

***ENHANCEMENT OF MAXIMUM LOADING FOR RADIAL
DISTRIBUTION NETWORK***

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

**Master of Engineering
in
Power Systems & Electric Drives**



Thapar University, Patiala

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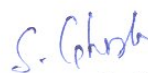
Certificate

I hereby certify that the work which is being presented in the thesis entitle "*Enhancement of Maximum Loading for Radial Distribution Network*", in partial fulfillment 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 an authentic record of my own work carried out under the supervision of **Dr. Smarajit Ghosh**.

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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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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Dedicated to My Parents

ABSTRACT

In this Thesis work, an attempt has been made for reconfiguration of electric power distribution system. A new formula for computing the reconfiguration of any distribution network is proposed in this thesis work. The node having the minimum value of voltage deviation w.r.t pu value is the most sensitive node. Using example of 69-node radial distribution networks, it has been shown that the node having the minimum value of voltage deviation w.r.t pu value become most sensitive node using the proposed method which is also the end node. The critical values of total real power load (TPL) and total reactive power load (TQL) for constant power are derived out for the sub-station voltage of 1.0 pu. for 69-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 voltage deviation is reduced to $\pm 6\%$ from $\pm 10\%$. The superiority of the proposed method has been established by taking results iteratively and comparing with other literatures.

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List of Symbols

NB	Total no. of nodes,
jj	Branch no. i.e., $jj = 1,2,3,\dots,\text{LN1}$,
L(i)	Length of the conductor, $i = 1,2,3,\dots$,
V(m1)	Voltage of sending – end node of branch – jj,
V(m2)	Voltage of receiving – 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,
I _r (jj)	Real component of I(jj),
I _m (jj)	Imaginary component of I(jj),
PL(m2)	Active power load at node m2,
QL(m2)	Reactive power load at node m2,
TPL	Total real power load and
TPL	Total real power load.
kV	Kilo Volts
kW	Kilo Watt

1.1 ELECTRICAL POWER SYSTEM

Electrical power is transmitted by high voltage transmission lines from sending–end substation to receiving–end substation. At the receiving–end substation the voltage is stepped down to a lower value (say 66kV or 33kV or 11kV). The secondary transmission system transfer power from this receiving–end substation to secondary substation. A secondary substation consists of two or more power transformers together with voltage regulating equipments, buses and switchgear. At the secondary substation voltage is stepped down to 11kV. The portion of the power network between a secondary substation and consumers is known as distribution system. The distribution system can be classified into primary and secondary system. Some large consumers are given high voltage supply from the receiving–end substations or secondary substation.

The area served by a secondary substation can be subdivided into a number of sub- areas. Each sub area has its primary and secondary distribution system. The primary distribution system consists of main feeders and laterals. The main feeder runs from the low voltage bus of the secondary substation and acts as the main source of supply to sub- feeders, laterals or direct connected distribution transformers. The lateral is supplied by the main feeder and extends through the load area with connection to distribution transformers. The distribution transformers are located at convenient places in the load area. They may be located in specially constructed enclosures or may be pole mounted. The distribution transformers for a large multi storied building may be located within the building itself. At the distribution transformer the voltage is stepped down to 400V and power is fed into the secondary distribution systems. The secondary distribution system consists of distributors which are laid along the road sides. The service connections to consumers are tapped off from the distributors. The main feeders, laterals and distributors may consists of overhead lines or cables or both. The distributors are 3– phase, 4 wire circuits, the neutral wire being necessary to supply the single phase loads. Most of the residential and commercial consumers are given single phase supply. Some large residential and

commercial consumers get 3– phase supply. The service connections of consumers are known as service mains.

The consumer receives power from the distribution system. The main part of distribution system includes:

1. Receiving substation
2. Sub- transmission lines
3. Distribution substation located nearer to the load centre
4. Secondary circuits on the LV side of the distribution transformer.
5. Service mains

Unlike main EHV–AC transmission systems, the distribution systems have several service lines, several distribution transformers and associated primary and secondary circuitry and one or two receiving substations. Unlike transmission systems distribution systems are more complicated and have to face more problems like voltage drop during peak load time and voltage rise during off peak load. In addition to above problems distribution transformer is overloaded during most period.

APPROXIMATE PERCENTAGE OF INVESTMENT IN INDIA

Table 1.1 Approximate Percentage of Investment in Various Sectors

CATEGORY	1990	2000
GENERATION	50%	55%
TRANSMISSION	15%	14%
DISTRIBUTION	30%	28%
RURAL DISTRIBUTION	5%	3%

Lapse in distribution planning results in ultimate power shortage in certain load areas, frequent power interruption, voltage flicker, poor quality power supply to consumer.

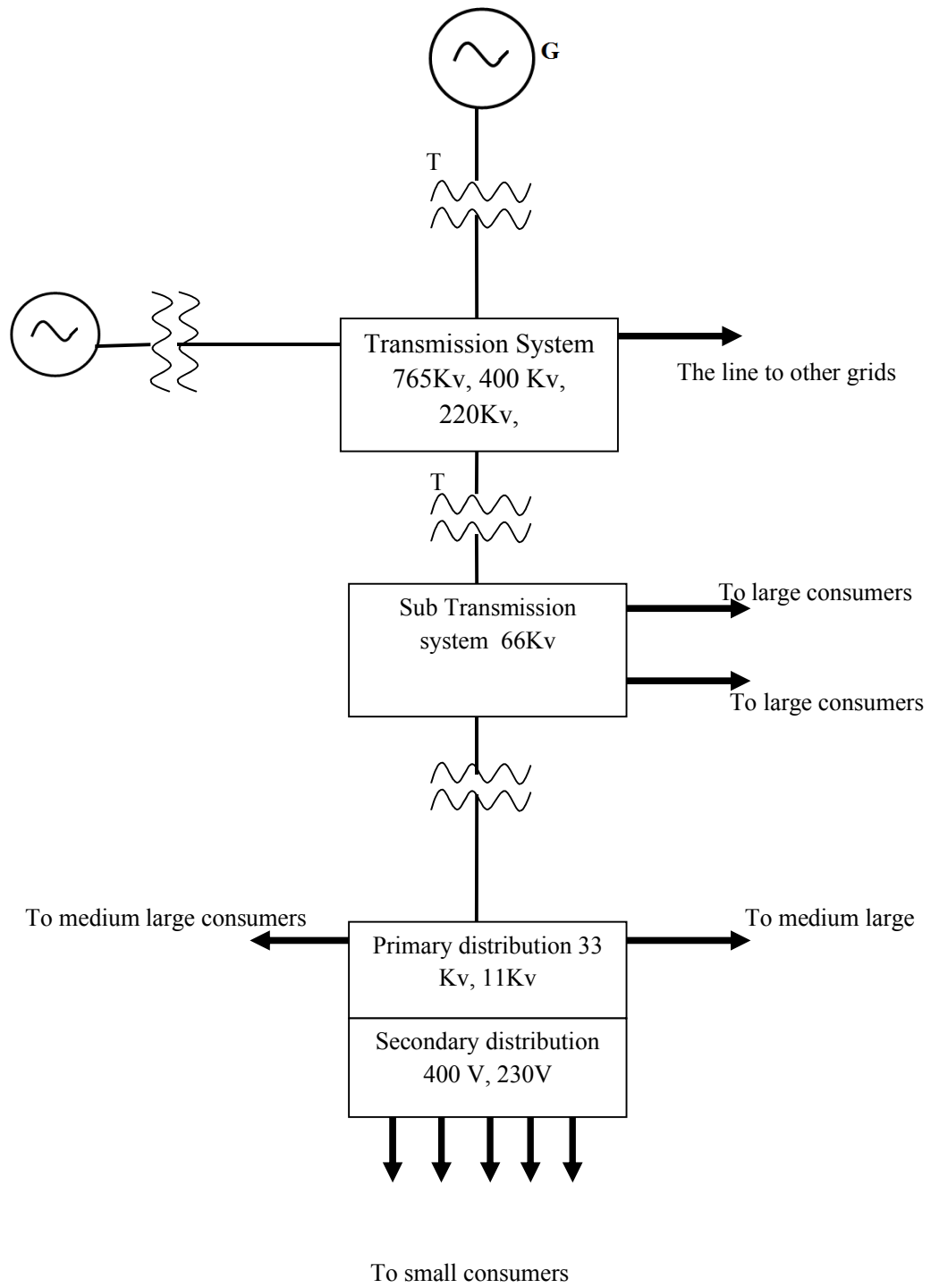


Figure 1.1 Single Line Power System Network

1.2 DISTRIBUTION SYSTEM

The part of power system which distributes electric power for local use is known as distribution system.

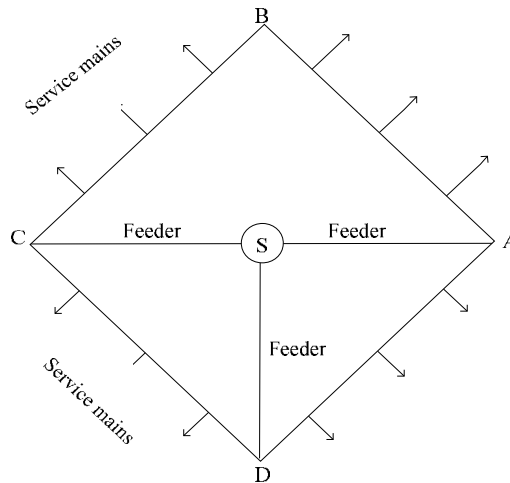


Figure 1.2 Single line diagram of a typical low tension distribution system.

In general, the distribution system is the electrical system between the sub-station fed by the transmission system and the consumer's meters. It generally consists of feeders, distributors and the service mains. Figure 1.2 shows the single line diagram of a typical low tension distribution system.

- (i) *Feeders:* A feeder is a conductor, which connects the sub-station (or localized generating station) to the area where power is to be distributed. Generally, no tappings are taken from the feeder so that the current in it remains the same throughout. The main consideration in the design of a feeder is the current carrying capacity.
- (ii) *Distributor:* A distributor is a conductor from which tappings are taken for supply to the consumers. In Figure 1.2, AB, BC, CD, and DA are the distributors. The current through a distributor is not constant because tappings are taken at various places along its length. While designing a distributor, voltage drop along its length is the main

consideration since the statutory limit of voltage variations is $\pm 10\%$ of rated value at the consumer's terminals.

- (iii) *Service mains*: A service mains is generally a small cable which connects the distributor to the consumer terminals.

1.3 OBJECTIVES OF DISTRIBUTION SYSTEMS

1. Planning, modernisation and automation.
2. To provide service connection to various urban, rural and industrial consumer in the allocated area.
3. Maximum security of supply and minimum duration of interruption.
4. Safety of consumers, utility personnel
5. To provide electricity of accepted quality in terms of :
 - a. Balanced three phase supply.
 - b. Good power factor.
 - c. Voltage flicker within permissible limits.
 - d. Less voltage dips.
 - e. Minimum interruption in power supply.

1.4 SUBTRANSMISSION AND DISTRIBUTION

Modern power system network is divided into three levels of transmission and distribution.

1. Main transmission network (EHV-AC)
2. Sub transmission network (HV-AC)
3. Distribution network (LV-AC)

*EHV-AC – Extra High Voltage Alternating Current, *HV-AC - High Voltage Alternating Current

*LV-AC - Low Voltage Alternating Current

Table 1.2 Function of Sub transmission and Distribution Network

Level title	Function	Remarks
Subtransmission network	<ol style="list-style-type: none"> 1. To receive power from transmission network and other local power station. 2. To deliver power to distribution network via HV transmission lines. 	<ol style="list-style-type: none"> 1. less meshed 2. More radial 3. Generally at high voltage AC (220 kV ,132 kV)
Distribution networks <ol style="list-style-type: none"> 1. Primary circuit 2. Distribution transformer 3. Secondary circuits 	<ol style="list-style-type: none"> 1. To receive power from the subtransmission network. 2. To deliver power to the consumer. 	<ol style="list-style-type: none"> 1. Low voltage level 33kV, 11kV 2. To reduce the voltage to 400/230V level.

The subtransmission systems are considered to be the part of the distribution system. They receive power from the bulk power system and delivers power to distribution network. Distribution network delivers power to HT and LT consumers. The subtransmission network is generally 3-phase, 3-wire, 50Hz overhead transmission system.

The distribution system have step down power transformers, its primary side is connected to HV subtransmission system whereas secondary is designed to supply LV consumers. Distribution substation is located near to the load centre. The distribution transformers are generally 3-phase, Δ/Y power transformer. Primary side is supplied by 11kV to 33kV 3-phase, 3 wire supply whereas secondary side 3-phase, 4 wire system with voltage level of 415V A2. Secondary circuits are generally radial type and consists of under ground secondary mains, service mains.

