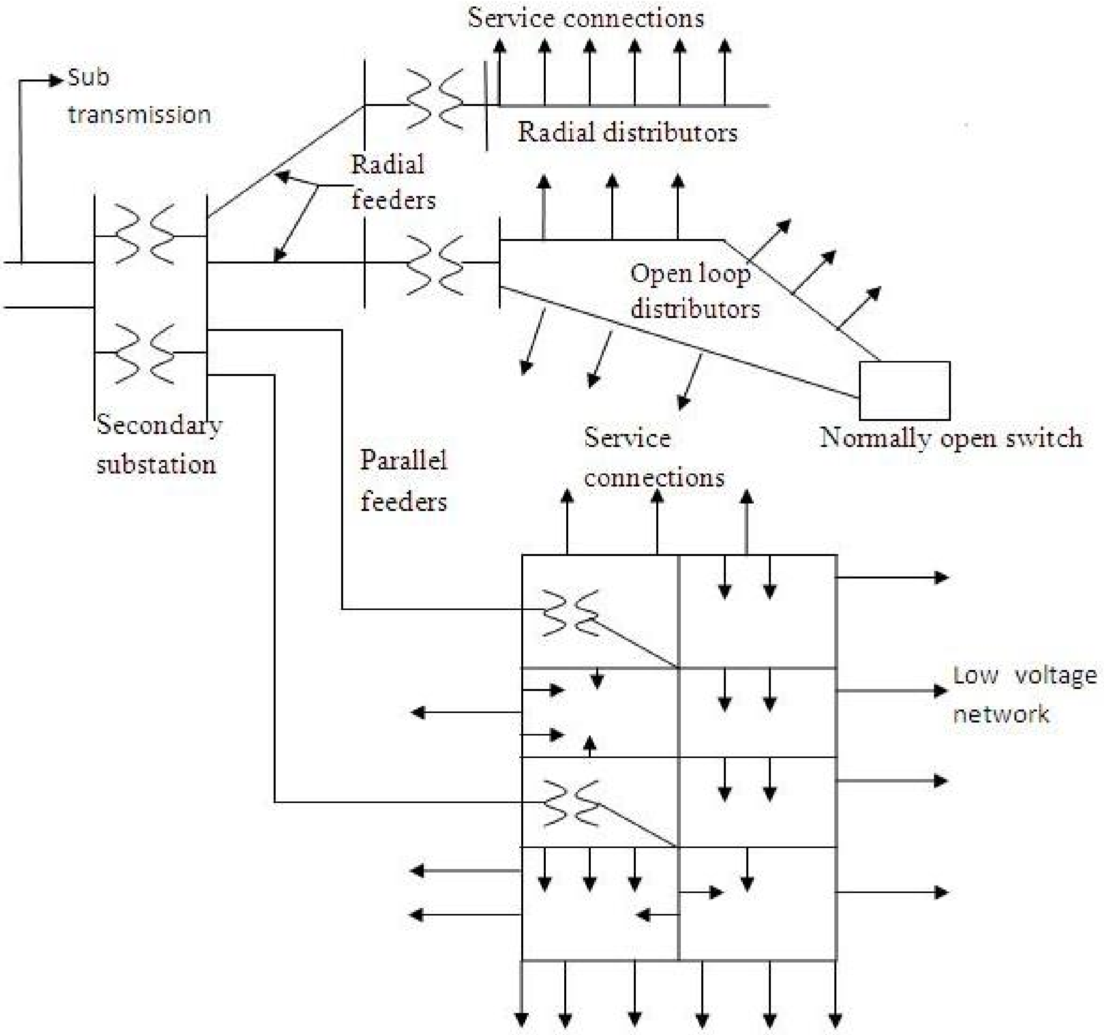

Figure 1.4 Secondary distribution system

1.7 Connection Scheme of Distribution System

The distribution system can be classified according to the type of connections. These are the following two systems:-

i) **Radial Systems**: The electric energy distribution originally was through radial systems. Radial feeders are characterized by having only one path for the power to flow from the source (distribution substation) to each customer. If the distributor is connected to the supply system on one end only, that system is called radial distribution system. In other words, in this system separate feeders radiate from a single substation and the distributors are fed at one end only. A typical radial distribution system is as shown below. Figure (a) given below shows a single line diagram of a radial distribution system for dc distribution. Here a feeder OC supplies a distributor AB at point A. Of course, the distributor is fed at one end only i.e point A. Figure (b) shows a single line diagram of a radial distribution system for ac distribution.

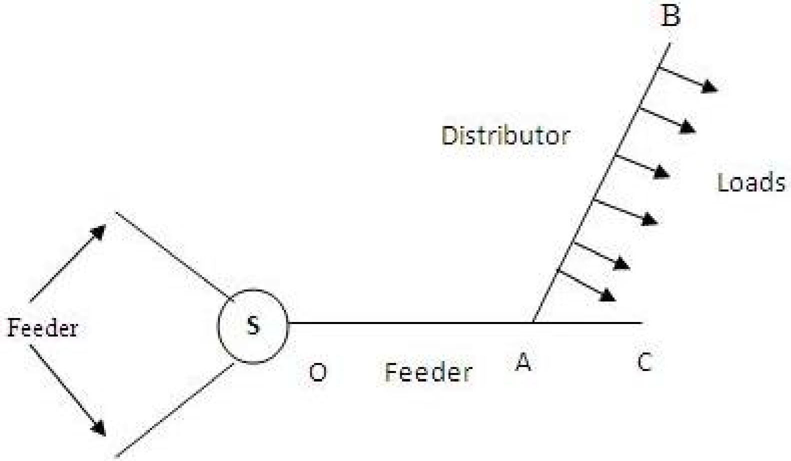

Figure 1.5 Diagram of radial distribution system for DC

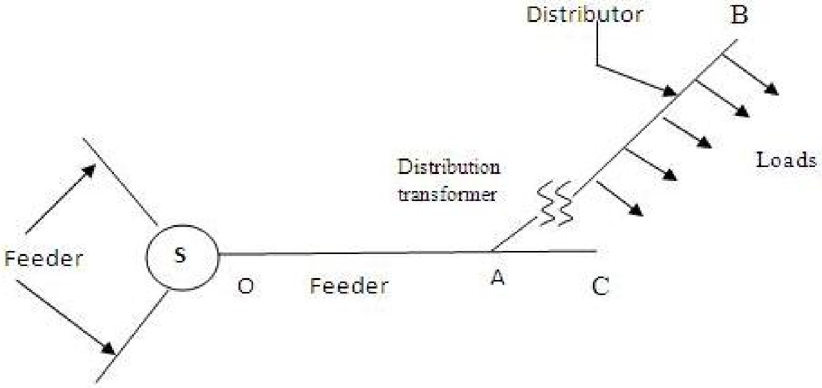

Figure1.6 Diagram of radial distribution system for AC

The radial system is employed only when the power is generated at low voltage and the substation is located at the centre of the load. This system is the simplest distribution circuit and low initial cost. On the other hand, it suffers from the following drawbacks:-

i) The end of the distributor nearest to the feeding point or the generation station will be heavily loaded.
ii) Consumers are dependent on a single feeder and on a single distributor. Therefore, any fault on the feeder or distributor cuts off supply to the consumers that are on the side of fault away from the substation.

The consumers at the end of distributor would be subjected to serious voltage fluctuations when the load on distribution changes. The advantages of radial system are its simplicity, and low cost, which result from a straight forward circuit arrangement where a single or radial path is provided between the consumer and source or bulk power supply. With such an arrangement, the amount of switching equipment required is small and protective relaying is simple. The major disadvantage of radial system is its lack of security of supply. When a fault occurs on any section of feeder, a number of consumers will be without supply for a considerable period of time. The radial system is normally used for rural distribution these days. Due to these limitations, this system is used for short distances only.

ii) **Ring main system**: In this system, the primaries of distribution transformer form a loop. The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation. Figure shows the single line diagram of ring main system for a.c. distribution where substation supplies to the closed feeder LMNOPQRS. The distributors are tapped from different points M, O and Q of the feeder through distribution transformers. The ring main system has the following advantages:
   a) There are very less voltage fluctuations at consumer’s terminals.
   b) The system is very reliable as each distributor is fed with two feeders. In case, of fault in any section of feeder, the continuity of supply is maintained. For instance, if the fault occurs at point F of section SLM of the feeder. Then section SLM of the feeder can be isolated for repairs and

at the time continuity of supply to the consumers is maintained through the feeder SRQPONM.

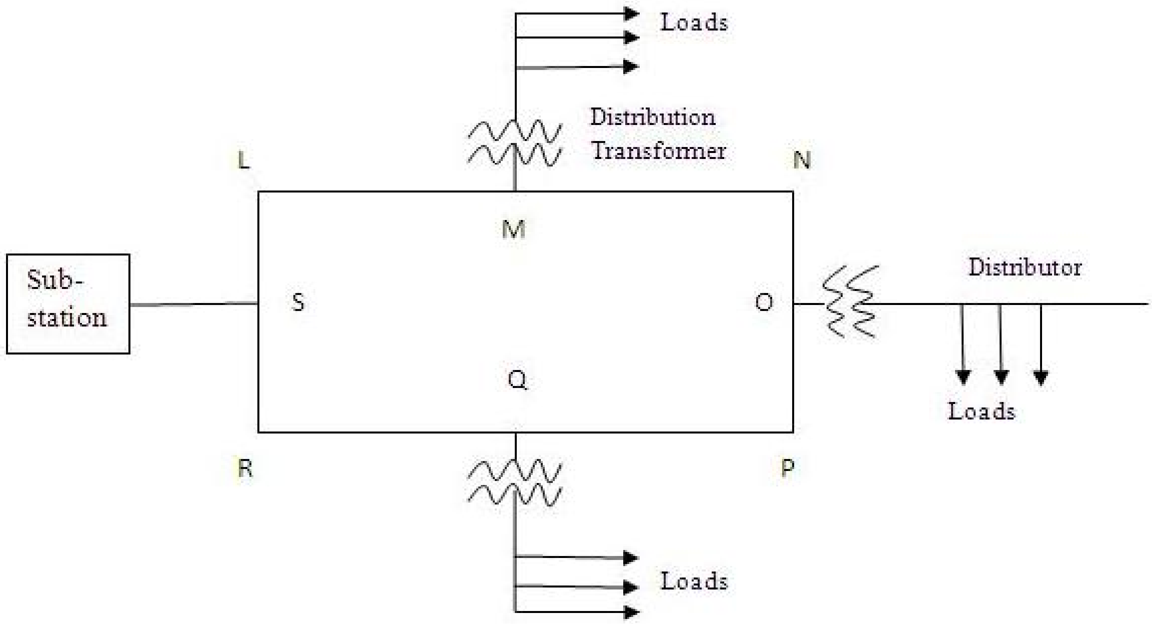

Figure 1.7 Ring Main System

iii) **Interconnected system**: Sometimes a feeder is energized by two or more generating stations or substations. Such a system of distribution is called an interconnected system. The system is most frequently to supply bulk loads such as industrial loads and medium or large commercial buildings where continuity of supply is of considerable importance. It is shown that when an interconnector is used in ring mains system, it reduces the voltage drop between the points to which it is connected. The ring mains system is used for urban distribution in contrast to radial systems. Fig shows a single line diagram of interconnected system. Here the closed feeder ring ABCD is supplied by two substations, S_1 and S_2 at points A and D resp. Distributors are connected to points O, P and Q of the feeder ring through a distribution transformer.

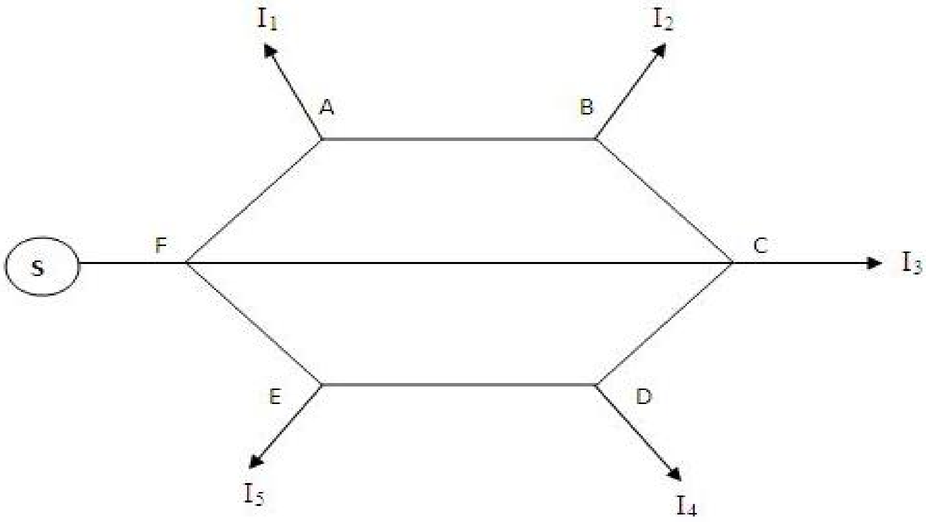

Figure 1.8 Feeder ring with one energy source

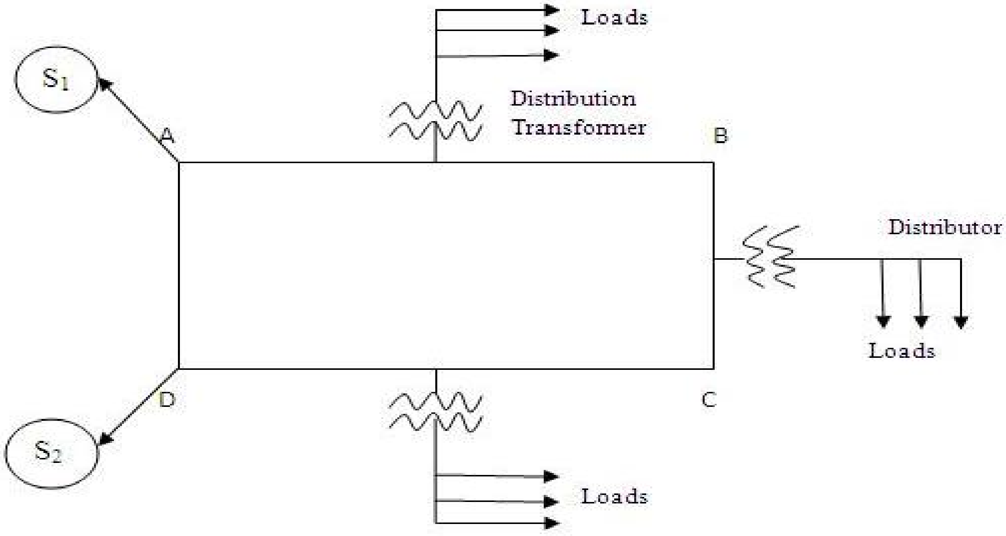

Figure1.9 Feeder ring with two energy sources

The ring main system has the following advantages:

a) It increases the service reliability.

b) Any area fed from one generating station during peak load hours can be fed from other generating station. This helps in decreasing reserve power capacity and increases the efficiency of the distribution system.

1.8 Comparison of Overhead System and Underground System

The distribution system can be overhead or underground. Overhead lines are generally mounted on wooden, concrete or steel poles which are arranged to carry distribution transformers in addition to the conductors. The choice between overhead and underground system depends upon a number of widely differing factors.

i) Flexibility: The overhead system is much more flexible than the underground system. In the overhead system new conductors can be laid along the existing ones for load expansion. In case of underground system new conductors are to be laid in new channels.

ii) Voltage Drop: In underground system because of less spacing between the conductors inductance is very low as compared to overhead lines, therefore, voltage drop is low in underground system.

iii) Initial Cost: Underground system is more expensive. For a particular amount of power to be transmitted at a given voltage the underground system costs almost double the cost of overhead system.

iv) Working Voltage: The underground system cannot be operated above 66 kV because of insulation difficulties but overhead system can be designed for operation upto 400 kV or higher even.

v) Maintenance Cost: Maintenance cost of underground system is very low in comparison with that of overhead system.

vi) Frequency of Faults or Failures: As the cables are laid underground, so these are not easily accessible. The insulation is also better, so there are few chances of power failures or fault as compared to overhead system.

vii) Appearance: Underground system of distribution or transmission is good looking because no wiring is visible. Due to its good looking, inspite of its higher cost it is adopted in modern cities like Chandigarh etc.

viii) Charging Current: On account of less spacing between the conductors the cables have much capacitance, so draw high charging current.

ix) Public Safety: Underground system is more safer than overhead system.

x) Frequency of Accidents: The chances of accidents in underground system are very low as compared to overhead distribution system.

xi) Jointing: Jointing of underground cables is difficult so tapping for loads and service mains is not conveniently possible in underground system.

xii) Damage due to Lightning and Thunder Storm: Underground system is free from interruption of services on account of thunder storm, lightning and objects falling across the wires.

xiii) Surge Effect: In underground system surge effect is smoothened down as surge energy is absorbed by the sheath.

xiv) Interference to Communication Circuits: In underground system there is no interference to communication circuits.

xv) Current carrying capacity: An overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section.

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1.9 VOLTAGE DROP IN DC DISTRIBUTORS

It is necessary to ensure that the voltage at the consumer premises is within the permissible limits. Therefore, it is necessary to calculate the voltage drop in different parts of the power supply network. The calculations of voltage drops in distributors are pretty lengthy because loads are tapped at many points along the route of the distributor.

1.9.1 Distributor fed at one end

Figure 1.10 shows a dc distributor having concentrated loads and fed at one end, I_1, I_2, I_3 are the load currents tapped at different points. R is the resistance per unit length of the distributor.

Voltage drop $= (I_1 + I_2 + I_3)(l_1\, r) + (I_2 + I_3)(I_2\, r) + I_3(l_3 r)$

$$= I_1 l_1 r + I_2\,(l_1 + l_2)\,r + I_3\,(l_1 + l_2 + l_3)r \qquad (1.9a)$$

where,

r = resistance per unit length

i = current of line

Thus the total voltage drop at the far end of the distributor is the sum of moments of various currents tapped off about the feeding point where the moment of a current is defined as the product of current and the total resistance through which it flows upto the point where it is tapped off. It is seen that I_1r is the resistance of the distributor upto point where I_1 is tapped off, $(l_1 + l_2)$ r is the resistance upto the point where I_2 is tapped off and so on. The drop upto any intermediate point is equal to the sum of the moments upto that point plus the moments of all the currents beyond that point assumed to be acting at that point.

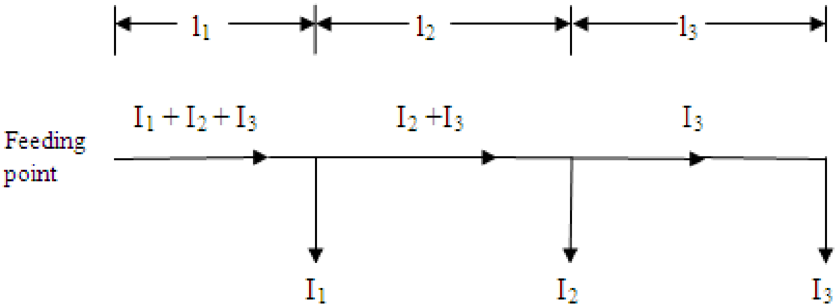

Figure 1.10 Distributor having concentrated loads

1.9.2 Uniformly Distributed Load

Figure 1.11 shows a uniformly loaded distributor fed at one end. The current tapped off per unit length is i. The total length of the distributor is l. The voltage drop upto a distance u from the feeding point is

Voltage drop upto distance u = (Sum of moments upto u) + (moments of loads beyond u assumed to be acting at distance u)

$$= \int_0^u r\,u\,i\,du + i(l-u)r\,u$$

$$= i\,l\,r\,u - \frac{1}{2}\,i\,r\,u^2 \qquad (1.9b)$$

Total voltage drop over the length l is obtained by substituting u = l in above equation

$$\text{Total voltage drop} = i\,r\,l^2 - \frac{1}{2}\,i\,r\,l^2 = \frac{1}{2}\,i\,r\,l^2 = \frac{1}{2}\,I\,r\,l \qquad (1.9c)$$

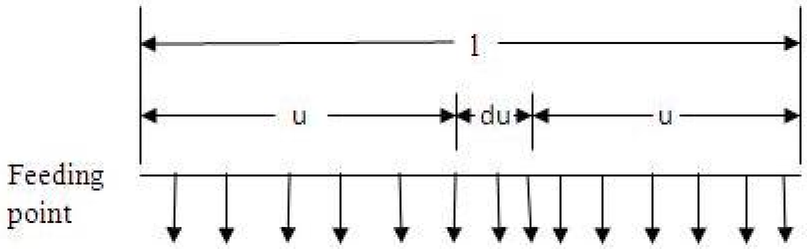

Figure1.11 Distributor uniformly fed at one end

where,

i = total current supplied by the distributor and equals il.

r = resistance per unit length of both wires of the distributor.

Equation (1.9b) indicates that a uniformly loaded distributor may be represented by the total load tapped of at the centre of the distributor.

1.9.3 Both Concentrated and Distributed Loads

It is possible that a distributor has concentrated loads at some points and a uniformly distributed load I A/m. Let the resistance per unit length be r and current fed at any point be I. The voltage drop in a length l from the point at which current I is fed is given by

$$\text{Voltage drop in length } l = \int_0^l r\,(I - iu)du = rl(I - \tfrac{1}{2}il) \qquad (1.9d)$$

1.9.4 Distributor fed at Both Ends

Such a distributor is used when the length of the distributor is long and the load currents are high. If such a distributor is fed at only one end, the voltage drop along the distributor may be rather high. The voltages at the feeding points may be equal or unequal.