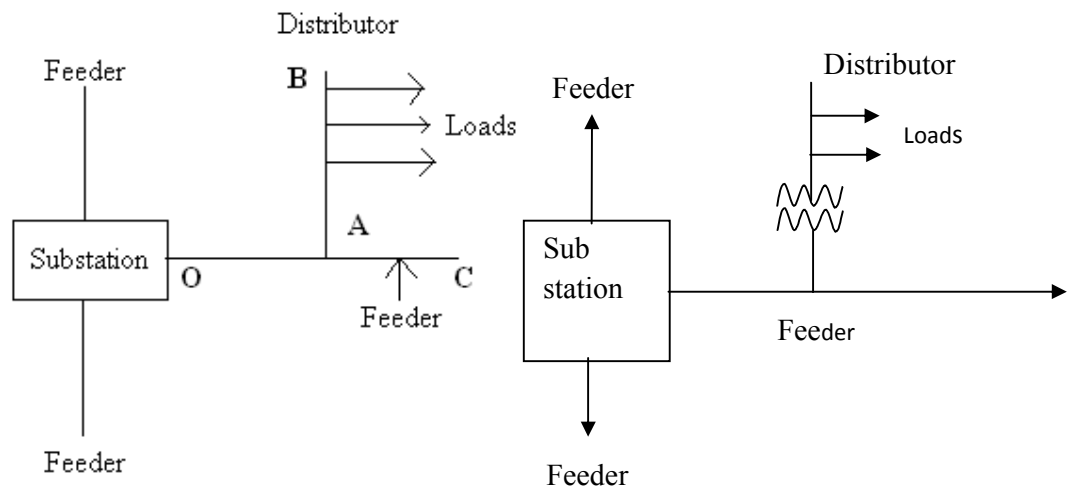
1.5 Connection Scheme of Distribution System

All distribution of electrical energy is done by constant voltage system. In practice, the following distribution circuits are generally used:

- (i) **Radial System:** In this system, separate feeders radiate from a single sub-station and feed the distributors at one end only. Figure 1.3 (a) shows a single line diagram of a radial system for D2. Distribution where a feeder OC supplies a distributor AB at point A. Obviously, the distributors are fed at

one point only i.e. point A in this case. Figure 1.3 (b) shows a single line diagram of radial system for A2. distribution. The radial system is employed only when power is generated at low voltage and the sub-station is located at the centre of load. This is the simplest distribution circuit and has the lowest initial cost. However, it suffers from the following drawbacks:

- (a) The end of the distributor nearest to the feeding point will be heavily loaded.
- (b) The consumers are dependent on a single feeder and single distributor. Therefore, any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the sub-station.
- (c) The consumers at the distant end of the distributor would be subjected to serious voltage fluctuations when the load on the distributor changes. Due to these limitations, this system is used for short distances only.



(a) Distribution for DC Systems

(b) Distribution for AC Systems

Figure1.3 Single line diagram of Radial System

(b) **Ring main system:** In this system, the primaries of distribution transformers from a loop. The loop circuit starts from the sub-station bus-bars, makes a loop through the area to be served, and returns to the sub-station. Figure 1.4 shows the single line diagram of ring main system for A2. Distribution where

sub-station supplies to the closed feeder LMNOPQRS and Q of the feeder through distribution transformers.

The ring main system has the following advantages:

- a. There are less voltage fluctuations at consumer's terminals
- b. The system is very reliable as each distributor is fed via two feeders. In the event of fault on any section of the feeder, the continuity of supply is maintained. For example, suppose that fault occurs at any point F of section SLM of the feeder. Then section SLM of the feeder can be isolated for repairs and at the same time continuity of supply is maintained to all the consumers via the feeder SRQPONM.

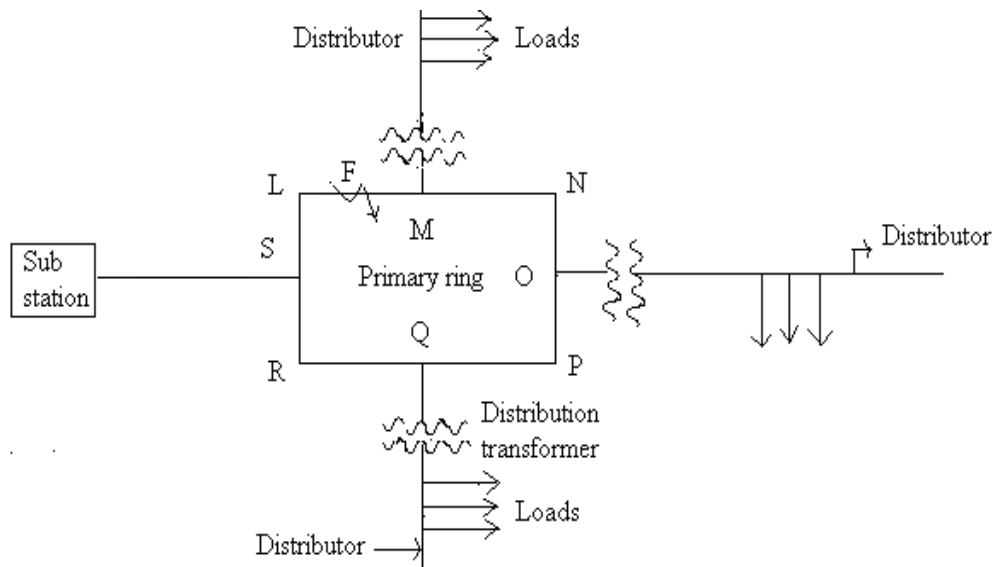


Figure 1.4 Ring Main System

(c) **Interconnected system:** When the feeder ring is energized by two or more than two generating stations or sub stations, it is called inter-connected system. Figure 1.5 shows the single line diagram of interconnected system where the closed feeder ring ABCD is supplied by two sub-stations S_1 and S_2 at points D and C respectively. Distributors are connected to points O, P, Q and R of the feeder ring through distribution transformers.

The interconnected system has the following advantages:

- a. It increases the service reliability.

system voltage is specified by the standards. The distribution system is designed and operated to ensure that the supply voltage at service connection is within specified limits at no load to peak load.

Table 1.3 Reference value of voltage limit in distribution system

CLASS	SYSTEM VOLTAGE NOMINAL RMS	PERMISSIBLE	
		HIGHEST SYSTEM VOLTAGE RMS	LOWEST SYSTEM VOLTAGE RMS
LV (1 Ph)	230V	264V	200V
LV(3 Ph)	400V	457V	347V
MV(3Ph)	3.3kV	3.6kV	3kV
	6.6kV	7.2kV	6kV
	11kV	12kV	10.5kV
	22kV	24kV	20kV
	33kV	36kV	30kV
HV(3Ph)	66kV	72.5kV	60kV

1.8 ESSENTIAL PARTS OF DISTRIBUTION SYSTEM

Various type of distribution system have identical subsystems and components. These components can be connected and configured in various alternative ways depending upon the area covered, load density, type and importance of consumer, reliability and freedom from interruption desired, cost of land and right of way available.

- a. Subtransmission Circuits
- b. Distribution Substations
- c. Primary Distribution Circuit
- d. Distribution Transformers
- e. Secondary Distribution System

TABLE 1.4 ELEMENTS OF DISTRIBUTION SYSTEMS

S.No.	ELEMENT	FUNCTION	REMARKS
1	Subtransmission circuits	To receive power from main bulk power receiving station and delivering power to the distribution substations	<ol style="list-style-type: none"> 3-phase 3 wire AC system at 50 Hz. High voltage overhead lines 66kV\33kV. Radial\loop\ring\mesh configurations.
2	Distribution substations	<ol style="list-style-type: none"> To step down voltage received from sub transmission level. To feed primary distribution circuits. To arrange switching, protection, metering, control. 	<ol style="list-style-type: none"> Out door air insulated or indoor SF₆ gas insulated. Two voltage level buses. Located near load centre.
3	Primary distribution system	To feed power to various distribution transformers through primary feeder.	<ol style="list-style-type: none"> Radial, modified radial, loop, ring circuit. High voltage for higher load densities.
4	Distribution transformers	To step down voltage to secondary distribution level.	It steps down voltage to 415V level. Distribution transformers are generally pole mounted, foundation mounted. Typical rating of transformer is 100 KVA to 500 KVA.
5	Secondary distribution system	To fed the consumer	<ol style="list-style-type: none"> Overhead + underground distribution lines. Radial network. 3-phase 4 wire system with grounded neutral. Service mains & service network

1.9 OVER HEAD VERSUS 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.

1. **Public Safety:** The underground system is more safe than overhead system because all distribution wiring is placed underground and there are little chances of any hazard.
2. **Initial Cost:** The underground system is more expensive due to the high cost of trenching, conduits, cables, manholes, and other special equipments. The initial cost of an underground system may be five to ten times than that of an overhead system.
3. **Flexibility:** The overhead system is much more flexible than the underground system. In the latter case, manholes, duct lines et2., are permanently placed once installed and the load expansion can only be met by laying new lines. However on an overhead system, poles, wires, transformer et2., can be easily shifted to meet the change in load conditions.
4. **Faults:** The chances of fault in underground system are very rare as the cables are laid underground and are generally provided with better insulation.
5. **Appearance:** The general appearance of an underground system is better as all the distribution lines are visible. This factor is exerting considerable public pressure on electric supply companies to switch over to underground system.
6. **Fault location and repairs:** In general, there are little chances of fault in an underground system. However, if a fault does occur, it is difficult to locate and repair the system. On an overhead system, the conductors are visible and easily accessible so that fault locations and repairs can easily be made.
7. **Current carrying capacity and voltage drop:** An overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section. On the other hand, underground cable conductor has much lower inductive reactance than that of an overhead conductor because of closer spacing of conductor.

8. **Useful Life:** The useful life of underground system is much longer than that of an overhead system. An overhead system may have a useful life of 25 years, whereas an underground system may have a useful life of more than 50 years.
9. **Maintenance cost:** The maintenance cost of underground system is very low as compared with that of overhead system because of less chances of fault and service interruptions from wind, ice, lightning as well as from traffic hazards.
10. **Interference with communication circuits:** An overhead system causes electromagnetic interference with telephone lines. The power line currents are superimposed on speech currents, resulting in the potential of the communication channel being raised to an undesirable level. However, there is no such interference with the underground 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 1.6 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, V_s is the voltage at feeding point and V_r is the voltage at far. Then

$$V_s = V_r + (I_1 + I_2 + I_3) L_1 (r + jx) + (I_2 + I_3) L_2 (r + jx) + I_3 L_3 (r + jx) \quad (1.10a)$$

$$= V_r + I_1 L_1 (r + jx) + I_2(L_1+L_2) (r + jx) + I_3(L_1 +L_2 +L_3) (r + jx) \quad (1.10b)$$

$$= V_r + I_1 L_1 r + I_2 (L_1 + L_2) r + I_3 (L_1 + L_2 + L_3) r + j [I_1 L_1 x + I_2 (L_1 + L_2) x + I_3 (L_1 + L_2 + L_3) x] \quad (1.10c)$$

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 (1.10c) can be written as,

$$V_s = V_r + I_1 L_1 r + I_2 (L_1 + L_2) r + I_3 (L_1 + L_2 + L_3) r \quad (1.10d)$$

$$\text{Voltage drop} = \text{Sending-End Voltage } (V_s) - \text{Receiving End Voltage } (V_r) \quad (1.10e)$$

Substituting V_s from Eq. (1.10d)

$$\text{Voltage Drop} = I_1 L_1 r + I_2 (L_1 + L_2) r + I_3 (L_1 + L_2 + L_3) r \quad (1.10f)$$

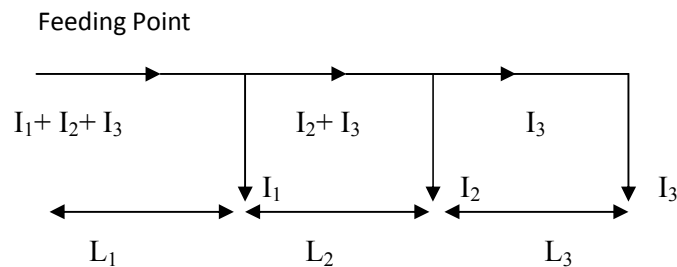


Figure 1.6 Single phase distributor supplying loads at unity power factor

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 $L_1 r$ 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 1.7 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:

$$\text{Voltage drop} = I_1 (\cos\phi_1 - j\sin\phi_1) L_1 (r + jx) + I_2 (\cos\phi_2 - j\sin\phi_2) \times (L_1 + L_2) (r + jx) + I_3 (\cos\phi_3 - j\sin\phi_3) (L_1 + L_2 + L_3) (r + jx) \quad (1.10g)$$

$$= I_1 L_1 (r\cos\phi_1 + x\sin\phi_1) + I_2 (L_1 + L_2) (r\cos\phi_2 + x\sin\phi_2) + I_3 (L_1 + L_2 + L_3) (r\cos\phi_3 + x\sin\phi_3) \quad (1.10h)$$

where,

r = resistance per unit length

x = reactance per unit length

I = current of line, L =length of line

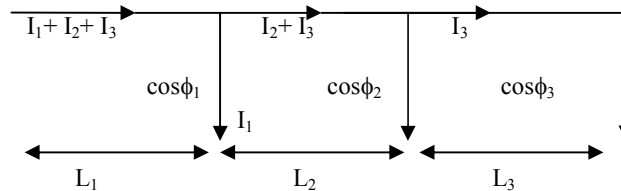


Figure 1.7 Single phase distributor supplying loads at different power factor

Comparing Eq. (1.10h) and Eq(1.10f) shows that the effect of power factor is to replace the term r by $(r\cos\phi + x\sin\phi)$. 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 ($R\cos\phi + X\sin\phi$) 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 $\cos\phi$ be tapped per unit length of distributor of total length L.

Voltage drop upto distance u = (sum of moments upto u) + (moments of load beyond u assumed acting at distance u) (1.10i)

$$= \int_0^u (r \cos\phi I u \, du + x \sin\phi I u \, du) + I (L-u) r \cos\phi u + I (L-u) x \sin\phi u \quad (1.10j)$$

$$= I L u \cos\phi - \frac{1}{2} I r u^2 \cos\phi + I L u x \sin\phi - \frac{1}{2} I x u^2 \sin\phi \quad (1.10k)$$

$$\text{Total voltage drop at the far end} = \frac{1}{2} I L^2 r \cos\phi + \frac{1}{2} I L^2 x \sin\phi \quad (1.10l)$$

1.10.4 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 SIZE OF FEEDER'S CONDUCTOR

The conductor size of a feeder is governed by the current carrying capacity, voltage drop, and overall economy.

The current carrying capacity of a conductor depends on the conductor losses and surroundings. The capacity is usually determined for a maximum operating

temperature of 75°C. Appendix A gives the current carrying capacity of different ACSR conductors as per IS 398–1976.

The value of conductor resistance at 20°C are also given in appendix A. From these values the effective resistance at the operating temperature can be calculated. For determining the voltage drop, it is necessary to calculate the inductive reactance of the feeder. After calculating the inductive reactance, the voltage drop of conductor can be calculated. If the voltage drop comes out to be higher than it is necessary to select another conductor size to reduce the voltage drop.

The value of conductor size obtained above should be checked for overall economy. By the application of Kelvin's law, the most economical conductor size can be calculated. According to Kelvin's law the most economical cross-section is that which makes the annual value of interest and depreciation of the conductor equal to the annual cost of the energy wasted in the conductor. The maximum current on the feeder is not remains always but it occurs certain times. At all the other time the value of current is less than the maximum value. And it is necessary to have a factor for this calculation. This factor is known as loss factor which is defined below,

Loss Factor = average power loss / power loss at peak load

$$\text{Loss} = 3 (I_{\max})^2 R (\text{loss factor})$$

If the load is constant through out the time than loss factor is one. In actual practice load varies time to time. If the actual load pattern is known then loss factor can be easily calculated. An approximate value of loss factor can be found from the following equation

$$\text{Loss Factor} = (0.3 \times \text{Load Factor}) + 0.7 (\text{Load Factor})^2$$

where Load Factor = average load / peak load

1.12 LITERATURE SURVEY

A fast algorithm to help the distribution engineer select proper conductors for his future expansion plan is presented. The optimal conductor type is determined for each feeder segment to maintain an acceptable voltage profile entire the feeder, minimizing capital investment and the cost of feeder losses. An optimal model for configuring

feeder networks to drive an overall expansion is discussed by H.N. Tram and D.L. Wall [1]. Although their algorithm is based on realistic assumptions and reliable optimization techniques, it is relatively complicated to handle for the engineer.

A model to represent feeder cost, energy loss cost and voltage regulation as a function of conductor cross-section and an objective function for optimizing the conductor cross-section have been formulated by M. Ponnavaikko and K.S. Prakasa Rao [2]. The method proposed by [2] takes into account the non-uniform distribution of loads along with the length of feeder and load growth in the future years of the plan period. A direct solution procedure for conductor grading is proposed, thereby eliminating the complexity of the dynamic programming approach by P.S Nagendra Rao [3]. In [3] a new computational procedure for obtaining the optimal conductor grading policy using PPR model was proposed. Method proposed by [3] is extremely simple and require very little computation and needed very little computer storage.

A new two step planning technique which uses both the minimum spanning tree concept and the Mixed Integer Programming (MIP) has been suggested by S. Salamat Sharif, M.M.A Salma and A. Vanelli [4]. Methods proposed by [1] – [3] can solve problems accurately for small scale but for large problem [1]–[3] can not guarantee for optimal solution. In [4] a new technique to optimizing the feeder routing problem which minimize the total cost of feeder subject to a set of specified constraints was discussed.

M. Ponnavaikko and K.S. Prakasa Rao [2] developed good mathematical models for the problem, and presented multi stage decision dynamic programming method. However this method fails in handling the large problem and give only approximate results. Tram and Wall [1] proposed an improved algorithm. Although their algorithm is based on the realistic assumptions and reliable optimization techniques, it is relatively complicated to be handled by engineer. The approach discussed by Zhuding Wang, Hanijun Liu, David C Yu, Hongquan Song [5] includes an economical current density based method and a heuristic method, which together enable a satisfactory solution which can be easily achieved.

Miu and Chaing are probably the first to propose a solution algorithm for distribution loading capability. In [6] the problem of determining the load capability of distribution networks or equivalently, the amount of load a feeder, specific area or circuit of a large-scale unbalanced distribution network can withstand before violating an operational constraint. A solution algorithm suitable for large-scale unbalanced distribution networks with capacitor control actions is developed and test. However their model is suitable only for constant current load and for radial main feeder only.

D. Das [7] a simple algorithm is proposed for determining the maximum loading of the feeders without violating the maximum current capacity of branch conductor. A predetermined annual load growth is also considered to determine allowable load growth period without violating the minimum voltage limit of the feeder. Method proposed by [2]– [3] is suitable only for constant load and for radial main feeder only. A dynamic model for the development of primary and secondary circuits supplying a residential area is described and exercised by Kirn and Adler [8]. Features of the model which support optimal conductor sizing are the evaluation of annual revenue requirements associated with capital requirement and energy losses as area load evolves. These revenue requirements are responsive to change in area load (positive or negative) arising with change in the number of residences and change in the load per residence year by year. Results of optimization trials explore the relative penalties incurred for optimal conductor policies based on incorrect projections of load growth, degree of load management expected, and costs of losses.

A method is proposed for selecting the optimal size of branch conductor for radial distribution network by S. Satyanarayana, T. Ramana, G.K. Rao and S.Sivanagaraju [9]. In the proposed method [9] the conductor will not only maintain maximum current carrying capacity but also maintain the voltage level for the distribution network.

Two algorithms for the reconfiguration of feeders is presented by S. Ghosh and D.Das [10] in the proposed method for first algorithm, during iterative process, closing of an open tie switch is based on the maximum voltage drop across it and this drop must be greater than some specified value. For the second algorithm closing of

an open switch is arbitrary, but the voltage drop across it must be greater than some specified value.

The load–flow proposed by S. Ghosh *et al.*[11] is used in this thesis work.

1.13 Objectives of the Thesis Work

The thesis work endeavors to derive a expression for maximum loading of conductor for radial distribution network and its applications in planning of power distribution system. The objectives are divided into the following:

- To derive a new expression for maximum loading of conductor for radial distribution network.
- To identify the most sensitive nodes in term of voltage deviation of the radial distribution networks.
- To compute the critical values of total real power load (TPL) and total reactive power load (TQL) of the system.

1.14 ORGANISATION OF THE THESIS WORK

Chapter 1 has presented the introduction of distribution system, load modelling, size of feeder conductor, voltage stability, voltage collapse, and literature survey, objectives of the research, scope of the research and organization of the research.

Chapter 2 presents a new expression for the maximum loading of the conductor of the distribution networks. 69 node radial distribution network [11] 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 loaded 85% of its maximum value, the reason for not taking 100% loading of conductor is that during fault condition if conductor is 100% loaded than it will burnout. After three switching options TPL and TQL is being calculated and it is found that TPL and TQL is increased after the reconfiguration using the proposed method.

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

References present the list of previous papers published by researchers in optimal conductor selection, maximum loading of conductor and reconfiguration of network of radial distribution system.

Appendix – A shows the line data and load data of 69 node radial distribution network available in [11].

Appendix – B shows the line data and load data of 69 node radial distribution network after reconfiguration of network.

Appendix – C shows rating of various ACSR conductors.

Appendix – D shows biography of candidate.

CHAPTER 2

MAXIMUM LOADING OF RADIAL DISTRIBUTION NETWORK

2.1 ASSUMPTION

The three phase radial distribution networks are assumed to be balanced and can be represented by their single line diagram. Load is assumed to be constant power load.

2.2 NETWORK RECONFIGURATION

Radial distribution networks have some advantages meshes 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. Their configuration may varied with manual or automatic switching operations to transfer loads among the feeders. There are two kind of switching in the primary distribution systems, namely, normally closed switches that connect line sections and normally open switches on the tie lines that connect two primary feeders, two substations, or loop type laterals. The former is called sectionalizing switches and the latter is called tie–line switch. Both of them are designed for fault isolation and network reconfiguration. The purpose of network reconfiguration is to produce the minimum loss possible under the circuit's capacity constraint.

2.3 SOLUTION METHODOLOGY

In this thesis 69 node radial distribution network [11] is taken as example. Initially the network have 5 tie line switches and connecting the nodes (11–43), (13– 21), (15– 46), (27– 65), (50– 59). First load– flow is run for radial network as given in [15] to find the current of different branches. 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 loaded 85% of its maximum value, the reason for not taking 100% loading of conductor is that during fault condition if conductor is 100% loaded than it will burnout.

Load-flow also gives voltages at every node, the percentage deviation of voltage w.r.t to pu voltage is calculated and it is derived that we have to operate on those nodes having minimum percentage voltage deviation. Then according to percentage voltage deviation the nodes are arranged in ascending order. Then in the arranged nodes, nodes having percentage deviation less than 1 are selected. According to voltage deviation the load is distributed on the branches.

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

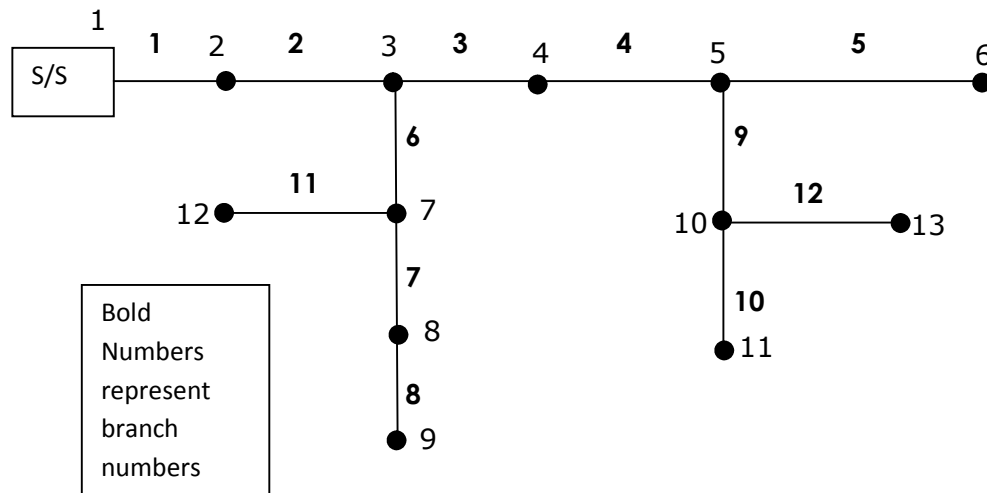


Figure 2.1 Single Line Diagram of Radial Distribution Network

Table 2.1 Branch number (jj), Sending end node (m1 = IS(jj)), Receiving end node (m2 = IR(jj)) and nodes beyond branches 1, 2, 3, ..., 10 of Figure 2.1

Branch Number (jj)	Sending end m1 = IS(jj)	Receiving end m2 = IR (jj)
1	1	2
2	2	3
3	3	4
4	4	5
5	5	6
6	3	7
7	7	8
8	8	9
9	5	10
10	10	11
11	7	12
12	10	13

The voltage at any receiving-end node (m2) of branch-jj is expressed by

$$V(m2) = V(m1) - I(jj)Z(jj) \quad (2.1)$$

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

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

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

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

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

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

$$LP = |I(jj)|^2 R(jj) \quad (2.6)$$

$$\text{and } LQ = |I(jj)|^2 X(jj) \quad (2.7)$$

respectively.

The current through branch-jj is the sum of all load currents of all nodes beyond branch-jj i.e.,

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

where $N(jj)$ is the total number of nodes beyond branch jj and $IE(jj, i)$ is the receiving-end node beyond branch-jj. The algorithm for identification of nodes beyond each branch-jj is available in [11]. Table 2.1 shows the nodes beyond each branch of Figure 2.1.