Load current would be partly supplied from end A and partly from end B. The minimum potential will occur at one of the load points. The current tapped off at the point of minimum potential would come partly from end A and partly from end B. The total voltage drop along the distributor must be equal to voltage differences V_A and $V_{B.}$

If a uniformly loaded distributor is fed at both the ends the minimum potential may occur at any point. Both concentrated and uniformly distributed loads may occur simultaneously.

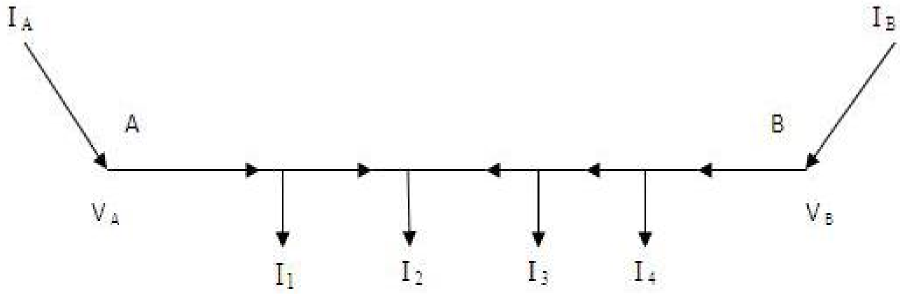

Figure 1.12 Distributor fed at both the ends

1.9.5 RING MAIN DISTRIBUTOR

If a distributor is designed to form a closed loop, it becomes a ring main. It may be fed at one or more points. A ring main or secondary network are more or less similar. Such a system has better reliability and flexibility. In case a fault develops in any section it can be isolated from both sides so that only that section suffers discontinuity of supply. The continuity of supply is maintained for the remaining sections. The voltage drop in such a distributor can be calculated by considering it as two radial distributors fed at both the ends.

Sometimes two or more ends of a ring main distributors are connected through connectors so as to form a complete network. The current distribution and voltage drop in such an arrangement can be found by direct application of kirchoff’s law. The addition of an interconnector to a ring main reduces the voltage drop in the distribution system.

1.10 VOLTAGE DROP IN AC DISTRIBUTORS

The calculation of voltage drop in ac distributors has to take into account the inductive reactance of the distributor. Therefore the calculations become more difficult than the calculations in the dc distributor. If the loads are at unity power factor, the effect of inductive reactance can be neglected and the calculations are exactly similar to those in dc distributors. Therefore voltage drop calculations for ac distributors feeding residential loads are generally done by neglecting the effect of inductive reactance.

In a balanced 3-phase, 4 wire circuit the current in the neutral wire is zero and only the voltage drop in the phase conductor need to be calculated. In actual practice the load are never balanced. However, the degree of balanced is quite small and the calculations can be neglecting the current in the neutral wire.

1.10.1 UNITY POWER FACTOR LOADS

Figure 1.13 shows a single phase distributor supplying three unity power factor loads. If I_1, I_2, I_3 are the lengths, r is the resistance and x is the inductive reactance per unit length of the distributor, Vs is the voltage at feeding point and V_r is the voltage at far end.

Then

$$V_s = V_r + (I_1 + I_2 + I_3)\, l_1\, (r + jx) + (\, I_2 + I_3)\, l_2\, (r + jx) + I_3\, l_3\, (r + jx)$$

$$= V_r + I_1\, l_1\, (r + jx) + I_2\, (l_1 + l_2)(r + jx) + I_3\, (l_1 + l_2 + l_3\,)(r + jx)$$

$$= V_r + I_1\, l_1\, r + I_2\, (l_1 + l_2)\, r + I_3\, (l_1 + l_2 + l_3\,)\, r + j([I_1\, l_1\, x + I_2(l_1 + l_2)\, x + I_3\, (l_1 + l_2 + l_3)\, x \qquad (1.10a)$$

where,

r = resistance per unit length

x = reactance per unit length

I = current of line

L = length of line

For short distance lines reactance is very very small and may be neglected

Therefore, equation (1.10a) can be written as,

$$V_s \cong V_r + I_1\, l_1\, r + I_2(l_1 + l_2)r + I_3(l_1 + l_2 + l_3)r \qquad (1.10b)$$

Voltage drop = Sending–End Voltage (V_s) – Receiving –End Voltage (V_r) (1.10c)

Substituting V_s from equation (1.10c)

Voltage Drop = $I_1 l_1 r + I_2 (l_1 + l_2) r + I_3 (l_1 + l_2 + l_3) r$

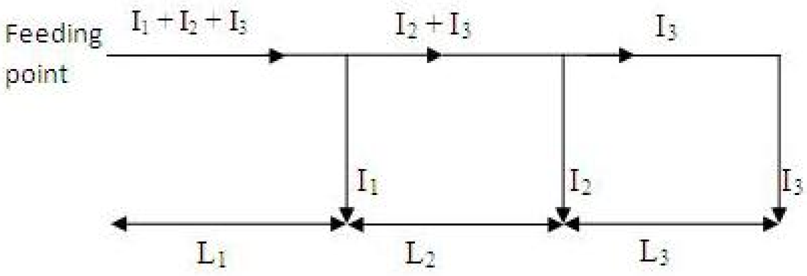

Figure 1.13 Single phase distributor supplying loads at unity power factor

Thus, the total voltage drop at the far end of the distributor is the sum of the moments of the various currents tapped off about the feeding point where the moment of a current is defined as the product of the current and the total resistance through which it flow upto the point where it is tapped off. The drop at any intermediate point is equal to the sum of moments upto the point plus moment of all the currents beyond the point assumed to be acting at that point. The quantity L_1r is the resistance of the distributor upto point where I_1 is tapped off, ($L_1 + L_2$) r is the resistance upto the point where I_2 is tapped off and so on.

1.10.2 LOADS AT DIFFERENT POWER FACTOR

The industrial loads have lagging power factor and in the calculations of voltage drop in the distributors feeding such loads, the inductive reactance must be taken in account. Figure 1.14 shows three load currents having I_1, I_2 and I_3 having power factor $cos\phi_1$, $cos\phi_2$ and $cos\phi_3$ tapped of a distributor. As in the previous case L_1, L_2 and L_3 are the lengths of the three sections and r and x are the resistance and inductive reactance per unit length. The voltage drop upto the far end is given by:

$$\text{Voltage drop} = I_1 \left(cos\phi_1 - jsin\phi_1\right) l_1(r + jx) + I_2\left(cos\phi_2 - jsin\phi_2\right)(l_1 + l_2)(r + jx) + I_3(cos\phi_3 - jsin\phi_3)(l_1 + l_2 + l_3)(r + jx)$$

$$\cong I_1 l_1\left(r\, cos\phi_1 + xsin\phi_1\right) + I_2(l_1 + l_2)\left(r\, cos\phi_2 + xsin\phi_2\right) I_3(l_1 + l_2 + l_3)(r\, cos\phi_3 + xsin\phi_3) \quad (1.10d)$$

where,

r = resistance per unit length

x = reactance per unit length

I = current of line, L=length of line

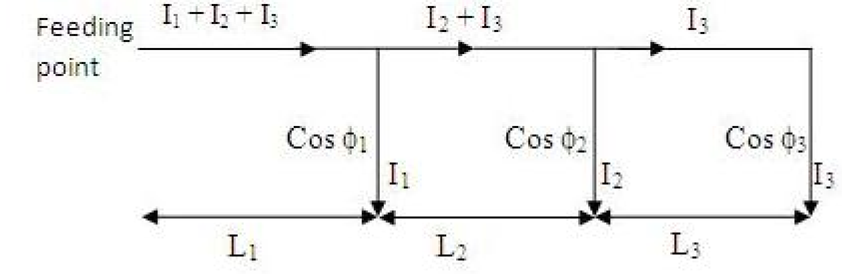

Figure 1.14 Single phase distributor supplying loads at different power factors

Comparing equation (1.10c) and equation (1.10d) shows that the effect of power factor is to replace the term r by (rcosϕ + xsinϕ). Thus the voltage drop in the ac distributor is also calculated as sum of moments of the various currents about the feeding point but, in this case, the moment is defined as the product of current and the term (Rcosϕ + Xsinϕ) where R and X are total resistance and reactance through which the current flows.

1.10.3 UNIFORMLY DISTRIBUTED LOAD

Let a current I at power factor cosϕ be tapped per unit length of distributor of total length L.

Voltage drop upto distance u = (sum of moments upto u) + (moments of load be assumed acting at distance u)

$$=\int_0^u (r\, cos\phi\, i\, u\, du + x\, sin\phi\, i\, u\, du) + i(l – u)\, r\, cos\phi u + i(l-u) x sin\phi u$$

$$= i\, l\, u\, r\, cos\phi - \frac{1}{2}\, i\, r\, u^2\, cos\phi + i\, l\, u\, x\, sin\phi \frac{1}{2}\, i\, x\, u^2 sin\phi \quad (1.10e)$$

Total voltage drop up to far end $= \frac{1}{2}\, i\, l^2\, r\, cos\phi + \frac{1}{2}\, i\, l^2\, x\, sin\phi$ (1.10f)

1.10.4 BOTH CONCENTRATED AND DISTRIBUTED LOADS

It is possible that an ac distributor has both concentrated and distributed loads. When these loads are at different power factors, the general expression for voltage drop becomes rather long. One method is to consider the concentrated and distributed loads separately using equations (1.10d) and (1.10f). The total voltage drop is obtained by algebraic addition of these voltage drops.

If the concentrated and distributed loads are at the same power factor cosϕ, the expression for voltage drop can be obtained by an extension of equation (1.10g). Let I be the current fed at any point i be the distributed load per metre, both these loads are at power factor cosϕ. The voltage drop in a length l from the point at which current I is fed is given by

$$\text{Voltage drop in length } l = \int_0^l \left[r(I - iu)cos\phi\, du + x(I - iu)sin\phi\ du\right]$$

$$= r\ cos\phi\, l\left(I - \frac{1}{2}\, il\right) + \ x\ sin\phi\, l\left(I - \frac{1}{2}\, i\, l\right)$$

$$= l\left(I - \frac{1}{2}\, i\, l\right)(r\ cos\phi\ + x\ sin\phi) \qquad (1.10g)$$

1.10.5 UNIFORMLY DISTRIBUTED LOADS FED AT BOTH ENDS

If an ac distributor of length l having a uniform load i, A/m at power factor cosϕ is fed at both the ends at the same voltage, minimum voltage occur at mid point.

Voltage drop upto mid point = $\frac{1}{8}\ (r\ i\ l^2\ cos\phi\ + x\ i\ l\ sin\phi)$

1.10.6 UNBALANCED LOADING

AC distributor supplies a mixture of 3–phase and single phase loads. If the degree of unbalance is large, the voltage drop in the neutral wire has also be taken into account. The voltage drop calculations are done for each of the 4 wire separately and then the voltage between each phase conductor and neutral conductor at the far end of the distributor can be calculated.

1.11 LITERATURE SURVEY

Ponnavaikko and Rao [1] presented models to represent substation feed area, feeder voltage drop, feeder load distribution, cost of losses in the feeders and transformers were formulated in terms of the variable system parameters. Based on these models, objective functions were defined which are employed in arriving at optimal substation size, feeder loading limits and conductor sizes. The technique suggested greatly reduced the computational time and effort compared to the other methods. The proposed method was highly promising, since it was very fast, simple and easy to program.

Ponnavaikko and Rao [2] presented a method of optimally choosing fixed and switched shunt capacitors on radial distribution feeders, considering load growth, growth in load factor and increase in cost of energy. Mathematical models were represented predicting cost saving due to energy loss reduction taking the growth factors into account, cost saving due to release in system capacities, capacitor cost and voltage rise during off-peak hours, as a function of capacitive current flows in the feeder sections have been formulated. Cost functions have been defined for optimizing the choice of both fixed and switched capacitors. A direct search technique known as the Method of Local Viariations has been employed for solving the resulting discrete variational problem. The problem has also been solved using Dynamic Programming Approach for comparison.

Nagendra Rao [3-4] presented a novel method for determining optimal conductor cross sections for radial distribution feeders. The aim of conductor grading was to design a feeder so as to minimise the sum of the capital investment and capitalised energy loss costs for the feeder. In finding such a design several factors such as non-uniform feeder loading, load growth, allowable voltage drop in the feeder, etc, have to be considered. The conductor grading problem being inherently a multistage decision problem, can be considered as a dynamic programming problem and has been solved as such, in the past. A direct solution procedure for conductor grading was proposed, thereby eliminating the complexity of the dynamic programming approach. The proposed solution technique was extremely simple, involves very little computation and needs very little computer storage.

Baran *et al*. [5] presented optimal sizing of capacitors placed on a radial distribution system. The problem was to determine the optimal size of capacitors placed on the nodes of a radial distribution system so that the real power losses will be minimized for a given load profile. This problem was formulated as a nonlinear programming problem. The ac power flow model of the system, constraints on the node voltage magnitudes, and the cost of capacitors are explicitly incorporated in the formulation. New formulation of the power flow equations in a radial distribution network and a numerically robust, computationally efficient solution scheme. This solution scheme was used as a subroutine in the optimization algorithm. Test results for both the capacitor sizing problem and the power flow solution schemes were presented.

Baran *et al*. [6] presented another technique for network reconfiguration in distribution systems for loss reduction and load balancing.

Sauer *et al*. [7–8] proposed power system steady-state stability and the load-flow jacobian. A relationship was presented between a detailed power system dynamic model and a standard load flow model. The linearized dynamic model was examined to show how the load-flow Jacobian appears in the system dynamic state Jacobian for evaluating steady-state Stability. Two special cases were given for the situation when singularity of the load-flow Jacobian implies singularity of the system dynamic state Jacobian. Standard load-flow is used t o find system voltages for a specified level of loading or interchange (regardless of the dynamic load model). It is also the starting point for determining the initial conditions for dynamic analysis. The standard load-flow Jacobian can provide information about the existence of a steady state equilibrium point for a specified level of loading or interchange. There are two very special cases when the determinant of the standard load-flow Jacobian implies something about the steady-state stability of a dynamic model. Both of these cases involve very drastic assumptions about the synchronous machines and their control systems. The load level which produces a singular load-flow Jacobian should be considered an optimistic upper bound on maximum loadability.

Chen *et al*. [9] proposed an efficient power flow solution was introduced . This solution is a current-injection based Newton–Raphson method in rectangular coordinates.

The Jacobian matrix of the proposed method could be decoupled into two identical sub-Jacobian matrices. The *G*-matrix is used to execute load flow. The “Fast-Decoupled” idea is incorporated into the distribution network analysis for the first time. Using the rectangular-coordinate system, the matrix symmetry is retained and the memory requirement of the traditional fast-decoupled load flow is reduced to half. This method was significantly faster than any other method developed so far. Tests have shown that this method has great potential for on-line operations.

Semlyen *et al.* [10] proposed a technique for the Calculation of the extreme loading condition of a power system for the assessment of voltage stability. The Extreme Loading Condition (XLC) of a power system was defined by assuming a load increase (according to a predefined pattern for both active and reactive powers) until a maximum was reached for anyone of the loads. The first bus where the load has reached its maximal value may be viewed as the weakest from the point of view of voltage stability. That bus is of particular interest for possible remedial action. The XLC was significant for the assessment of voltage stability. Its calculation, based on increasing the load admittances while first keeping the generator voltage phasors constant and then adjusting these phasors for satisfying operational requirements with respect to the generation powers. The secant method was used for the efficient and reliable determination of the maximal value of the loading parameter μ**,** while for the voltage adjustment a fast convergent Newton module was employed. The XLC can be calculated for both normal operation and for contingencies. The new approach was fast and simple and can be used only on larger systems. The method is based on the calculation of the load voltages with a set of fixed generator voltage phasors Vg**.** This assures that the generation will automatically follow the load and only a redistribution of generator powers is necessary for achieving a measure of optimality during the simulation of the loading process. The redistribution of generations is obtained by the adjustment of the generator voltages.

Zeng *et al*. [11] developed a simplified approach to estimate maximum loading conditions in the load flow problem. This technique describes a computationally efficient and simple approach to estimate maximum loading conditions in the load flow problem. These operating points were known to result in a number of undesirable phenomena such as the singularity of the Jacobian, solution bifurcations, and voltage collapse. The approach presented here generated precise estimates of the maximum possible amount of load increase that the system can tolerate along a specified path, as well as the corresponding voltage vector. The method described was simple and efficient since it was based primarily on conventional load flow solutions. Tests on several standard power networks confirmed the accuracy and efficiency of the technique.

Das *et al.* [12−13] presented a method in order to solve radial distribution. The radial feature of the network has been fully exploited to develop an algorithm by a unique lateral, node and branch numbering scheme. The proposed method involves only the evaluation of simple algebraic voltage expressions without any trigonometric functions. Thus, computationally, the proposed method was very efficient and requires less computer memory storage as all data is stored in vector form. The proposed method can easily handle different types of load characteristics. Several Indian rural distribution networks have been successfully solved using the proposed method. A novel load flow technique, named ‘forward sweeping method’, has been proposed for solving radial distribution networks. It completely exploits the radial feature of the distribution network. A unique lateral, node and branch numbering scheme has been suggested which helps to obtain the load flow solution of the radial distribution network. The forward sweeping method always guarantees convergence of any type of practical radial distribution network with a realisic R/X ratio. Computationally, the proposed method was extremely efficient, as compared to the coupled NR and FDLF methods, as it solves simple algebraic recursive expressions of voltage magnitude only. Another advantage of the proposed method was that all data can be stored in vector form, thus saving an enormous amount of computer memory. The method can easily handle the composite loads if the break up of the loads were known.

Rahman *et al.* [14] presented a method for voltage collapse. Voltage collapse may occur in a power system due to lost in voltage stability in the system. Therefore voltage stability analysis is important in order to identify critical buses in a power system i.e buses which are closed to their voltage stability limits and thus enable certain measures to be taken by the control engineer in order to avoid any incidence of voltage collapse.

Author presents a new technique to determine the static voltage stability of load buses in a power system for a certain operating condition and hence identifies load buses which are close to voltage collapse. A voltage stability index with respect to a load bus is formulated from the voltage equation derived from a two bus network and it is computed using Thevenin equivalent circuit of the power system referred to a load bus. This index indicates how far the load buses from their voltage stability limits and hence identifies the critical buses. The performance of this index is tested using 9 bus radial network and the 24 bus IEEE Reliability Test System for its validity. A comparison is also made between this index. Author presented a new loadflow technique to compute power flow solution for radial network which found to be more superior than the Second Order Newton Raphson since it takes less iterations to give a loadflow solution.

Zeng *et al.* [15] developed a method for the voltage stability analysis considering dynamic load model. The modeling of loads has a significant effect on the accuracy of voltage stability analysis. This technique investigates the dynamic nature of voltage instability considering dynamic load model. It developed the system small-signal voltage stability models adopting exponential recovery load models and adaptive load models. Moreover it investigated the influence of the parameters related to the load models and of the consequent change of the operating points on the voltage stability. The differences and similarities of the two specific models were also pointed out. Author describes the models of loads (exponential recovery load model and adaptive load model) that can be adopted for small-signal voltage stability analysis of power systems. He studies the influence of the various model parameters on the voltage stability limits and presents the comparison between these two specific models, by means of the study of the critical eigenvalue-of the state matrix.

Gubina *et al.* [16] proposed a simple approach to voltage stability assessment in radial networks. Analytical approach to voltage collapse proximity determination was proposed for radial networks. Under corresponding assumptions, a radial network with arbitrary bus loads was transformed into a two bus equivalent. The voltage phasors at the generator bus and at the last load bus of the radial network are transformed to form the voltage phasors of the two bus equivalent. The latter were further used for assessment of voltage collapse proximity. Exact stability limit relations for a two bus system derived from Jacobian matrix can be exploited. Moreover, an analytical expression was derived for calculation of active and reactive power reserve margins for radial network equivalent. The proposed procedure [15] was tested for practical examples of radial networks with inductive and capacitive loads.

Zhang *et al*. [17] proposed a modified Newton method for radial distribution systems. In this method Jacobian matrix is in UDUT form, where U is a constant upper triangular matrix depending solely on system topology and D is a block diagonal matrix. With this formulation, the conventional steps of forming the Jacobian matrix, LU factorization and forward/back substitution are replaced by back/forward sweeps on radial feeders with equivalent impedances. Tests on several large distribution systems ranged from 490 to 1651 in nodes, 0.15 to 5.48 in r/x ratio and 0.0004 SL to 3.07 SZ in line impedance have shown that the proposed method is as robust and efficient **as** the back/forward sweep method. The proposed method can be applied to other applications, such as state estimation. The proposed method can also be extended to the solution of systems with loops, dispersed generators and three phase (unbalanced) representation.

Ghosh *et al*. [18] proposed a method for the load flow solution of radial distribution networks. In this proposed scheme a simple and efficient load – flow technique for solving radial distribution networks is presented. The proposed method involves only the evaluation of a receiving – end voltages. Computationally the proposed method is very efficient and reliable. In this method author have tried to solve the problems with the Newton – Raphson (NR) and Gauss – Siedel (GS) methods. This method has fast and good convergence characteristics compared with other existing methods. Several radial distribution networks have been solved successfully using the proposed method.