Let $CI_{max}(jj)$ be the maximum current capacity of the conductor of branch-jj. After running the load-flow, current through the each branch and voltage of each node can be obtained. The difference $\Delta I(jj) = 0.85 \times CI_{max}(jj) - I(jj)$ can be computed. The percentage change in voltage of each node is arranged in ascending order. The node having the voltage less than 1.0000 pu are taken into account only. The load of this node are increased slowly until the $\Delta I(jj)$ remains positive. The network is reconfigured and the similar technique is applied. The complete algorithm is shown below.

- Step -1 : Start
- Step -2 : Read sending-end and receiving-end nodes and total number of nodes and branches.
- Step -3 : Set $V(i) = 1.0 + j 0.0$ for all i i.e., $i = 1, 2, \dots, NB$
Set $VV(i) = V(i)$ for all i i.e., $i = 1, 2, \dots, NB$
- Step -4 : Set $ISS(jj) = IS(jj)$ and $IRR(jj) = IR(jj)$ for

- $jj = 1,2,3,\dots,\text{LN1}$
- Step -5 : Set iteration count $k = 1$
- Step -6 : Set $k\text{MAX} = 100$ (say)
- Step -7 : Set $DV\text{MAX} = 0.0$ and $\varepsilon = 0.00001$
- Step -8 : Identify the nodes beyond each branch using the IDENT software available in ref.[11].
- Step -9 : Compute load currents $I_L(m2)$ for all the node $m2$ i.e., for $m2 = 2,3,4,\dots,\text{NB}$ using Eq. (2.5).
- Step-10 : Compute the current through each branch i.e., $I(jj)$ for all jj i.e., $jj = 1,2,3,\dots,\text{LN1}$ using Eq. (2.8).
- Step -11 : Set $jj = 1$
- Step -12 : Compute $\Delta I(jj) = 0.85 \times C\text{I}_{\text{max}}(jj) - I(jj)$
- Step -13 : Set $m1 = \text{ISS}(jj)$ and $m2 = \text{IRR}(jj)$. Compute receiving-end voltage $V(m2)$ for all $m2$ using Eq. (2.2).
- Step -14 : Compute the voltage deviation $VD(m2) = 1 - V(m2)$
- Step -15 : $jj = jj + 1$
- Step -16 : If $jj < \text{LN1}$, go to Step-13, otherwise go to next Step.
- Step -17 : Find the percentage voltage deviation $\% VD(m2)$
- Step -18 : Arrange $\% \text{voltage deviation } \% VD(m2)$ in ascending order.
- Step -19 : If all $VD(m2) > 1.000$, go to Stop
- Step -20 : Set $m2 = 0$
- Step -21 : Calculated total number of nodes having $VD(m2) < 1.000$.
- Step -22 : $M3 = m2 + 1$
- Step -23 : Increase the Real Power (p_l).

- Step –24 : Increase the Reactive Power (ql).
- Step –25 : Increase pl & ql till $\Delta I(jj)$ is positive.
- Step –26 : Print “Results”
- Step –27 : Stop .

2.4 Example

The example is a 69–node radial distribution network shown in Figure 2.2. Base values are 12.66 kV and 100 MVA. Load data and line data for 69–node radial distribution network are available in [11] shown in Appendix–A (Table A1 and A2 respectively). Initially the real and reactive power losses of radial network are 224.933 and 102.129 respectively. Node 65 have the lowest voltage level i.e 0.9091 pu. The total real and reactive power load on the system are 3801.89 kW and 2692.60 MVA_r respectively.

Table 2.2 shows the branch current, maximum current rating and allowable current rating and their difference for 69 node radial distribution network [11]. Table 2.3 shows the voltage (pu) and voltage deviation (pu) and the percentage deviation of voltage for 69 node radial distribution network before network reconfiguration [11]. Table 2.4 shows Percentage Voltage Deviation w.r.t to pu Voltage of 69 Node Radial Distribution Network [11] Network Reconfiguration in Ascending Order. Table 2.5 shows voltage (pu) and voltage deviation (pu) and the percentage deviation of voltage for 69 node radial distribution network [11] in ascending order less than 1.000 before network reconfiguration. Total 32 nodes having percentage voltage deviation less than 1.000. Table 2.6 shows the real power (pl) and reactive power (ql) of 69– node distribution network [11] before network reconfiguration. The real and reactive power losses are 224.933kW and 102.129 kVAR.

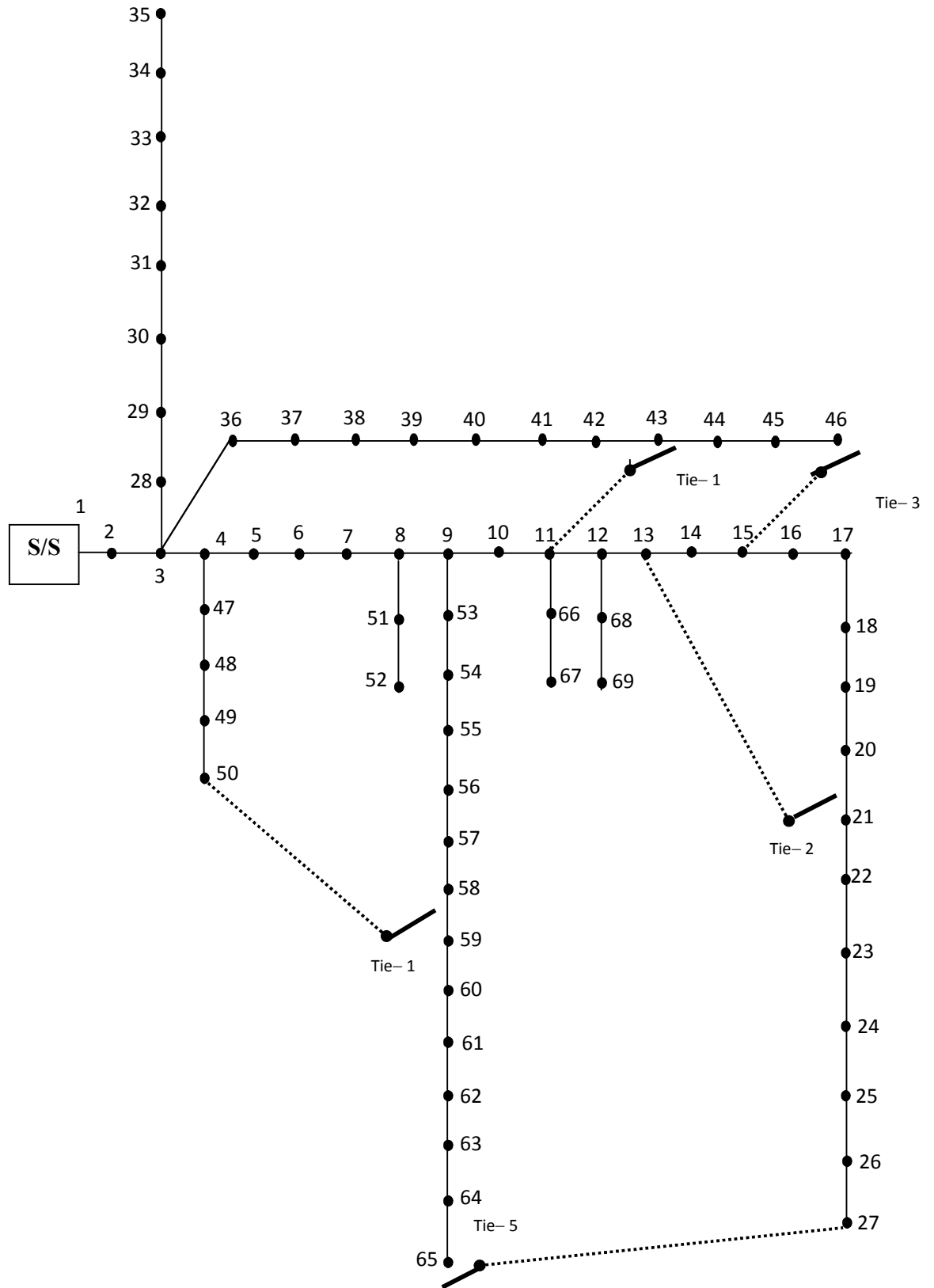


Figure 2.1 69 Node Radial Distribution Network [11]

Table 2.2 Branch Current, Maximum Current Rating and Allowable Current Rating and their difference for 69 Node Radial Distribution Network [11].

Branch Number	Branch Current	Conductor Name	Maximum Current Rating	Allowable Current Rating	Difference
1	223.53	CAT	290	246.5	22.96
2	223.53	CAT	290	246.5	22.97
3	208.09	CAT	290	246.5	38.41
4	160.35	FERRET	175	148.75	9.65
5	160.35	FERRET	175	148.75	9.65
6	160.19	FERRET	175	148.75	9.81
7	157.85	FERRET	175	148.75	12.15
8	151.03	FERRET	175	148.75	18.97
9	44.06	MOLE	70	59.5	15.44
10	42.47	MOLE	70	59.5	17.03
11	32.01	MOLE	70	59.5	27.49
12	20.37	MOLE	70	59.5	39.13
13	19.93	MOLE	70	59.5	39.57
14	19.48	MOLE	70	59.5	40.02
15	19.48	MOLE	70	59.5	40.02
16	16.89	MOLE	70	59.5	42.61
17	13.59	MOLE	70	59.5	45.91
18	10.29	MOLE	70	59.5	49.21
19	10.29	MOLE	70	59.5	49.21
20	10.24	MOLE	70	59.5	49.26
21	3.57	SQUIRREL	120	102	55.93
22	3.28	SQUIRREL	120	102	56.22
23	3.28	SQUIRREL	120	102	56.22
24	1.64	SQUIRREL	120	102	57.86
25	1.64	SQUIRREL	120	102	57.86
26	0.82	SQUIRREL	120	102	8.68
27	5.13	SQUIRREL	120	102	4.37
28	3.67	SQUIRREL	120	102	55.83
29	2.21	SQUIRREL	120	102	57.29
30	2.21	SQUIRREL	120	102	57.29
31	2.21	SQUIRREL	120	102	57.29
32	2.21	SQUIRREL	120	102	57.29
33	1.42	MOLE	70	59.5	58.08
34	0.33	MOLE	70	59.5	59.17
35	10.32	MOLE	70	59.5	49.18

36	8.86	MOLE	70	59.5	50.64
37	7.41	MOLE	70	59.5	52.09
38	7.41	MOLE	70	59.5	52.09
39	6.06	MOLE	70	59.5	53.44
40	4.72	MOLE	70	59.5	54.78
41	4.65	MOLE	70	59.5	54.85
42	4.65	MOLE	70	59.5	54.85
43	4.31	MOLE	70	59.5	55.19
44	4.31	MOLE	70	59.5	55.19
45	2.16	MOLE	70	59.5	57.34
46	47.75	MOLE	70	59.5	11.75
47	47.75	MOLE	70	59.5	11.75
48	43.32	MOLE	70	59.5	16.18
49	21.67	MOLE	70	59.5	37.83
50	2.51	MOLE	70	59.5	56.99
51	0.21	MOLE	70	59.5	59.29
52	105.24	MOLE	70	59.5	5.26
53	104.98	MOLE	70	59.5	5.52
54	103.45	SQUIRREL	120	102	7.05
55	102.06	SQUIRREL	120	102	8.44
56	102.06	SQUIRREL	120	102	8.44
57	102.06	SQUIRREL	120	102	8.44
58	102.06	SQUIRREL	120	102	8.44
59	95.98	GOPHER	130	110.5	14.52
60	95.98	GOPHER	130	110.5	14.52
61	19.58	MOLE	70	59.5	39.92
62	17.61	SQUIRREL	70	59.5	41.89
63	17.61	MOLE	70	59.5	41.89
64	3.63	MOLE	70	59.5	55.87
65	2.09	MOLE	70	59.5	57.41
66	1.04	MOLE	70	59.5	58.46
67	3.24	MOLE	70	59.5	56.26
68	1.62	MOLE	70	59.5	57.88

Table 2.3 Voltage (pu) and Voltage Deviation (pu) and the Percentage Deviation of Voltage for 69 Node Radial Distribution Network [11]

Node Number	Pu Voltage	Deviation	% Deviation
2	0.999967	0.000033	0.003350
3	0.999933	0.000067	0.006700
4	0.999839	0.000161	0.016054
5	0.999021	0.000979	0.098038
6	0.990087	0.009913	1.001204
7	0.980796	0.019204	1.958041
8	0.978580	0.021420	2.188880
9	0.977447	0.022553	2.307353
10	0.972450	0.027550	2.833042
11	0.971349	0.028651	2.949578
12	0.968191	0.031809	3.285434
13	0.965269	0.034731	3.598036
14	0.962373	0.037627	3.909781
15	0.959505	0.040495	4.220364
16	0.958972	0.041028	4.278282
17	0.958093	0.041907	4.374048
18	0.958084	0.041916	4.375016
19	0.957619	0.042381	4.425637
20	0.957321	0.042679	4.458171
21	0.956839	0.043161	4.510748
22	0.956833	0.043167	4.511497
23	0.956761	0.043239	4.519349
24	0.956604	0.043396	4.536431
25	0.956435	0.043565	4.554914
26	0.956365	0.043635	4.562538
27	0.956346	0.043654	4.564675
28	0.999926	0.000074	0.007392
29	0.999854	0.000146	0.014564
30	0.999733	0.000267	0.026680
31	0.999712	0.000288	0.028821
32	0.999605	0.000395	0.039516
33	0.999349	0.000651	0.065161
34	0.999013	0.000987	0.098767