D.Das [19] presented a method for obtaining the maximum allowable loading of radial of distribution feeders for different types of loads without violating the maximum current carrying capacity of branch conductors. Minimum voltage of the feeders can also be maintained by allowing the feeders to take load growth up to a specific period of time. A simple mathematical formula for calculating power loss in *k*th year was proposed.

Another mathematical expression for the present worth of the cost of feeder energy loss over the entire life time was also proposed for different types of load modeling considering the effect of load growth, load factor and cost of energy. Results were also presented for a radial distribution feeders.

Wang *et al.* [20] developed a practical approach to the conductor size selection in planning radial distribution systems. A new approach was presented to the optimization problem of conductor size selection in planning radial distribution systems. In this study, a multisection, branching feeder model with nonuniform load distribution has been chosen to best approximate actual conditions found in most distribution systems. Since the optimization problem was formulated as an integer programming problem, it was difficult to solve such a large-scale problem accurately. Therefore, in order to find an approximately optimal solution quickly, the authors have developed a simple, practical approach, which relies on the combined usage of an economical current density based method and a heuristic index directed method. This approach needs no sophisticated optimization technique and, thus, was easy to implement. Because of the practicality of its features, the proposed approach can be a useful tool for distribution engineers.

Miu *et al.* [21] presented a technique to undertake the problem of determining the load percentage capability of distribution networks, or, equivalently, the amount of percentage of load a feeder, specific area or circuit of a large-scale unbalanced percentage distribution network can withstand before violating an operational percentage constraint. A new formulation is given. A solution algorithm suitable percentage for large-scale unbalanced distribution networks with capacitor control percentage actions is developed and test results on a NYSEG 394-bus distribution percentage network are included.

Gan *et al.* [22] gave a Stability-Constrained Optimal Power Flow. Stability was an important constraint in power system operation. Often trial and error heuristics were used that can be costly and imprecise. A new methodology that eliminates the need for repeated simulation to determine a transiently secure operating point was presented. The theoretical development was straight forward: dynamic equations were converted to numerically equivalent algebraic equations and then integrated into the standard OPF formulation. The objective of monitoring and ultimately controlling the stability of a power system is desirable. While the technology for stability simulation is rather stable now, little theoretical work has been done for computing stability limits precisely. There is, however, an increasing need of solutions for this challenging problem. Author, have developed a basis for one approach to this problem. The method naturally inherits the advantages SBSI has such as, it has little limitations on component modeling, it is robust, and it provides all system swing information. He demonstrated that, using this general methodology, for the first time the stability limits of power systems can be precisely and automatically estimated. Author is hoping that the methodology can be further developed into a practical tool. This will require that it be efficiently implemented.

Chakravorty *et al.* [23] presented a method for the voltage stability analysis of radial distribution networks. A new voltage stability index is proposed for identifying the node, which is most sensitive to voltage collapse. Composite load modelling is considered for the purpose of voltage stability analysis. It is also shown that the load flow solution of radial distribution networks is unique.

Hong *et al.* [24] proposed a method for the energy loss (kWh) estimation of distribution systems is an important task for the system operation and planning. Because the losses are obtained through estimation, providing a fuzzy range of losses to engineers is essential. A new method based on fuzzy-c-number (FCN) and cluster-wise fuzzy regression (CWFR) analysis is proposed for developing loss formulas to estimate losses. A realistic distribution system is used for illustrating the applicability of the proposed method. Distribution networks are unique.

Aumulle *et al.* [25] provided an overview of a dynamic analysis carried out on a modified Nordic test system to determine the impact of the Powerformer on voltage stability. The unique aspects of the Powerformer were highlighted and the modelling of long-term dynamic elements, especially those pertinent to the study of the Powerformer was discussed. The unique aspects of the Powerformer, from a system voltage stability perspective, have been highlighted. Most important, the stator overload capability of the Powerformer was examined. The impact of the type of overexcitation limiters chosen on the time to collapse following a contingency has been illustrated. The importance of choosing the right value of gain for the overexcitation limiter model has also been highlighted. The value of the gain must be sufficiently large enough to ensure that the current is kept below rated values but not so large as to decrease the time to collapse. The impact of location of the Powerformer and its additional overload capability and the impact of the compensation scheme chosen for the Powerformer was also been discussed.

Eminoglu *et al*. [26] gave a simple and efficient method to solve the power flow problem in radial distribution systems. The proposed method takes into account voltage dependency of static loads, and line charging capacitance. The method was based on the forward and backward voltage updating by using polynomial voltage equation for each branch and backward ladder equation (Kirchoff's Laws). Convergence ability and reliability of the method was compared with the Ratio-Flow method, which was based on classical forward–backward ladder method, for different loading conditions, R/X ratios and different source voltage levels, under the wide range of exponents of loads. Results demonstrate that the proposed power flow algorithm has a robust convergence ability when compared with the improved version of the classical forward-backward ladder method, i.e., Ratio-Flow. A new power flow technique, which is simple, efficient and has fast convergence ability, has been proposed for the power flow analysis in ill-conditioned radial distribution networks. The method is based on the forward and backward voltage updating by using polynomial equation for each branch and backward ladder formula. The advantages of the proposed method are that, it has fast convergence ability and gives an ability to use of the line shunt capacitance and exponents of static loads in solution of power flow problems.

Lee *et al*. [27] proposed a maximum loading margin method for static voltage stability in power systems. The maximum loading margin (MLM) approach was proposed in finding generation directions to maximize the static voltage stability margin, where the MLM was evaluated at various possible generation directions in the generation direction space. An approximate and simple model represented the relationship between the generation direction and the LM was used to obtain the MLM point. The proposed method was validated in the modified IEEE 14-bus test system and applied to the Thailand power system. LMs of the system with the generation directions were compared for different generator combinations using the proposed technique.

Satyanarayana *et al*. [28] gave a method for network reconfiguration is performed by altering the topological structure of distribution feeders. By reconfiguring the network, maximum loadability index (MLI) can be enhanced for the particular set of loads in distribution systems. A simple algorithm is proposed for enhancement of maximum loadability by reducing losses through network reconfiguration. Reconfiguration involves selection of the best set of branches to be opened, one from each loop, such that the resulting radial distribution system is maximizing the MVA load at minimum MLI. The effectiveness of the proposed method is illustrated on two radial distribution systems.

1.12 OBJECTIVES OF THESIS WORK

The objective of thesis work is to compute the maximum loading on radial distribution network. The difference of each branch current has been taken into account. The branch conductors of the network considered are taken as uniform i.e., the conductor of maximum current carrying capacity i.e., at the conductor of the first branch.

1.13 SCOPE OF THESIS WORK

Eminoglu *et al*. [26] while deriving the expression for power flow in radial networks voltage dependency of static loads and line charging capacitance which leads to wrong results.

Satyanarayana *et al*. [28] while deriving the expression for loading has introduced the concept of network reconfiguration to enhance maximum loadability. But this method requires a number of iterations for convergence.

A new expression for maximum loading is derived for electric power distribution networks to be computed for all nodes. With the help of derived expression for loading the most sensitive nodes of the networks are identified. The critical values of TPL and TQL are also computed. The critical values of TPL and TQL of the network selected by utility have also been computed.

1.14 ORGANISATION OF THE THESIS WORK

Chapter 1 has presented the introduction of distribution system, voltage drop in AC distributors, voltage drop in DC distributors, literature survey, objectives of research work, scope of work in calculating the loading of radial distribution networks and the organization of the thesis work

Chapter 2 presents a new expression for the maximum loading of the conductor of the distribution networks. 56 node radial distribution network [18] is selected for applying in the proposed system. The results of load – flow will give branch current using these branch currents conductor as per their maximum current carrying capability is being selected for their respective branch. In this thesis work conductor is not loaded fully, the reason for not taking 100% loading of conductor is that during fault condition if conductor is 100% loaded than it will burnout. The TPL and TQL is being calculated and it is found that TPL and TQL is increased in the final case using the proposed method.

Chapter 3 presents the overall conclusions and the future scope of the research work.

References gives the list of previous papers published by researchers in the loading and voltage stability of power distribution system.

Appendix – A shows the line and load data of 56 Node Radial Distribution Network.

Appendix – B shows the data of conductor

Appendix – C shows the biography of candidate

CHAPTER – 2

MAXIMUM LOADING OF RADIAL DISTRIBUTION NETWORK

2.1 INTRODUCTION

Radial distribution networks have some advantages over the meshed distribution networks such as lower short circuit current and simpler switching and protecting equipment. On the other hand, the radial structure provide lower overall reliability. Therefore, to use the benefits of the radial structure and at the same time to overcome the difficulties, distribution systems are planned and built as weakly meshed networks, but operated as radial networks. Distribution systems consist of group of interconnection radial circuits. If a conductor is loaded up to or near its thermal rating, the losses will be increased. Therefore, line conductors are loaded below their thermal limit. The power loss is significantly high in distribution systems because of lower voltages and higher currents, when compared to that in high voltage transmission systems. Reduction of total loss in distribution systems is very essential to improve the overall efficiency of power delivery.

The pressure of improving the overall efficiency of power delivery has forced the power utilities to reduce the loss, especially at distribution level.

In this thesis work a method is proposed for improving the maximum allowable loading of radial distribution feeders for different types of loads without violating the maximum current carrying capacity of branch conductors by optimum conductor selection. The conductor, which is determined by the proposed method, will maximize the total savings in cost of conducting material and energy losses by maintaining acceptable voltage levels in radial distribution systems. Minimum voltage of the feeder can also be maintained by allowing the feeders to take load growth up to a specific period of time. The effectiveness of the proposed method is illustrated with a practical 56 node radial distribution system.

2.2 ASSUMPTIONS

A balanced three phase radial distribution feeder is assumed and can be represented by its equivalent single – line diagram. Line charging capacitance is negligible at the distribution voltage levels. The load modeling has been considered as constant power.

2.3 SOLUTION METHODOLOGY

Figure 2.1 shows a sample radial distribution network. Table 2.1 shows branch number, sending-end node, receiving-end node of figure 2.1

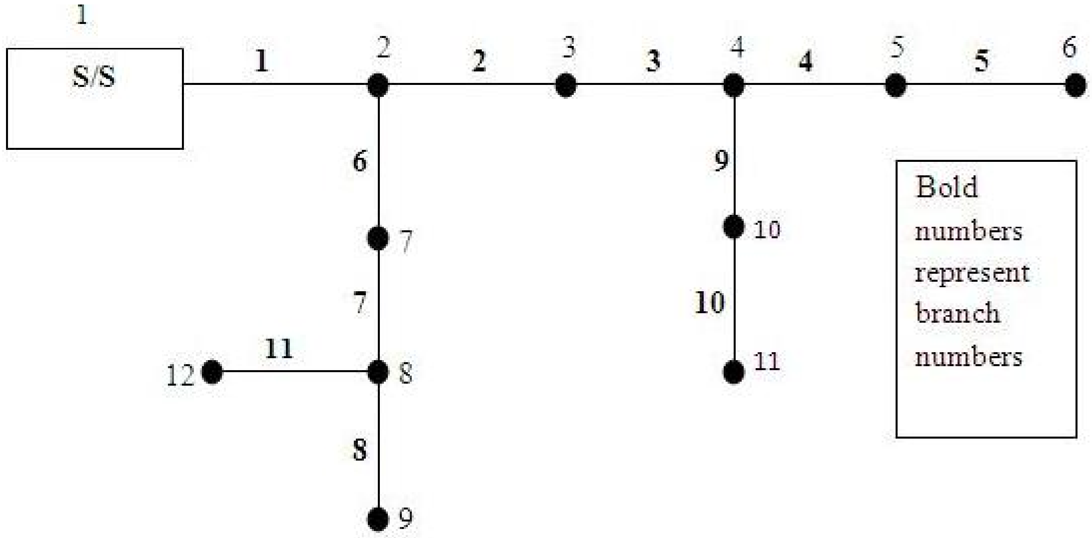

Figure 2.1 Single Line Diagram of Radial Distribution Network

Table 2.1 Branch number (jj), Sending end node (m1 = IS(jj)), Receiving end node (m2 = IR(jj)) of figure 2.1

Branch Number (jj)	**Sending End Node m1 = IS (jj)**	**Receiving End Node m2 = IR (jj)**
1	1	2
2	2	3
3	3	4

4	4	5
5	5	6
6	2	7
7	7	8
8	8	9
9	4	10
10	10	11
11	8	12

The voltage at the receiving – end node is expressed by

$$V(m2) = V(m1) - I(jj)Z(jj) \tag{2.1}$$

$$\text{i.e. } V(m2) = V(m1) - I(jj)[R(jj) + X(jj)] \tag{2.2}$$

$$\text{where } m1 = IS(jj) \tag{2.3}$$

$$\text{and } m2 = IR(jj) \tag{2.4}$$

The load current of the receiving – end node m2 = IR(jj) of branch – jj is expressed by

$$IL(m2) = \frac{PL(m2) - jQL(m2)}{V^*(m2)} \tag{2.5}$$

The real and reactive power losses of branch – jj are expressed by

$$LP(jj) = |I(jj)|^2 R(jj) \tag{2.6}$$

$$LQ(jj) = |I(jj)|^2 X(jj) \tag{2.7}$$

The current through branch – jj is the sum of all load currents of all nodes beyond branch – jj is given by

$$I(jj) = \sum_{i=1}^{N(jj)} IL\{IE(jj,i)\} \tag{2.8}$$

where N(jj) is the total number of nodes beyond branch jj and IE(jj, i) is the receiving-end node beyond branch–jj.

Table 2.2 Nodes beyond each branch of Figure 2.1

Branch Number (jj)	**Nodes beyond branch (jj)**	**Total number of nodes N (jj) beyond branch (jj)**
1	2,3,7,8,510,9,12,6,11	11
2	3,4,5,10,6,11	6
3	4,5,10,6,11	5
4	5,6	2
5	6	1
6	7,8,9,12	4
7	8,9,12	3
8	9	1
9	10,11	2
10	11	1
11	12	1

The loading (real and reactive) of each node is increased in each step of 0.1. The load – flow is run in each step. Before proposing the algorithm, to compute maximum loading, the method to identify nodes beyond each branch is discussed below.

2.3.1 Identification of nodes beyond all the branches

The following variables are defined first, in order to identify the nodes beyond all the branches.

id is the node count (identifies the number of nodes beyond a particular branch)

IK(id) is the node identifier (helping to identify nodes beyond all the branches),

N(jj) is the total number of nodes beyond branch jj, IE(jj, id + 1) is the receiving-end node and

IE(jj, id + 1) is explained below.

Let us consider the first branch in Figure 2.1 (Table 2.1), i.e. jj = 1; the receiving-end node of branch−1 is 2, i.e. IR(jj) = IR(1) = 2. Therefore, IE(jj, id + 1) = IE(1, id + 1) will help to identify all the nodes beyond branch−1. This will help to compute the exact current flowing through branch−1. Similarly , for branch−2, i.e. jj = 2; the receiving-end node of branch−2 is 3, i.e. IR(jj) = IR(2) = 3. Therefore, IE(jj, id + 1) = IE(2, id + 1) will identify all the nodes beyond branch−2 that will help to compute the exact current flowing through branch−2. Before identification of nodes beyond a particular branch, 'id' has to be reset to zero. For identification of nodes beyond a particular branch, 'id' will be incremented by 1. For jj = 1 (first branch of Figure 2.1), IR(jj) = IR(1)= 2; we check whether IR(1) = IS(i) or not for i = 2, 3, 4, ..., LN1. It is seen that IR(1) = IS(2) = 2, the corresponding receiving-end nodes are IR(2) = 3. Therefore, IE(1, 1) = 2, IE(1,2) = 3. There should not be any repetition of nodes while identifying nodes beyond a particular branch. From the above discussion, it is seen that node 2 is connected to node 3 and 7. The logic will check whether node 3 appears in the left-hand column of Table 2.2. It is seen that node 3 is connected to nodes 4 and 7. Therefore, IE(1,3) = 4 and IE(1,4) = 7. Next the algorithm will check whether nodes 4 and 7 appear in the left–hand column of Table 2.1. It is seen that the node 3 is connected to node 4 and node 7 is connected to node 8. Therefore, IE(1, 5) = 8. The proposed logic will thereafter again check whether nodes 4 and 8 are connected to any other nodes. This process will continue unless all nodes are identified beyond branch−1. The nodes beyond branch−1 are as shown in Table 2.2. The total current flowing through branch−1 is equal to the sum of the load currents of all nodes beyond branch−1. For jj = 2 (second branch of Figure 2.1; Table 2.1), IR(jj) = IR(2) = 3, we check whether IR(2) = IS(i) or not for i = 3, 4,..., LN1. It is seen that IR (2) = IS (3) = 3 and IR(2) = IS(6) = 3. The corresponding receiving-end nodes are IR (3) = 4 and IR (6) =7. Therefore, IE(2,1) = 3 and IE(2, 2) = 4. Again node 3 is connected to nodes 4. The proposed logic will identify the nodes that are connected to nodes 4. It will check whether node 4 appear in the left-hand column of Table 2.1 or not. It is seen that node 5 and 10 are connected to node 4. Therefore, IE (2, 3) = 5 and IE(2,4) = 10. The proposed logic will check whether nodes 5 and 10 are connected to any other nodes or not. This process will continue unless all nodes are identified beyond branch–2. The nodes beyond branch–2 are shown in Table 2.2. Similarly it is necessary to consider the receiving-end node of branch–3, branch–4,..., branch–LN1 (= 11) in Figure 2.1 and, in a similar way to that discussed above, the nodes are to be identified beyond the rest of branches. The nodes beyond each branch of Figure 2.1 are shown in Table 2.2. If the receiving–end node of any branch in Figure 2.1 is an end node of a particular lateral, the total current of this branch is equal to the load current of this node. For example, consider node 6 in Figure 2.1 (branch–5, Table 2.1); this is an end node. Therefore, the branch current I(5) is equal to the load current of node 6 only. Similarly, 9, 11 and 12 are end nodes of Figure 2.1

The algorithm to compute maximum loading of the network is shown below

Step –1 : Read the system data.
Step –2 : Set v(i) =1.0 + j 0.0 for all i i.e., i =1,2,….,NB.
Set VV(i) = v(i) for all i i.e., i = 1,2,…….,NB.
Step –3 : Set ISS(jj) = IS(jj) and IRR(jj) = IR(jj) for jj = 1,2,3,………,LN1.
Step –4 : Set iteration count k =1
Step –5 : Set kMAX = 100(say)
Step –6 : Set DVMAX = 0.0
Step –7 : Identify the nodes beyond each branch using the software proposed by Ghosh and Das [18].
Step –8 : Calculate load currents at all nodes i.e., for i =2,3,4,….,NB using equation (2.8).
Step–9 : Calculate the current through each branch i.e., I(jj).
Step –10 : Set jj =1
Step –11 : Set m1 = ISS(jj) and m2 = IRR(jj). Compute receiving–end voltage V(m2) by using equation (2.1).
Step –12 : Calculate the absolute change in voltage at node m2 i.e.,

DV(m2) = ABS(|V(m2)|− |VV(m2)|).

Step −13 : If DV(m2) > DVMAX go to Step−14. Otherwise go to Step−15.

Step −14 : DVMAX = DV(m2)

Step −15 : jj = jj + 1

Step −16 : If jj < LN1, go to Step−11, otherwise go to Step−17.

Step −17 : If DVMAX< ε go to Step−21.

Step −18 : k = k+1

Step −19 : Set VV(m2) = V(m2) for m2 = 2,3,……….,NB.

Step −20 : If k < kMAX, go to Step−6, otherwise go to Step−30.

Step −21 : Print solution has converged.

Step−22 : Calculate voltages of each node. Calculate line losses.

Step−23 : Calculate the ΔI(jj) = CMAX(jj) − I(jj)

Step−24 : Get min value of ΔI(jj) i.e., $\Delta I(jj)|_{min}$

Step−25 : If $\Delta I(jj)|_{min} > 0$, go to Step−25 else goto Step−30.

Step−26 : Set TT = 1.1

Step−27 : Multiply real and reactive power load of all nodes by TT.

Step−28 : Goto Step−2.

Step−29 : Print Solution has not converged.

Step−30 : Stop

2.4 EXAMPLE

The example is a 56−node radial distribution network shown in Figure 2.2. Load data and line data for 56−node radial distribution network are available in [18] shown in Appendix−A (Table A1 and A2 respectively). Data for conductor is shown in Appendix−B (table B1).

Table 2.3 shows the voltage magnitude (pu) of each node for 56 Node Radial Distribution Network [18] for the final case. Table 2.4 shows the branch current and difference in current for each branch of 56 node radial distribution network [18] for the final case. Table 2.5 shows the real and reactive power losses of each branch for 56 node radial distribution network [18] for the final case.

Table 2.6 shows the voltage magnitude (pu) of each node for 56 Node Radial Distribution Network [18] for the base case. Table 2.7 shows the branch current and difference in current for each branch of 56 node radial distribution network [18] for the base case. Table 2.8 shows the real and reactive power losses of each branch for 56 node radial distribution network [18] for the base case.