35	0.998946	0.001054	0.105522
36	0.999919	0.000081	0.008083
37	0.999747	0.000253	0.025273
38	0.999589	0.000411	0.041138
39	0.999543	0.000457	0.045720
40	0.999541	0.000459	0.045941
41	0.998843	0.001157	0.115821
42	0.998551	0.001449	0.145133
43	0.998512	0.001488	0.149007
44	0.998504	0.001496	0.149844
45	0.998405	0.001595	0.159727
46	0.998405	0.001595	0.159769
47	0.999789	0.000211	0.021057
48	0.998545	0.001455	0.145719
49	0.994704	0.005296	0.532371
50	0.994160	0.005840	0.587413
51	0.978545	0.021455	2.192584
52	0.978535	0.021465	2.193579
53	0.974660	0.025340	2.599833
54	0.971418	0.028582	2.942345
55	0.966944	0.033056	3.418588
56	0.962576	0.037424	3.887942
57	0.940102	0.059898	6.371445
58	0.929042	0.070958	7.637714
59	0.924765	0.075235	8.135610
60	0.919740	0.080260	8.726341
61	0.912343	0.087657	9.607868
62	0.912054	0.087946	9.642673
63	0.911666	0.088334	9.689304
64	0.909766	0.090234	9.918408
65	0.909191	0.090809	9.987839
66	0.971293	0.028707	2.955586
67	0.971292	0.028708	2.955655
68	0.967861	0.032139	3.320647
69	0.967860	0.032140	3.320762

Table 2.4 Voltage (pu) and Voltage Deviation (pu) and the Percentage Deviation of Voltage for 69 Node Radial Distribution Network [11] in Ascending Order.

NODE NUMBER	% VOLTAGE DEVIATION	NODE NUMBER	%VOLTAGE DEVIATION	NODE NUMBER	% VOLTAGE DEVIATION
2	0.003308	55	0.386709	23	3.184032
3	0.006617	56	0.386709	24	3.294884
28	0.007308	10	0.497600	25	3.517444
4	0.013586	11	0.524161	26	3.609520
29	0.014480	66	0.529762	64	4.220474
36	0.014736	67	0.529829	63	4.242426
30	0.026597	41	1.119570	62	4.246902
5	0.026799	49	1.472454	57	4.277148
47	0.026984	42	1.475369	58	4.277148
31	0.028738	43	1.522559	59	4.277148
32	0.039432	44	1.533464	60	4.696609
33	0.065077	45	1.662765	61	5.320424
34	0.098683	46	1.663812		
35	0.105438	50	1.734405		
37	0.129826	15	2.457332		
6	0.169935	16	2.565417		
38	0.254089	14	2.649205		
39	0.290011	17	2.757833		
40	0.292091	18	2.760036		
7	0.318519	13	2.832267		
8	0.351306	19	2.897133		
51	0.354811	20	2.985371		
52	0.355754	12	3.006566		
48	0.361241	68	3.041494		
9	0.363792	69	3.041608		
53	0.372024	21	3.128648		
54	0.380840	22	3.133175		

Table 2.5 Voltage (pu) and Voltage Deviation (pu) and the Percentage Deviation of Voltage for 69 Node Radial Distribution Network [11] in Ascending Order Less than 1.000 Before Network Reconfiguration.

NODE NUMBER	% VOLTAGE DEVIATION	NODE NUMBER	% VOLTAGE DEVIATION
2	0.003308	55	0.386709
3	0.006617	56	0.386709
28	0.007308	10	0.497600
4	0.013586	11	0.524161
29	0.014480	66	0.529762
36	0.014736		
30	0.026597		
5	0.026799		
47	0.026984		
31	0.028738		
32	0.039432		
33	0.065077		
34	0.098683		
35	0.105438		
37	0.129826		
6	0.169935		
38	0.254089		
39	0.290011		
40	0.292091		
7	0.318519		
8	0.351306		
51	0.354811		
52	0.355754		
48	0.361241		
9	0.363792		
53	0.372024		
54	0.380840		

Table 2.6 Real Power (PL) and Reactive Power (QL) Of 69– Node Distribution Network [11] Before Network Reconfiguration.

Node Number	Real Load(PI) Increase (kW)	Reactive Load(QI) Increase(kVAR)
2	0.000	0.000
3	0.000	0.000
28	42.120	30.132
4	0.000	0.000
29	42.120	30.132
36	42.120	30.051
30	0.000	0.000
5	0.000	0.000
47	0.000	0.000
31	0.000	0.000
32	0.000	0.000
33	22.680	16.200
34	31.590	22.680
35	9.720	6.480
37	42.120	30.051
6	4.212	3.564
38	0.000	0.000
39	38.880	27.540
40	38.880	27.540
7	65.448	48.600
8	121.500	87.480
51	65.610	45.846
52	5.832	4.374
48	127.980	91.368
9	48.600	35.640
53	7.047	5.670
54	42.768	30.780

The table 2.7 shows branch current, maximum current rating and allowable current rating and their difference for 69 node radial distribution network [11] after network reconfiguration. the maximum current is at branch 1 having current 219.0057A. Table 2.8 shows voltage (pu) and voltage deviation (pu) and the percentage deviation of voltage for 69 node radial distribution network [11] after network reconfiguration node number 2 have minimum voltage deviation i.e 0.003308. Table 2.9 shows voltage (pu) and voltage deviation (pu) and the percentage deviation of voltage for 69 node radial distribution network [11] in ascending order after network reconfiguration. Table 2.10 shows percentage voltage deviation w.r.t pu voltage of 69 node radial distribution network [11] in ascending order for percentage voltage deviation less than 1.000 after network reconfiguration total 28 nodes have percentage voltage deviation less than 1. Table 2.11 shows increase in real power (pl) and reactive power (ql) of 69 node distribution network [11] after network reconfiguration. Total real and reactive power losses are 104.939 kW and 99.059 kVAR respectively. Total real and reactive power loading is 3801.890 kW and 2693.599 kVAR.

The table 2.12 shows branch current, maximum current rating and allowable current rating and their difference for 69 node radial distribution network [11] after network reconfiguration. the maximum current is at branch 1 having current 244.880A. Table 2.13 shows voltage (pu) and voltage deviation (pu) and the percentage deviation of voltage for 69 node radial distribution network [11] after network reconfiguration node number 2 have minimum voltage deviation i.e 0.003696 . Table 2.14 shows voltage (pu) and voltage deviation (pu) and the percentage deviation of voltage for 69 node radial distribution network [11] in ascending order after network reconfiguration. Table 2.15 shows percentage voltage deviation w.r.t pu voltage of 69 node radial distribution network [11] in ascending order for percentage voltage deviation less than 1.000 after network reconfiguration total 31 nodes have percentage voltage deviation less than 1.000. Table 2.16 shows increase in real power (pl) and reactive power (ql) of 69 node distribution network [11] after network reconfiguration. Total real and reactive power losses are 152.638 kW and 110.348 kVAR respectively. Total real and reactive power loading is 4226.186 kW and 2997.647 kVAR.

The table 2.17 shows branch current, maximum current rating and allowable current rating and their difference for 69 node radial distribution network [11] after network reconfiguration. the maximum current is at branch 1 having current 219.006A. Table 2.18 shows voltage (pu) and voltage deviation (pu) and the percentage deviation of voltage for 69 node radial distribution network [11] after network reconfiguration node number 2 have minimum voltage deviation i.e 0.003308 . Table 2.19 shows voltage (pu) and voltage deviation (pu) and the percentage deviation of voltage for 69 node radial distribution network [11] in ascending order after network reconfiguration. Table 2.20 shows percentage voltage deviation w.r.t pu voltage of 69 node radial distribution network [11] in ascending order for percentage voltage deviation less than 1.000 after network reconfiguration total 32 nodes have percentage voltage deviation less than 1.000. Table 2.21 shows increase in real power (pl) and reactive power (ql) of 69 node distribution network [11] after network reconfiguration. Total real and reactive power losses are 104.939 kW and 99.059kVAR respectively. Total real and reactive power loading is 4226.186 kW and 2997.647 kVAR.

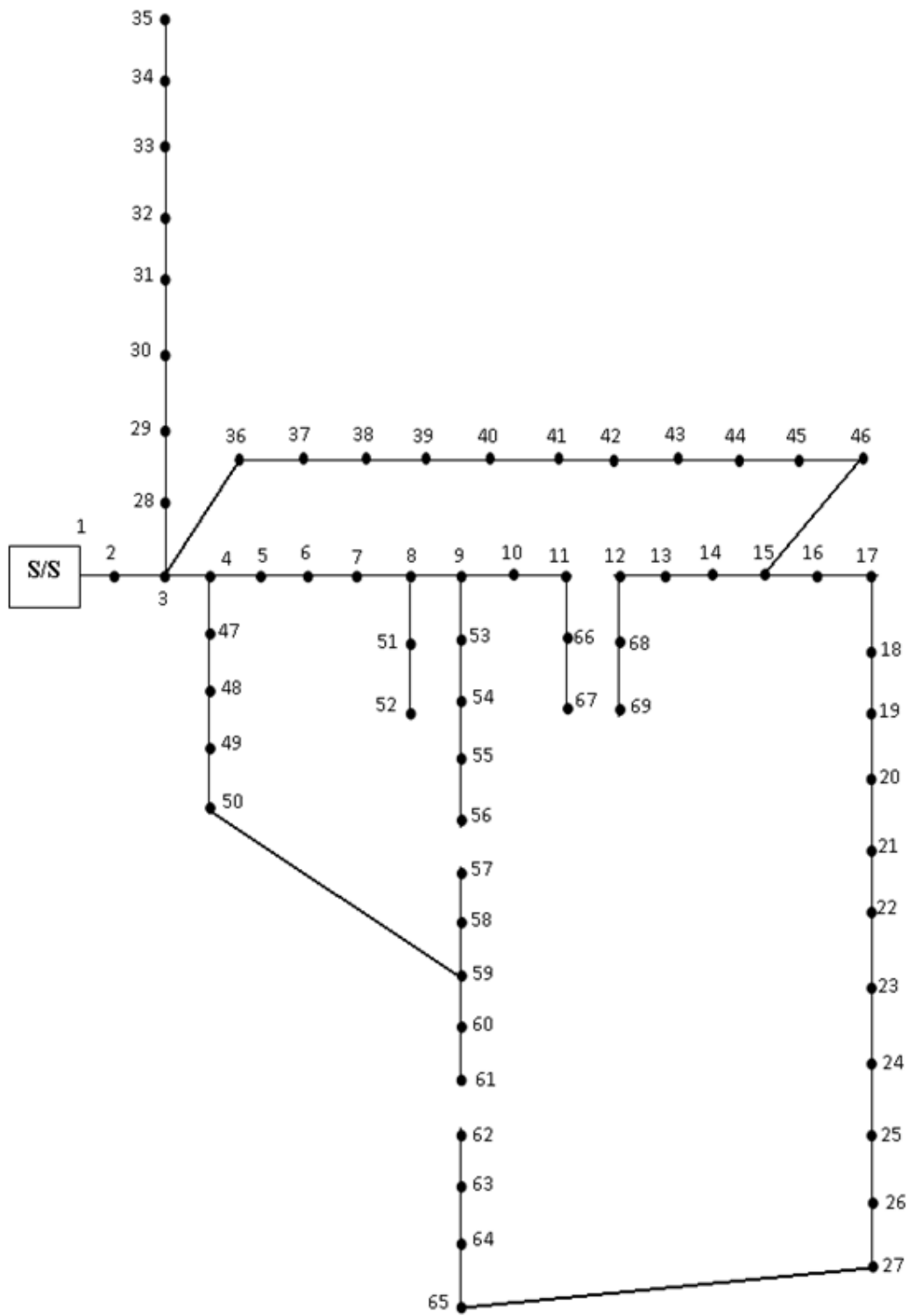


Figure 2.2 Reconfigured 69 Node Radial Distribution Network [11]

Table 2.7 Branch Current, Maximum Current Rating and Allowable Current Rating and their difference for 69 Node Radial Distribution Network [11] after Network Reconfiguration