Table 2.9 shows the comparison of real and reactive power losses. The real and reactive power for the base case is 749.046143kW and 733.06958kVAr. The real and reactive power for the final case is 2656.02064 kW and 2599.368896 kVAr.

Table 2.10 shows the comparison of minimum voltage magnitude and the respective node number. Node number 52 has the minimum voltage of 0.426835(pu) for the final case. Node number 52 has the minimum voltage of 0.707579(pu) for the base case.

Table 2.11 shows the comparison of real and reactive power load. For the final case total real and reactive power load is 4672.481120 and 4653.200880. For the base case total real and reactive power load is 3466.671333 and 3442.316875.

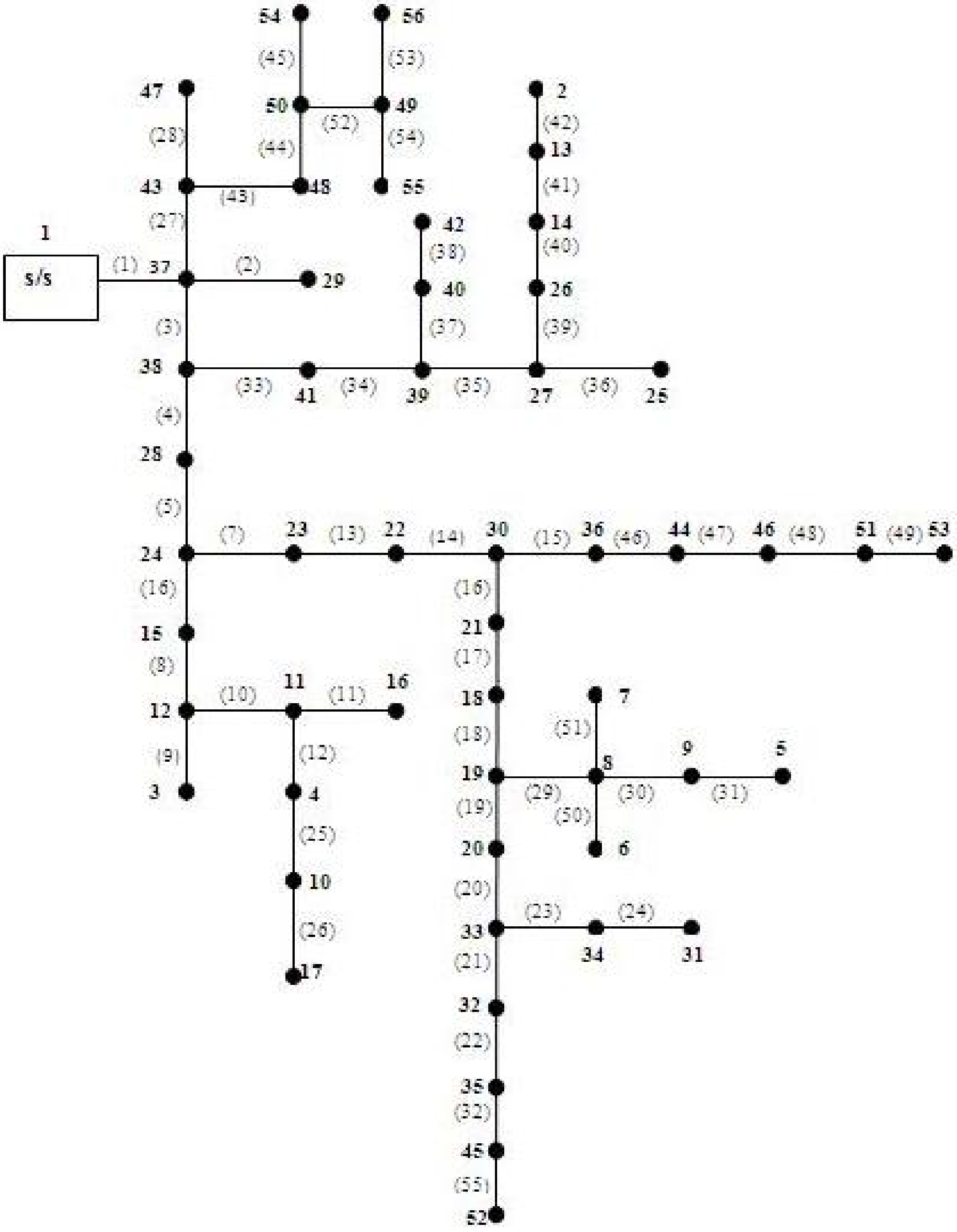

Figure 2.2   56 Node Radial Distribution Network [18]

Table 2.3 Voltage magnitude (pu) of each node for 56 Node Radial Distribution Network for the final case

Node Number	Voltage (pu)	Node Number	Voltage (pu)
37	0.959802	2	0.825728
29	0.959048	48	0.940359
38	0.87351	50	0.934857
28	0.802629	54	0.933351
24	0.745619	44	0.577755
15	0.733612	46	0.569753
23	0.696501	53	0.560934
12	0.720485	6	0.474564
3	0.717840	7	0.471347
11	0.711430	49	0.929449
16	0.709529	56	0.926737
4	0.706578	55	0.928519
22	0.640708	52	0.426835
30	0.595427		
36	0.587337		
21	0.561460		
18	0.524994		
19	0.491120		
20	0.470768		
33	0.456027		
32	0.448583		
35	0.441035		
34	0.448976		
31	0.444080		
10	0.702306		
17	0.700292		
43	0.948832		
47	0.946963		
8	0.476643		
9	0.470842		
5	0.466508		
45	0.434112		
41	0.858904		
39	0.846867		
27	0.839512		
25	0.837652		
40	0.843623		
42	0.841943		
26	0.833914		
14	0.829561		
13	0.827567		

Table 2.4 Current and the Difference in Current of each branch for 56 Node Radial Distribution Network for the final case

Branch number	Current	Difference in current
1	96.641220	103.358780
2	0.008809	199.991196
3	74.965317	125.034683
4	52.770485	147.229523
5	50.999477	149.000519
6	2.155883	197.844116
7	30.669756	169.330246
8	1.788120	198.211884
9	0.094440	199.905563
10	0.859517	199.140488
11	0.061706	199.938293
12	0.282279	199.717728
13	29.264650	170.735352
14	25.759220	174.240784
15	0.913303	199.086700
16	15.943995	184.056000
17	14.815287	185.184708
18	13.445988	186.554016
19	4.703924	195.296082
20	3.788530	196.211472
21	1.055404	198.944595
22	0.658299	199.341705
23	0.502608	199.497391
24	0.239519	199.760483
25	0.168976	199.831024
26	0.079495	199.920502
27	1.012474	198.987534
28	0.042072	199.957932
29	1.730804	198.269196
30	0.371742	199.628265
31	0.178958	199.821045
32	0.391841	199.608154
33	1.677000	198.322998
34	1.419329	198.580673
35	0.615109	199.384888
36	0.048877	199.951126
37	0.094716	199.905289
38	0.038923	199.961075
39	0.237812	199.762192
40	0.160910	199.839096
41	0.091456	199.908539

42	0.044438	199.955566
43	0.529738	199.470261
44	0.425069	199.574936
45	0.041109	199.958893
46	0.640069	199.359924
47	0.423872	199.576126
48	0.250457	199.749542
49	0.130720	199.869278
50	0.026138	199.973862
51	0.165364	199.834641
52	0.132859	199.867142
53	0.044072	199.955933
54	0.004613	199.995392
55	0.197701	199.802292

Table 2.5 Real and Reactive Power Loss of each Branch for 56 Node Radial Distribution Network for the final case

Branch Number	Real power loss (KW)	Reactive power loss (KVAr)
1	296.212830	289.894928
2	0.053037	0.051906
3	560.065002	548.119446
4	385.963318	377.731079
5	305.190094	298.680725
6	13.215908	12.934028
7	203.925995	199.576447
8	13.159123	12.878452
9	0.609619	0.596616
10	6.292999	6.158776
11	0.354132	0.346579
12	1.932383	1.891167
13	226.294662	221.468018
14	172.342499	168.666641
15	5.800873	5.677147
16	101.822205	99.650459
17	105.408379	103.160133
18	93.340073	91.349220
19	33.137192	32.430408
20	21.559402	21.099562
21	5.754756	5.632014
22	4.601151	4.503014
23	3.754981	3.674891
24	1.801804	1.763373
25	1.316267	1.288192
26	0.426149	0.417059
27	8.279299	8.102710
28	0.293726	0.287461
29	14.385344	14.078518
30	2.730131	2.671900
31	1.437774	1.407107
32	3.267141	3.197456
33	14.214184	13.911011
34	10.780787	10.550843
35	4.347641	4.254910
36	0.310447	0.303825
37	0.748482	0.732518
38	0.248906	0.243598
39	2.061674	2.017701
40	1.321232	1.293052

41	0.457085	0.447336
42	0.296947	0.290613
43	4.622779	4.524180
44	2.688723	2.631375
45	0.229097	0.224210
46	5.749370	5.626742
47	3.915401	3.831889
48	2.286395	2.237628
49	0.750207	0.734205
50	0.253790	0.248377
51	1.616887	1.582401
52	1.481494	1.449896
53	0.427170	0.418059
54	0.047766	0.046748
55	2.435432	2.383487

Table 2.6 Voltage magnitude (pu) of each node for 56 Node Radial Distribution Network for the base case

Node Number	Voltage(pu)	Node Number	Voltage(pu)
37	0.976867	2	0.897518
29	0.976126	48	0.964257
38	0.928520	50	0.960819
28	0.890619	44	0.774529
24	0.860496	46	0.770486
15	0.853601	51	0.767850
23	0.835546	6	0.727522
12	0.846429	7	0.727382
3	0.845450	49	0.957279
11	0.841262	56	0.956133
16	0.840562	55	0.956376
4	0.838404	52	0.707579
22	0.807638	54	0.960181
30	0.784526		
36	0.779805		
21	0.779805		
18	0.750714		
19	0.734978		
20	0.725346		
33	0.718666		
32	0.715201		
35	0.712011		
34	0.715976		
31	0.714649		
10	0.836204		
17	0.835468		
43	0.969860		
47	0.969064		
8	0.728878		
9	0.726578		
5	0.725363		
45	0.709494		
41	0.918672		
39	0.910830		
27	0.906131		
25	0.905381		
40	0.908907		
42	0.908228		
26	0.902212		
14	0.899377		
13	0.898256		

Table 2.7 Current and the Difference in Current each branch for 56 Node Radial Distribution Network for the base case