Branch Number	Branch Current	Conductor Name	Maximum Current Rating	Allowable Current Rating	Difference
1	219.0057	CAT	290	246.5	27.4943
2	219.0057	CAT	290	246.5	27.4943
3	153.1999	CAT	290	246.5	93.3001
4	25.7184	MOLE	70	59.5	33.7816
5	25.7184	MOLE	70	59.5	33.7816
6	25.5633	MOLE	70	59.5	33.9367
7	23.2614	MOLE	70	59.5	36.2386
8	16.5651	MOLE	70	59.5	42.9349
9	11.7665	MOLE	70	59.5	47.7335
10	10.2162	MOLE	70	59.5	49.2838
11	2.0359	MOLE	70	59.5	57.4641
12	1.0179	MOLE	70	59.5	58.4821
13	5.1261	MOLE	70	59.5	54.3739
14	3.6681	MOLE	70	59.5	55.8319
15	2.2100	MOLE	70	59.5	57.2900
16	2.2100	MOLE	70	59.5	57.2900
17	2.2100	MOLE	70	59.5	57.2900
18	2.2100	MOLE	70	59.5	57.2900
19	1.4249	MOLE	70	59.5	58.0751
20	0.3292	MOLE	70	59.5	59.1708
21	60.6870	SQUIRREL	120	102	41.3130
22	59.2304	MOLE	70	59.5	0.2696
23	57.7721	MOLE	70	59.5	1.7279
24	57.7721	MOLE	70	59.5	1.7279
25	56.4270	MOLE	70	59.5	3.0730
26	55.0819	MOLE	70	59.5	4.4181
27	55.0102	MOLE	70	59.5	4.4898
28	55.0102	MOLE	70	59.5	4.4898
29	54.6685	MOLE	70	59.5	4.8315
30	54.6685	MOLE	70	59.5	4.8315
31	52.4793	MOLE	70	59.5	7.0207
32	50.2901	MOLE	70	59.5	9.2099
33	37.7662	MOLE	70	59.5	21.7338

34	35.2174	MOLE	70	59.5	24.2826
35	31.9716	MOLE	70	59.5	27.5284
36	28.7278	MOLE	70	59.5	30.7722
37	28.7278	MOLE	70	59.5	30.7722
38	28.6732	MOLE	70	59.5	30.8268
39	22.0961	MOLE	70	59.5	37.4039
40	21.8090	MOLE	70	59.5	37.6910
41	21.8090	MOLE	70	59.5	37.6910
42	20.1881	MOLE	70	59.5	39.3119
43	20.1881	MOLE	70	59.5	39.3119
44	19.3752	MOLE	70	59.5	40.1248
45	18.5619	MOLE	70	59.5	40.9381
46	15.1283	MOLE	70	59.5	44.3717
47	1.8735	MOLE	70	59.5	57.6265
48	1.8735	MOLE	70	59.5	57.6265
49	12.5258	MOLE	70	59.5	46.9742
50	12.0714	MOLE	70	59.5	47.4286
51	11.6162	MOLE	70	59.5	47.8838
52	3.2339	MOLE	70	59.5	56.2661
53	1.6169	MOLE	70	59.5	57.8831
54	127.4816	FERRET	175	148.75	21.2684
55	127.4816	FERRET	175	148.75	21.2684
56	123.0390	FERRET	175	148.75	25.7110
57	101.1829	GOPHER	130	110.5	9.3171
58	79.2705	SQUIRREL	120	102	22.7295
59	110.5000	GOPHER	130	110.5	0.9590
60	110.5000	GOPHER	130	110.5	0.9590
61	73.4108	SQUIRREL	120	102	28.5892
62	73.4108	SQUIRREL	120	102	28.5892
63	2.4670	MOLE	70	59.5	57.0330
64	0.2059	MOLE	70	59.5	59.2941
65	3.0960	MOLE	70	59.5	56.4040
66	2.8407	MOLE	70	59.5	56.6593
67	1.3518	MOLE	70	59.5	58.1482
68	59.5000	MOLE	70	59.5	0.9961

Table 2.8 Voltage (pu) and Voltage Deviation (pu) and the Percentage Deviation of Voltage for 69 Node Radial Distribution Network [11] after Network Reconfiguration

Node Number	Pu Voltage	Deviation	% Deviation
2	1.0000	0.0000	0.0033
3	0.9999	0.0001	0.0066
4	0.9999	0.0001	0.0136
5	0.9997	0.0003	0.0268
6	0.9983	0.0017	0.1699
7	0.9968	0.0032	0.3185
8	0.9965	0.0035	0.3513
9	0.9964	0.0036	0.3638
10	0.9950	0.0050	0.4976
11	0.9948	0.0052	0.5242
12	0.9947	0.0053	0.5298
13	0.9947	0.0053	0.5298
14	0.9999	0.0001	0.0073
15	0.9999	0.0001	0.0145
16	0.9997	0.0003	0.0266
17	0.9997	0.0003	0.0287
18	0.9996	0.0004	0.0394
19	0.9993	0.0006	0.0651
20	0.9990	0.0010	0.0987
21	0.9989	0.0011	0.1054
22	0.9999	0.0001	0.0147
23	0.9987	0.0013	0.1298
24	0.9975	0.0025	0.2541
25	0.9971	0.0029	0.2900
26	0.9971	0.0029	0.2921
27	0.9889	0.0111	1.1196
28	0.9855	0.0145	1.4754
29	0.9850	0.0150	1.5226
30	0.9849	0.0151	1.5335
31	0.9836	0.0164	1.6628
32	0.9836	0.0164	1.6638
33	0.9760	0.0240	2.4573

34	0.9750	0.0250	2.5654
35	0.9732	0.0268	2.7578
36	0.9731	0.0269	2.7600
37	0.9718	0.0282	2.8971
38	0.9710	0.0290	2.9854
39	0.9697	0.0303	3.1286
40	0.9696	0.0304	3.1332
41	0.9691	0.0309	3.1840
42	0.9681	0.0319	3.2949
43	0.9660	0.0340	3.5174
44	0.9652	0.0348	3.6095
45	0.9647	0.0353	3.6591
46	0.9619	0.0381	3.9614
47	0.9595	0.0405	4.2205
48	0.9593	0.0407	4.2424
49	0.9593	0.0407	4.2469
50	0.9742	0.0258	2.6492
51	0.9725	0.0275	2.8323
52	0.9708	0.0292	3.0066
53	0.9705	0.0295	3.0415
54	0.9705	0.0295	3.0416
55	0.9997	0.0003	0.0270
56	0.9964	0.0036	0.3612
57	0.9855	0.0145	1.4725
58	0.9830	0.0170	1.7344
59	0.9590	0.0410	4.2771
60	0.0410	4.2771	0.0000
61	0.0410	4.2771	0.0000
62	0.9551	0.0449	4.6966
63	0.9495	0.0505	5.3204
64	0.9965	0.0035	0.3548
65	0.9965	0.0035	0.3558
66	0.9963	0.0037	0.3720
67	0.9962	0.0038	0.3808
68	0.9961	0.0039	0.3867
69	0.0039	0.3867	0.0000

Table 2.9 Voltage (pu) and Voltage Deviation (pu) and the Percentage Deviation of Voltage for 69 Node Radial Distribution Network [11] in Ascending Order after Network Reconfiguration.

NODE NUMBER	% VOLTAGE DEVIATION	NODE NUMBER	%VOLTAGE DEVIATION	NODE NUMBER	% VOLTAGE DEVIATION
2	0.003308	55	0.386709	23	3.184032
3	0.006617	56	0.386709	24	3.294884
28	0.007308	10	0.497600	25	3.517444
4	0.013586	11	0.524161	26	3.609520
29	0.014480	66	0.529762	64	4.220474
36	0.014736	67	0.529829	63	4.242426
30	0.026597	41	1.119570	62	4.246902
5	0.026799	49	1.472454	57	4.277148
47	0.026984	42	1.475369	58	4.277148
31	0.028738	43	1.522559	59	4.277148
32	0.039432	44	1.533464	60	4.696609
33	0.065077	45	1.662765	61	5.320424
34	0.098683	46	1.663812		
35	0.105438	50	1.734405		
37	0.129826	15	2.457332		
6	0.169935	16	2.565417		
38	0.254089	14	2.649205		
39	0.290011	17	2.757833		
40	0.292091	18	2.760036		
7	0.318519	13	2.832267		
8	0.351306	19	2.897133		
51	0.354811	20	2.985371		
52	0.355754	12	3.006566		
48	0.361241	68	3.041494		
9	0.363792	69	3.041608		
53	0.372024	21	3.128648		
54	0.380840	22	3.133175		

Table 2.10 Percentage Voltage Deviation w.r.t pu Voltage of 69 Node Radial Distribution Network [11] in Ascending Order for % Deviation Less than 1.000 After Network Reconfiguration

NODE NUMBER	% VOLTAGE DEVIATION	NODE NUMBER	% VOLTAGE DEVIATION
2	0.003308	55	0.386709
3	0.006617	56	0.386709
28	0.007308	10	0.497600
4	0.013586	11	0.524161
29	0.014480	66	0.529762
36	0.014736		
30	0.026597		
5	0.026799		
47	0.026984		
31	0.028738		
32	0.039432		
33	0.065077		
34	0.098683		
35	0.105438		
37	0.129826		
6	0.169935		
38	0.254089		
39	0.290011		
40	0.292091		
7	0.318519		
8	0.351306		
51	0.354811		
52	0.355754		
48	0.361241		
9	0.363792		
53	0.372024		
54	0.380840		

Table 2.11 Increase in Real Power (PL) and Reactive Power (QL) of 69 Node Distribution Network [11] After Network Reconfiguration.

Node Number	Real Load (PL) Increase(KW)	Reactive Load (QL) Increase(KVAR)
2	0.000000	0.000000
3	0.000000	0.000000
28	42.120001	30.132002
4	0.000000	0.000000
29	42.120001	30.132002
36	42.120001	30.050997
30	0.000000	0.000000
5	0.000000	0.000000
47	0.000000	0.000000
31	0.000000	0.000000
32	0.000000	0.000000
33	22.680001	16.200000
34	31.589999	22.680001
35	9.720000	6.480000
37	42.120001	30.050997
6	4.212000	3.564000
38	0.000000	0.000000
39	38.879999	27.540000
40	38.879999	27.540000
7	65.448001	48.600003
8	121.500005	87.479997
51	65.609999	45.846001
52	5.831999	4.374000
48	127.980008	91.368001
9	48.600003	35.640001
53	7.047000	5.670000
54	42.768000	30.780002
55	0.000000	0.000000
56	0.000000	0.000000
10	45.360002	30.780002
11	234.899996	168.480002
66	29.160001	21.060000

Table 2.12 Branch Current, Maximum Current Rating and Allowable Current Rating and their difference for 69 Node Radial Distribution Network [11] After Network Reconfiguration

Branch Number	Branch Current	Conductor Name	Maximum Current Rating	Allowable Current Rating	Difference
1	244.880585	CAT	290	246.5	1.619415
2	244.880585	CAT	290	246.5	1.619415
3	142.369858	CAT	290	246.5	104.130142
4	60.195580	FERRET	175	148.75	88.55442
5	60.195580	FERRET	175	148.75	88.55442
6	59.943829	FERRET	175	148.75	88.806171
7	56.199608	MOLE	70	59.5	113.800392
8	33.161572	MOLE	70	59.5	136.838425
9	24.548611	MOLE	70	59.5	34.951389
10	22.021473	MOLE	70	59.5	37.478527
11	8.683351	MOLE	70	59.5	50.816650
12	0.448055	MOLE	70	59.5	59.051945
13	15.729753	MOLE	70	59.5	43.770248
14	15.287145	MOLE	70	59.5	44.212856
15	15.287145	MOLE	70	59.5	44.212856
16	12.798759	MOLE	70	59.5	46.701241
17	9.630812	MOLE	70	59.5	49.869186
18	6.465467	MOLE	70	59.5	53.034531
19	6.465467	MOLE	70	59.5	53.034531
20	6.412222	MOLE	70	59.5	53.087776
21	86.796112	SQUIRREL	120	102	15.203888
22	86.517731	SQUIRREL	120	102	15.482269
23	86.517731	SQUIRREL	120	102	15.482269
24	84.942635	SQUIRREL	120	102	17.057365
25	84.942635	SQUIRREL	120	102	17.057365
26	84.154648	SQUIRREL	120	102	17.845352
27	83.356644	SQUIRREL	120	102	18.643356
28	80.941666	SQUIRREL	120	102	21.058334
29	78.525032	SQUIRREL	120	102	23.474968
30	78.525032	SQUIRREL	120	102	23.474968
31	78.525032	SQUIRREL	120	102	23.474968
32	78.525032	SQUIRREL	120	102	23.474968
33	47.651665	MOLE	70	59.5	11.848335
34	45.808495	MOLE	70	59.5	13.691505
35	45.253544	MOLE	70	59.5	14.246456

36	42.794975	MOLE	70	59.5	16.705025
37	40.331440	MOLE	70	59.5	19.168560
38	40.331440	MOLE	70	59.5	19.168560
39	38.055546	MOLE	70	59.5	21.444454
40	35.779480	MOLE	70	59.5	23.720520
41	35.705059	MOLE	70	59.5	23.794941
42	35.705059	MOLE	70	59.5	23.794941
43	35.350140	MOLE	70	59.5	24.149860
44	35.350140	MOLE	70	59.5	24.149860
45	33.074593	MOLE	70	59.5	26.425407
46	30.787104	MOLE	70	59.5	28.712896
47	30.787104	MOLE	70	59.5	28.712896
48	23.100302	MOLE	70	59.5	36.399696
49	29.554586	MOLE	70	59.5	29.945414
50	7.097080	MOLE	70	59.5	52.402920
51	3.287634	MOLE	70	59.5	56.212368
52	2.940487	MOLE	70	59.5	107.559509
53	2.510144	MOLE	70	59.5	107.989853
54	82.174271	SQUIRREL	120	102	20.825729
55	80.827415	SQUIRREL	120	102	21.172585
56	80.827415	SQUIRREL	120	102	21.172585
57	80.827415	SQUIRREL	120	102	21.172585
58	80.827415	SQUIRREL	120	102	21.172585
59	73.134209	GOPHER	130	110.5	37.365791
60	73.134209	GOPHER	130	110.5	37.365791
61	1.864372	MOLE	70	59.5	57.635628
62	0.000000	SQUIRREL	70	59.5	59.500000
63	16.154993	MOLE	70	59.5	43.345009
64	3.330841	MOLE	70	59.5	56.169159
65	5.841801	MOLE	70	59.5	53.658199
66	4.187454	MOLE	70	59.5	55.312546
67	3.166123	MOLE	70	59.5	56.333878
68	1.583116	MOLE	70	59.5	57.916885

Table 2.13 Voltage (pu) and Voltage Deviation (pu) and the Percentage Deviation of Voltage for 69 Node Radial Distribution Network [11] after Network Reconfiguration.

Node Number	Pu Voltage	Deviation	% Deviation
2	0.999963	0.000037	0.003696
3	0.999926	0.000074	0.007392
4	0.999862	0.000138	0.013848
5	0.999553	0.000447	0.044765
6	0.996208	0.003792	0.380648
7	0.992740	0.007260	0.731318
8	0.991953	0.008047	0.811226
9	0.991705	0.008295	0.836456
10	0.988937	0.011063	1.118716
11	0.988369	0.011631	1.176740
12	0.988133	0.011867	1.200969
13	0.988133	0.011867	1.200999
14	0.999906	0.000094	0.009448
15	0.999615	0.000385	0.038472
16	0.998767	0.001233	0.123415
17	0.998642	0.001358	0.135982
18	0.998172	0.001828	0.183106
19	0.997423	0.002577	0.258396
20	0.995901	0.004099	0.411558
21	0.994599	0.005401	0.542986
22	0.999809	0.000191	0.019095
23	0.998118	0.001882	0.188574
24	0.996258	0.003742	0.375555
25	0.995732	0.004268	0.428671
26	0.995700	0.004300	0.431815
27	0.983197	0.016803	1.709013
28	0.977928	0.022072	2.257031
29	0.977252	0.022748	2.327745
30	0.977100	0.022900	2.343712
31	0.975295	0.024705	2.533104
32	0.975279	0.024721	2.534721
33	0.963401	0.036599	3.798987

34	0.962107	0.037893	3.938504
35	0.959740	0.040260	4.194888
36	0.959710	0.040290	4.198091
37	0.957776	0.042224	4.408591
38	0.956604	0.043396	4.536425
39	0.954703	0.045297	4.744587
40	0.954630	0.045370	4.752645
41	0.953844	0.046156	4.838912
42	0.952138	0.047862	5.026785
43	0.948450	0.051550	5.435194
44	0.946944	0.053056	5.602879
45	0.946100	0.053900	5.697106
46	0.941099	0.058901	6.258768
47	0.936231	0.063769	6.811211
48	0.932909	0.067091	7.191548
49	0.932401	0.067599	7.250012
50	0.959095	0.040905	4.264913
51	0.958076	0.041924	4.375873
52	0.957612	0.042388	4.426449
53	0.957314	0.042686	4.458965
54	0.957312	0.042688	4.459141
55	0.999776	0.000224	0.022452
56	0.997671	0.002329	0.233401
57	0.990521	0.009479	0.956970
58	0.988497	0.011503	1.163702
59	0.964053	0.035947	3.728695
60	0.960988	0.039012	4.059528
61	0.953074	0.046926	4.923616
62	0.963956	0.036044	3.739175
63	0.963956	0.036044	3.739175
64	0.991725	0.008275	0.834372
65	0.991573	0.008427	0.849895
66	0.991551	0.008449	0.852150
67	0.991422	0.008578	0.865271
68	0.991285	0.008715	0.879171
69	0.991217	0.008783	0.886056

Table 2.14 Voltage (pu) and Voltage Deviation (pu) and the Percentage Deviation of Voltage for 69 Node Radial Distribution Network [11] in Ascending Order after Network Reconfiguration.

Node Number	% Voltage Deviation	Node Number	% Voltage Deviation	Node Number	% Voltage Deviation
2	0.003696	55	0.879171	12	4.426449
3	0.007392	56	0.886056	68	4.458965
28	0.009448	49	0.956970	69	4.459141
4	0.013848	10	1.118716	20	4.536425
29	0.019095	50	1.163702	21	4.744587
36	0.022452	11	1.176740	22	4.752645
30	0.038472	66	1.200969	23	4.838912
5	0.044765	67	1.200999	57	4.923616
47	0.123415	41	1.709013	24	5.026785
31	0.135982	42	2.257031	25	5.435194
32	0.183106	43	2.327745	26	5.602879
33	0.188574	44	2.343712	27	5.697106
34	0.233401	45	2.533104	65	6.258768
35	0.258396	46	2.534721	64	6.811211
37	0.375555	59	3.728695	63	7.191548
6	0.380648	60	3.739175	62	7.250012
38	0.411558	61	3.739175		
39	0.428671	60	3.739175		
40	0.431815	61	3.739175		
7	0.542986	15	3.798987		
8	0.731318	16	3.938504		
51	0.811226	58	4.059528		
52	0.834372	17	4.194888		
48	0.836456	18	4.198091		
9	0.849895	14	4.264913		
53	0.852150	13	4.375873		
54	0.865271	19	4.408591		

Table 2.15 Voltage (pu) and Voltage Deviation (pu) and the Percentage Deviation of Voltage for 69 Node Radial Distribution Network [11] in Ascending Order Less than 1.000 after Network Reconfiguration.

NODE NUMBER	% VOLTAGE DEVIATION	NODE NUMBER	% VOLTAGE DEVIATION
2	0.003308	55	0.386709
3	0.006617	56	0.386709
28	0.007308	10	0.497600
4	0.013586	11	0.524161
29	0.014480	66	0.529762
36	0.014736		
30	0.026597		
5	0.026799		
47	0.026984		
31	0.028738		
32	0.039432		
33	0.065077		
34	0.098683		
35	0.105438		
37	0.129826		
6	0.169935		
38	0.254089		
39	0.290011		
40	0.292091		
7	0.318519		
8	0.351306		
51	0.354811		
52	0.355754		
48	0.361241		
9	0.363792		
53	0.372024		
54	0.380840		

Table 2.16 Increase in Real Power (PL) and Reactive Power (QL) Of 69– Node Distribution Network [11] after Network Reconfiguration.

Node Number	Real Load(PL) Increase (kW)	Reactive Load(QL) Increase(kVAR)
2	0.000	0.000
3	0.000	0.000
28	42.120	30.132
4	0.000	0.000
29	42.120	30.132
36	42.120	30.051
30	0.000	0.000
5	0.000	0.000
47	0.000	0.000
31	0.000	0.000
32	0.000	0.000
33	22.680	16.200
34	31.590	22.680
35	9.720	6.480
37	42.120	30.051
6	4.212	3.564
38	0.000	0.000
39	38.880	27.540
40	38.880	27.540
7	65.448	48.600
8	121.500	87.480
51	65.610	45.846
52	5.832	4.374
48	127.980	91.368
9	48.600	35.640
53	7.047	5.670
54	42.768	30.780

Table 2.17 Branch Current, Maximum Current Rating and Allowable Current Rating and their difference for 69 Node Radial Distribution Network after Network Reconfiguration [11].

Branch Number	Branch Current	Conductor Name	Maximum Current Rating	Allowable Current Rating	Difference
1	219.006	CAT	290	246.5	27.494
2	219.006	CAT	290	246.5	27.494
3	153.200	CAT	290	246.5	93.300
4	25.718	MOLE	70	59.5	33.782
5	25.718	MOLE	70	59.5	33.782
6	25.563	MOLE	70	59.5	33.937
7	23.261	MOLE	70	59.5	36.239
8	16.565	MOLE	70	59.5	42.935
9	11.767	MOLE	70	59.5	47.733
10	10.216	MOLE	70	59.5	49.284
11	2.036	MOLE	70	59.5	57.464
12	1.018	MOLE	70	59.5	58.482
13	5.126	MOLE	70	59.5	54.374
14	3.668	MOLE	70	59.5	55.832
15	2.210	MOLE	70	59.5	57.290
16	2.210	MOLE	70	59.5	57.290
17	2.210	MOLE	70	59.5	57.290
18	2.210	MOLE	70	59.5	57.290
19	1.425	MOLE	70	59.5	58.075
20	0.329	MOLE	70	59.5	59.171
21	60.687	SQUIRREL	120	102	41.313
22	59.230	MOLE	70	59.5	0.270
23	57.772	MOLE	70	59.5	1.728
24	57.772	MOLE	70	59.5	1.728
25	56.427	MOLE	70	59.5	3.073
26	55.082	MOLE	70	59.5	4.418
27	55.010	MOLE	70	59.5	4.490
28	55.010	MOLE	70	59.5	4.490
29	54.668	MOLE	70	59.5	4.832
30	54.668	MOLE	70	59.5	4.832
31	52.479	MOLE	70	59.5	7.021
32	50.290	MOLE	70	59.5	9.210

33	37.766	MOLE	70	59.5	21.734
34	35.217	MOLE	70	59.5	24.283
35	31.972	MOLE	70	59.5	27.528
36	28.728	MOLE	70	59.5	30.772
37	28.728	MOLE	70	59.5	30.772
38	28.673	MOLE	70	59.5	30.827
39	22.096	MOLE	70	59.5	37.404
40	21.809	MOLE	70	59.5	37.691
41	21.809	MOLE	70	59.5	37.691
42	20.188	MOLE	70	59.5	39.312
43	20.188	MOLE	70	59.5	39.312
44	19.375	MOLE	70	59.5	40.125
45	18.562	MOLE	70	59.5	40.938
46	15.128	MOLE	70	59.5	44.372
47	1.874	MOLE	70	59.5	57.626
48	1.874	MOLE	70	59.5	57.626
49	12.526	MOLE	70	59.5	46.974
50	12.071	MOLE	70	59.5	47.429
51	11.616	MOLE	70	59.5	47.884
52	3.234	MOLE	70	59.5	107.266
53	1.617	MOLE	70	59.5	108.883
54	127.482	FERRET	175	148.75	21.268
55	127.482	FERRET	175	148.75	21.268
56	123.039	FERRET	175	148.75	25.711
57	101.183	GOPHER	130	110.5	9.317
58	79.270	GOPHER	130	110.5	31.230
59	0.000	GOPHER	130	110.5	110.500
60	0.000	GOPHER	130	110.5	110.500
61	73.411	SQUIRREL	120	102	28.589
62	73.411	SQUIRREL	120	102	28.589
63	2.467	MOLE	70	59.5	57.033
64	0.206	MOLE	70	59.5	59.294
65	3.096	MOLE	70	59.5	56.404
66	2.841	MOLE	70	59.5	56.659
67	1.352	MOLE	70	59.5	58.148
68	0.000	MOLE	70	59.5	59.500

Table 2.18 Voltage (pu) and Voltage Deviation (pu) and the Percentage Deviation of Voltage for 69 Node Radial Distribution Network [11] after Network Reconfiguration.