Branch number	Current	Difference in current
1	32.005138	167.994858
2	0.008503	199.991501
3	23.531834	176.468170
4	15.087430	184.912567
5	14.239047	185.760956
6	0.710827	199.289169
7	7.913518	192.086487
8	0.533577	199.466431
9	0.012949	199.987045
10	0.279940	199.720062
11	0.008362	199.991638
12	0.098027	199.901978
13	7.323164	192.676834
14	6.710570	193.289429
15	0.310608	199.689392
16	3.746974	196.253021
17	3.350686	196.649307
18	2.900360	197.099640
19	1.053281	198.946716
20	0.777702	199.222305
21	0.228699	199.771301
22	0.117502	199.882492
23	0.073075	199.926926
24	0.017590	199.982407
25	0.044868	199.955139
26	0.010623	199.989380
27	0.412638	199.587357
28	0.007641	199.992355
29	0.307606	199.692398
30	0.057586	199.942413
31	0.014079	199.985916
32	0.051973	199.948029
33	0.761685	199.238312
34	0.601902	199.398102
35	0.249914	199.750092
36	0.007957	199.992050
37	0.033412	199.966583
38	0.006362	199.993637
39	0.115928	199.884079
40	0.067801	199.932205
41	0.028650	199.971344

42	0.007154	199.992844
43	0.231702	199.768295
45	0.007388	199.992615
46	0.193830	199.806168
47	0.108072	199.891922
48	0.047219	199.952774
49	0.013298	199.986694
50	0.011122	199.988876
51	0.013207	199.986786
52	0.057067	199.942932
53	0.007875	199.992126
54	0.004348	199.995651
55	0.013683	199.986313

Table 2.8 Real and Reactive Power Loss of each Branch for 56 Node Radial Distribution Network for the base case

Branch Number	**Real power (KW)**	**Reactive power (KVAr)**
1	98.098244	96.005905
2	0.051198	0.050106
3	175.806061	172.056305
4	110.349464	107.995804
5	85.209045	83.391624
6	4.357481	4.264540
7	52.617699	51.495415
8	3.926695	3.842942
9	0.083585	0.081802
10	2.049591	2.005875
11	0.047991	0.046967
12	0.671061	0.656747
13	56.627808	55.419991
14	44.897182	43.939579
15	1.972839	1.930761
16	23.929079	23.418699
17	23.839598	23.331123
18	20.133875	19.704439
19	7.419926	7.261665
20	4.425673	4.331278
21	1.247017	1.220420
22	0.821273	0.803756
23	0.545943	0.534299
24	0.132325	0.129503
25	0.349503	0.342048
26	0.056944	0.055730
27	3.374262	3.302292
28	0.053345	0.052207
29	2.556624	2.502094
30	0.422922	0.413902
31	0.113109	0.110696
32	0.433345	0.424102
33	6.456012	6.318312
34	4.571863	4.474350
35	1.766415	1.728740
36	0.050541	0.049463
37	0.264031	0.258400
38	0.040682	0.039814
39	1.005020	0.983585
40	0.556719	0.544845

41	0.143188	0.140134
42	0.047803	0.046784
43	2.021960	1.978833
44	1.049775	1.027384
45	0.041171	0.040293
46	1.741061	1.703926
47	0.998285	0.976993
48	0.431054	0.421860
49	0.076320	0.074692
50	0.107988	0.105685
51	0.129132	0.126378
52	0.636346	0.622774
53	0.076325	0.074697
54	0.045024	0.044064
55	0.168557	0.164962

Final Results

Table 2.9 shows the comparison between change in real and reactive power losses in the base case and the final case. In the base case the solution gets converged in nine iterations whereas in the final case the result gets converged in ninety eight iterations. Real and reactive power losses before in the final case are 2656.02064 kW and 2599.368896 kVAr respectively. Real and reactive power losses in the base case are 749.046143 kW and 733.069580 kVAr. The result shows that real and reactive power losses are decreased.

Table 2.10 shows the comparison between Comparison of Minimum pu Voltage Level and Respective Node Number. In the final case node number 52 have minimum voltage level with magnitude 0.426835 pu. In the base case number 52 have minimum voltage level with magnitude 0.707579 pu..

Table 2.11 shows the Comparison between Total Real and Reactive Power Load in the base case and the final case. Results in the final case takes ninety eight iterations to get converged. Results shows that their is an increase in total real and reactive power load in the network, the real and reactive power load before in the final case is 4672.481120 kW and 4653.200880 kVAr. The real and reactive power load in the base case is 3466.671333 kW and3442.316875 kVAr.

Table 2.9 Comparison of Real and Reactive Power Losses

	Number of Iterations	**Real Power Loss (kW)**	**Reactive Power Loss (kVAr)**
Final case	98	2656.02064	2599.368896
Base case	9	749.046143	733.06958

Table 2.10 Comparison of Minimum pu Voltage Level and Respective Node Number

	Number of Iterations	**Node Number**	**Voltage Level (pu)**
Final case	98	52	0.426835
Base case	9	52	0.707579

Table 2.11 Comparison of Total Real and Reactive Power Load

	Number of Iterations	**Real Power load (TPL)**	**Reactive Power Load (TQL)**
Final case	98	4672.481120	4653.200880
Base case	9	3466.671333	3442.316875

CHAPTER – 3

CONCLUSIONS AND FUTURE SCOPES OF WORK

3.1 Conclusions

A formula for maximum loading of conductor for radial distribution network is proposed in this thesis work to compute the change in loading of the radial network distribution system. In this proposed method, the most sensitive node and the node having the minimum voltage deviation are found and operated in this thesis work nodes having voltage deviation less than 1% are operated. The critical loadings of the 56-node radial distribution network [18] have been found , load modelling for substation voltage of 1.0 pu. and the results are obtained by the proposed method. The comparison of will shows that the critical loading by the proposed method is superior. The overall loss i.e real and reactive power losses are increased, voltage profile of the network is improved upto certain extent and total loading of network is decreased.

3.2 Future scopes of work

The following points are recommended for future extension of work-

- A hybrid optimization approach for distribution capacitor allocation considering varying load conditions.
- Fuzzy Evolutionary Programming for selecting the optimal size of branch conductor of radial distribution feeders.

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APPENDIX – A

Table A.1 Line data for 69–Node Radial Distribution Network

Branch Number	Sending end Node	Receiving end Node	Resistance (in ohms)	Reactance (in ohms)
1	1	37	0.280965	0.274973
2	37	29	2.492042	0.705596
3	37	38	0.821809	0.804280
4	38	28	1.197020	0.808060
5	28	24	0.979380	0.661140
6	24	15	2.537219	0.718387
7	24	23	1.088200	0.734600
8	15	12	3.045905	0.862416
9	12	3	2.671709	0.756466
10	12	11	3.030325	0.858005
11	11	16	2.375343	0.762554
12	11	4	2.833357	0.802235
13	23	22	2.118467	0.883160
14	22	30	1.832949	0.764131
15	30	36	2.628844	0.744330
16	30	21	2.643209	0.748397
17	21	18	2.944769	0.833781
18	18	19	2.873172	0.813509
19	19	20	2.915692	0.825548
20	20	33	2.355332	0.666888
21	33	32	2.256806	0.638991
22	32	35	2.892875	0.819087
23	33	34	3.092176	0.875517
24	34	31	3.113533	0.881564
25	4	10	3.224071	0.912862
26	10	17	3.224071	0.628211
27	37	43	2.218732	0.958289
28	43	47	3.384511	0.818160
29	19	8	2.889600	0.974000
30	8	9	3.440000	0.860655
31	9	5	3.039684	0.941511
32	35	45	3.325254	0.977112
33	38	41	3.450990	0.993289
34	41	39	3.508126	0.890131
35	39	27	3.143790	0.828301
36	27	25	2.925416	0.744330
37	39	40	2.628844	0.926068
38	40	42	3.270713	0.749411

39	27	26	2.646790	1.015953
40	26	14	3.588169	0.962241
41	14	13	3.398470	0.585697
42	13	2	2.068581	0.783086
43	43	48	2.765726	1.022654
44	48	50	3.611836	0.741265
45	50	54	2.306594	0.653088
46	36	44	3.717747	1.052641
47	44	46	3.823202	1.082500
48	46	51	3.778367	1.069805
49	51	53	2.375343	0.672554
50	8	6	4.018768	1.137872
51	8	7	4.049636	1.145847
52	50	49	4.615244	1.306758
53	49	56	4.011695	1.135869
54	49	55	4.285529	1.213403
55	45	52	5.098632	1.443624

Table A.2 Load Data of 56 Node Radial Distribution Network

Node Number	**PL (KW)**	**QL (kVAr)**
1	53.999998	47.623523
2	50.249998	44.316333
3	67.500002	59.529406
4	66.000002	58.206526
5	82.500000	72.758162
6	48.749999	42.993459
7	89.999998	79.372537
8	56.249998	49.607840
9	75.000001	66.143781
10	75.000001	66.143781
11	75.000001	66.143781
12	67.500002	59.529406
13	75.000001	66.143781
14	57.749997	50.930714
15	50.249998	44.316333
16	60.000003	52.915030
17	75.000001	66.143781
18	67.500002	59.529406
19	89.999998	79.372537
20	65.250002	57.545089
21	56.249998	49.607840
22	57.749997	50.930714
23	63.750002	56.222215
24	62.250002	54.899341
25	75.000001	66.143781
26	63.750002	56.222215
27	65.250002	57.545089
28	50.249998	44.316333
29	75.000001	66.143781
30	60.000003	52.915030
31	60.000003	52.915030
32	60.000003	52.915030
33	75.000001	66.143781
34	67.500002	59.529406
35	71.250001	62.836596
36	63.750002	56.222215
37	82.500000	72.758162
38	73.500001	64.820907
39	71.250001	62.836596
40	71.250001	62.836596
41	60.000003	52.915030
42	82.500000	72.758162

43	65.250002	57.545089
44	56.999997	50.269277
45	71.250001	62.836596
46	75.000001	66.143781
47	65.250002	57.545089
48	75.000001	66.143781
49	60.000003	52.545089
50	75.000001	66.143781
51	67.500002	59.529406
52	60.000003	52.915030
53	44.999999	39.686271
54	63.750002	56.222215
55	75.000001	66.143781

BASE kV = 12.66 and BASE MVA = 100

APPENDIX-B

Table B.1 Data for conductor

Type of conductor	Area of cross section (mm^2)	Resistance (Ω/km)	Reactance (Ω/km)	Maximum current carrying capacity (Amp)	Cost of conductor (Rs/km)
Raccon	48.39	0.3657	0.3579	200.0	10950

APPENDIX - C

BIOGRAPHY OF CANDIDATE

Personal Information

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Academic Qualification

M.E in Power System and Electrical Drives from Thapar University, securing 8.00 CGPA.

B.Tech in Electrical Engg. from Guru Nanak Dev Engineering College, Ludhiana Affiliated to PTU, Jalandhar in June 2007 securing 72%.

Higher Secondary from Central Board of Secondary Education in 2003 securing 68.2 %.

High School from Central Board of Secondary Education in 2001 securing 70%.

Campus Placements

Chitkara University

Lovely Professional University