Node Number	Pu Voltage	Voltage Deviation	% Voltage Deviation
2	0.999967	0.000033	0.003308
3	0.999934	0.000066	0.006617
4	0.999864	0.000136	0.013586
5	0.999732	0.000268	0.026799
6	0.998304	0.001696	0.169935
7	0.996825	0.003175	0.318519
8	0.996499	0.003501	0.351306
9	0.996375	0.003625	0.363792
10	0.995049	0.004951	0.497600
11	0.994786	0.005214	0.524161
12	0.994730	0.005270	0.529762
13	0.994730	0.005270	0.529829
14	0.999927	0.000073	0.007308
15	0.999855	0.000145	0.014480
16	0.999734	0.000266	0.026597
17	0.999713	0.000287	0.028738
18	0.999606	0.000394	0.039432
19	0.999350	0.000650	0.065077
20	0.999014	0.000986	0.098683
21	0.998947	0.001053	0.105438
22	0.999853	0.000147	0.014736
23	0.998703	0.001297	0.129826
24	0.997466	0.002534	0.254089
25	0.997108	0.002892	0.290011
26	0.997088	0.002912	0.292091
27	0.988928	0.011072	1.119570
28	0.985461	0.014539	1.475369
29	0.985003	0.014997	1.522559
30	0.984897	0.015103	1.533464
31	0.983644	0.016356	1.662765
32	0.983634	0.016366	1.663812
33	0.976016	0.023984	2.457332
34	0.974988	0.025012	2.565417
35	0.973162	0.026838	2.757833
36	0.973141	0.026859	2.760036

37	0.971844	0.028156	2.897133
38	0.971012	0.028988	2.985371
39	0.969663	0.030337	3.128648
40	0.969620	0.030380	3.133175
41	0.969142	0.030858	3.184032
42	0.968102	0.031898	3.294884
43	0.966021	0.033979	3.517444
44	0.965162	0.034838	3.609520
45	0.964700	0.035300	3.659126
46	0.961896	0.038104	3.961394
47	0.959504	0.040496	4.220474
48	0.959302	0.040698	4.242426
49	0.959261	0.040739	4.246902
50	0.974192	0.025808	2.649205
51	0.972457	0.027543	2.832267
52	0.970812	0.029188	3.006566
53	1 0.97048	3 0.02951	7 3.041494
54	4 0.97048	2 0.02951	8 3.041608
55	6 0.99973	0 0.00027	0 0.026984
56	0.996401	0.003599	0.361241
57	0.985489	0.014511	1.472454
58	0.982952	0.017048	1.734405
59	0.958983	0.041017	4.277148
60	0.958983	0.041017	4.277148
61	0.958983	0.041017	4.277148
62	0.955141	0.044859	4.696609
63	0.949483	0.050517	5.320424
64	0.996464	0.003536	0.354811
65	0.996455	0.003545	0.355754
66	0.996294	0.003706	0.372024
67	0.996206	0.003794	0.380840
68	0.996148	0.003852	0.386709
69	0.996148	0.003852	0.386709

Table 2.19 Voltage (pu) and Voltage Deviation (pu) and the Percentage Deviation of Voltage for 69 Node Radial Distribution Network [11] in Ascending Order after Network Reconfiguration.

Node Number	% Voltage Deviation	Node Number	% Voltage Deviation	Node Number	% Voltage Deviation
2	0.003308	55	0.386709	12	4.426449
3	0.006617	56	0.386709	68	4.458965
28	0.007308	10	0.497600	69	4.459141
4	0.013586	11	0.524161	20	4.536425
29	0.014480	66	0.529762	21	4.744587
36	0.014736	50	1.176740	22	4.752645
30	0.026597	49	1.200969	23	4.838912
5	0.026799	67	1.200999	57	4.923616
47	0.026984	41	1.709013	24	5.026785
31	0.028738	42	2.257031	25	5.435194
32	0.039432	43	2.327745	26	5.602879
33	0.065077	44	2.343712	27	5.697106
34	0.098683	45	2.533104	65	6.258768
35	0.105438	46	2.534721	64	6.811211
37	0.129826	59	3.728695	63	7.191548
6	0.169935	60	3.739175	62	7.250012
38	0.254089	61	3.739175		
39	0.290011	60	3.739175		
40	0.292091	61	3.739175		
7	0.318519	15	3.798987		
8	0.351306	16	3.938504		
51	0.354811	58	4.059528		
52	0.355754	17	4.194888		
48	0.361241	18	4.198091		
9	0.363792	14	4.264913		
53	0.372024	13	4.375873		
54	0.380840	19	4.408591		

Table 2.20 Voltage (pu) and Voltage Deviation (pu) and the Percentage Deviation of Voltage for 69 Node Radial Distribution Network [11] in Ascending Order Less than 1.000 after Network Reconfiguration.

Node Number	% Voltage Deviation	Node Number	% Voltage Deviation
2	0.003308	55	0.386709
3	0.006617	56	0.386709
28	0.007308	10	0.497600
4	0.013586	11	0.524161
29	0.014480	66	0.529762
36	0.014736		
30	0.026597		
5	0.026799		
47	0.026984		
31	0.028738		
32	0.039432		
33	0.065077		
34	0.098683		
35	0.105438		
37	0.129826		
6	0.169935		
38	0.254089		
39	0.290011		
40	0.292091		
7	0.318519		
8	0.351306		
51	0.354811		
52	0.355754		
48	0.361241		
9	0.363792		
53	0.372024		
54	0.380840		

Table 2.21 Increase in Real Power (PL) and Reactive Power (QL) Of 69– Node Distribution Network [11] After Network Reconfiguration.

Node Number	Real Load(PI) Increase (kW)	Reactive Load(QI) Increase(kVAR)
2	0.000	0.000
3	0.000	0.000
28	42.120	30.132
4	0.000	0.000
29	42.120	30.132
36	42.120	30.051
30	0.000	0.000
5	0.000	0.000
47	0.000	0.000
31	0.000	0.000
32	0.000	0.000
33	22.680	16.200
34	31.590	22.680
35	9.720	6.480
37	42.120	30.051
6	4.212	3.564
38	0.000	0.000
39	38.880	27.540
40	38.880	27.540
7	65.448	48.600
8	121.500	87.480
51	65.610	45.846
52	5.832	4.374
48	127.980	91.368
9	48.600	35.640
53	7.047	5.670
54	42.768	30.780
56	0.000	0.000
10	0.000	0.000
11	45.360	30.780
66	234.900	168.480

2.7 Final Results

Table 2.18 shows the comparison between change in real and reactive power losses before and after network reconfiguration. before network reconfiguration the solution gets converged in five iterations whereas after network reconfiguration the result gets converged in four iterations. Real and reactive power losses before and after network reconfiguration are 224.933 kW and 102.129 kVAR respectively. The result shows that real and reactive power losses are reduced after network reconfiguration.

Table 2.19 shows the comparison between Comparison of Minimum pu Voltage Level and Respective Node Number. Before network reconfiguration node number 65 have minimum voltage level with magnitude 0.909191 pu. After network reconfiguration node number 61 have minimum voltage level with magnitude 0.949483 pu. The results shows that their is an improvement in voltage profile of the radial distribution network.

Table 2.20 shows the Comparison between Total Real and Reactive Power Load before and after network reconfiguration. According to results the reconfigured network takes less iterations to get converged i.e four instead of five. Results shows that their is an increase in total real and reactive power load in the network, the real and reactive power load before network reconfiguration is 3801.890090 kW and 2692.599781kVAR. The real and reactive power load after network reconfiguration is 4226.187244 kW and 2997.647785 kVAR.

Table 2.22 Comparison of Real and Reactive Power Losses

	Number of Iterations	Real Power Loss (kW)	Reactive Power Loss(kVAR)
Before Network Reconfiguration	5	224.933	102.129
After Network Reconfiguration	4	104.939	99.059
	4	152.638	110.348
	4	104.939	99.059

Table 2.23 Comparison of Minimum pu Voltage Level and Respective Node Number

	Number of Iterations	Branch Number	Voltage Level (pu)
Before Network Reconfiguration	5	65	0.909191
After Network Reconfiguration	4	61	0.949483
	4	62	0.932401
	4	61	0.949483

Table 2.24 Comparison of Total Real and Reactive Power Load

	Number of Iterations	Real Power Load (TPL)	Reactive Power Load(TQL)
Before Network Reconfiguration	5	3801.890090	2692.599781
After Network Reconfiguration	4	3801.890090	2693.599649
	4	4226.186872	2997.647785
	4	4226.187244	2997.647785

Chapter- 3 Conclusions and Future Scope 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. 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 69–node radial distribution network [11] have been found out for constant power, load modelling for substation voltage of 1.0 pu. and the results are obtained by the proposed method. The comparison of various switching options will show that the critical loading by the proposed method is superior. The overall loss i.e real and reactive power losses are reduced, voltage profile of the network is improved and total loading of network is increased.

3.2 Future Scope Of work

After carrying thesis work in maximum loading analysis of distribution systems, the following guidelines seem to be worth pursuing in this area:

1. Fuzzy based maximum loading of radial distribution network.
2. Maximum loading using optimal conductor selection.

References

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APPENDIX A

Table A.1 Load Data of 69 Node Radial Distribution Network [11]

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

Table A.2 Line Data of 69 Node Radial Distribution Network [11]

Branch Number	Sending-end	Receiving-end	Resistance (Ω)	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

APPENDIX B

Table B.1 Load Data of Reconfigured 69 Node Radial Distribution Network [11]

Node Number	PL(kW)	QL(kVAR)	Node Number	PL(kW)	QL(kVAR)
2	00.00	00.00	19	00.00	00.00
3	00.00	00.00	20	1.000	0.600
4	00.00	00.00	21	114.0	81.00
5	00.00	00.00	22	5.000	3.500
6	2.600	2.200	23	00.00	00.00
7	40.40	30.00	24	28.00	20.00
8	75.00	54.00	25	00.00	00.00
9	30.00	22.00	26	14.00	10.00
10	28.00	19.00	27	14.00	10.00
11	145.0	104.0	65	59.00	42.00
66	18.00	13.00	64	227.0	162.0
67	18.00	13.00	63	00.00	00.00
28	26.00	18.60	62	32.00	23.00
29	26.00	18.60	14	8.000	5.500
30	00.00	00.00	13	8.000	5.500
31	00.00	00.00	12	145.0	104.0
32	00.00	00.00	68	28.00	20.00
33	14.00	10.00	69	28.00	20.00
34	19.50	14.00	47	00.00	00.00
35	6.000	4.000	48	79.00	56.40
36	26.00	18.55	49	384.7	274.0

37	26.00	18.55	50	384.7	274.0
38	00.00	00.00	59	100.0	72.00
39	24.00	17.00	58	00.00	00.00
40	24.00	17.00	57	00.00	00.00
41	1.200	1.000	60	00.00	00.00
42	00.00	00.00	61	1244.	0 888.0
43	6.000	4.300	51	40.50	28.30
44	00.00	00.00	52	3.600	2.70
45	39.22	26.30	53	4.350	3.50
46	39.22	26.30	54	26.40	19.00
15	00.00	00.00	55	24.00	17.20
16	45.50	30.00	56	00.00	00.00
17	60.00	35.00			
18	60.00	35.00			

BASE kV = 12.66 and BASE MVA = 100

Table B.2 Line Data of Reconfigured 69 Node Radial Distribution Network [11]

Branch Number	Sending-end	Receiving-end	Resistance (Ω)	Reactance (Ω)
1	01	02	0.0005	0.0012
2	02	03	0.0005	0.0012
3	03	04	0.0015	0.0036
4	04	05	0.0251	0.0294
5	05	06	0.3660	0.1864
6	06	07	0.3811	0.1941
7	07	08	0.0922	0.0470
8	08	09	0.0493	0.0257
9	09	10	0.8190	0.2707
10	10	11	0.1872	0.0619
11	11	66	0.2012	0.2351
12	66	67	0.0047	0.3400
13	03	28	0.0044	0.3450
14	28	29	0.0640	0.3496
15	29	30	0.3978	0.0650
16	30	31	0.0702	0.1238
17	31	32	0.3510	0.0016
18	32	33	0.8390	0.1083
19	33	34	1.7080	0.0696
20	34	35	1.4740	0.1129
21	03	36	0.0044	0.0046
22	36	37	0.0640	0.0526

23	37	38	0.1053	0.1145
24	38	39	0.0304	0.2475
25	39	40	0.0018	0.1021
26	40	41	0.7283	0.0572
27	41	42	0.3100	0.0108
28	42	43	0.0410	0.1565
29	43	44	0.0092	0.1315
30	44	45	0.1089	0.0232
31	45	46	0.0009	0.1160
32	46	15	1.0000	0.2816
33	15	16	0.1966	0.5646
34	16	17	0.3744	0.4873
35	17	18	0.0047	0.0108
36	18	19	0.3276	0.1565
37	19	20	0.2106	0.1230
38	20	21	0.3416	0.0355
39	21	22	0.0140	0.0021
40	22	23	0.1591	0.8509
41	23	24	0.3463	0.3623
42	24	25	0.7488	0.0478
43	25	26	0.3089	0.0116
44	26	27	0.1732	0.1373
45	27	65	1.0000	0.0012
46	65	64	1.0410	0.0084
47	64	63	0.7105	0.2083

48	63	62	0.1450	0.7091
49	15	14	1.0580	0.2011
50	14	13	1.0440	0.0473
51	13	12	1.0300	0.1114
52	12	68	0.7394	0.0886
56	68	69	0.0047	0.1034
53	04	47	0.0034	0.1447
54	47	48	0.0851	0.1433
55	48	49	0.2898	0.5337
56	49	50	0.0822	0.2630
57	50	59	2.0000	0.1006
58	59	58	0.3042	0.1172
59	58	57	0.7837	0.2585
60	59	60	0.3861	0.0496
61	60	61	0.5075	0.0738
62	08	51	0.0928	0.3619
63	51	52	0.3319	0.5302
64	09	53	0.1740	0.0611
65	53	54	0.2030	0.0014
67	54	55	0.2842	0.2444
68	55	56	0.2813	0.0016

APPENDIX D

Biography of Candidate

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M.E in Power System and Electrical Drives from Thapar University, securing 7.32 CGPA.

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High School from C.B.S.E Board in 1999.

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