

**SELECTION OF APPROPRIATE LOCATION
OF SUBSTATION FOR PLANNING OF
DISTRIBUTION SYSTEM**

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

degree of

Master of Engineering

in

Power Systems & Electric Drives



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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, "Selection of Appropriate Location of Substation for Planning of Distribution System" 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 and refers other researcher's works which are duly listed in the reference section.

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

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ABSTARCT

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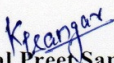
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Kamal Preet Sangar

ABSTRACT

In this Thesis work, an attempt has been made for the design of a rule-based expert system for load allocation in the expansion planning of a distribution system. Generalised algorithm is developed for obtaining the location of substation based on minimum loss criteria. Algorithm aimed at minimizing power loss, is developed to reach proper load allocation plans. The expert system using the developed algorithms and knowledge base is applied to reallocate some loads in a distribution system. The proposed method can handle all the heuristic rules. The load flow and branch conductor optimization techniques are used as subroutine in the generalized distribution planning algorithm. Using example of 71-node radial distribution networks, the critical values of real power losses and reactive power losses are derived out for the sub-station voltage of 1.0 (p.u.). The proposed method will reduce the real and reactive power losses. Several problems have been successfully tested using the proposed algorithm and results are highly satisfactory.

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List of Symbols

NB	Total no. of nodes,
jj	Branch no. i.e., $jj = 1, 2, 3, \dots, LN1,$
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,
LP(j)	Real power losses in branch -jj,
LQ(j)	Reactive power losses in branch -jj,
P(m2)	Active power load at node m2,
Q(m2)	Reactive power load at node m2,
kV	Kilo Volts
kW	Kilo Watt

1.1 Electrical Power System

Electrical energy is produced through an energy conversion process. The electric power system is a network of interconnected components which generate electricity by converting different forms of energy (potential energy, kinetic energy, or chemical energy are the most common forms of energy converted) to electrical energy. The electric power system consists of three main subsystems: the generation subsystem, the transmission subsystem, and the distribution subsystem as shown in figure 1.1. Electricity is generated at the generating station by converting a primary source of energy to electrical energy. The voltage output of the generators is then stepped-up to appropriate transmission levels using a step-up transformer.

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 sub-transmission system designates the circuits, which deliver energy from the transmission subsystem to the distribution subsystem. Usually the transmission substations supply the sub-transmission system, but it is still referred to as the sub transmission. Many sub-transmission systems were previously transmission lines. Load growth and demand for more power resulted in the transmission voltage being too low. 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

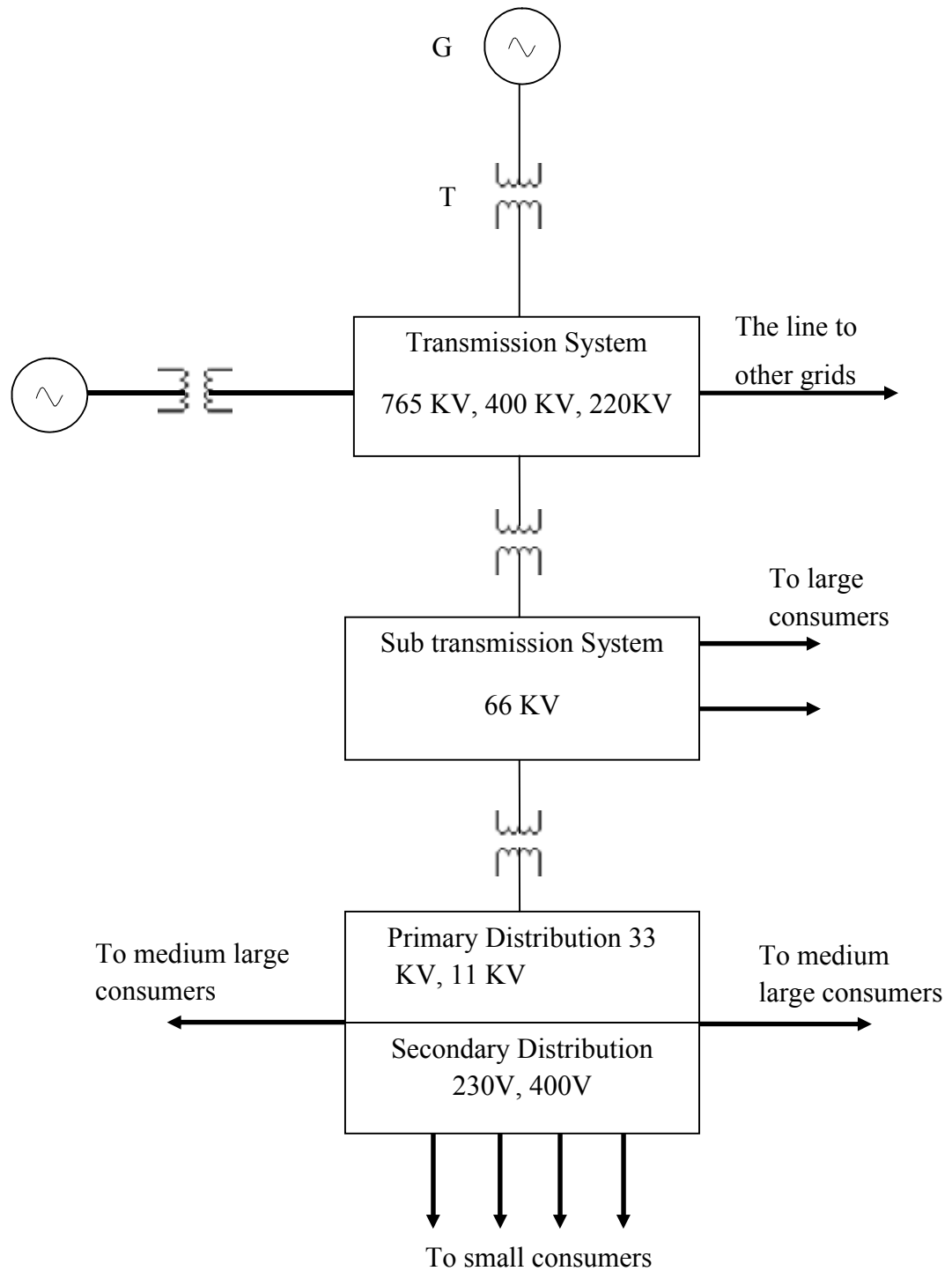


Figure 1.1 Single line Power System Network

1.2 Distribution system

Distribution system is the final stage in the delivery of electricity to end users. A distribution system's network carries electricity from the transmission system and delivers it to consumers. Typically, the network would include medium-voltage (less than 50 kV) power lines, electrical substations and pole-mounted transformers, low-voltage (less than 1000 V) distribution wiring. The distribution system begins after the Main Substations. Its transmission components may be divided into 3 parts and shown in figure 1.2:

1) Feeders

2) Distributors

3) Service Mains

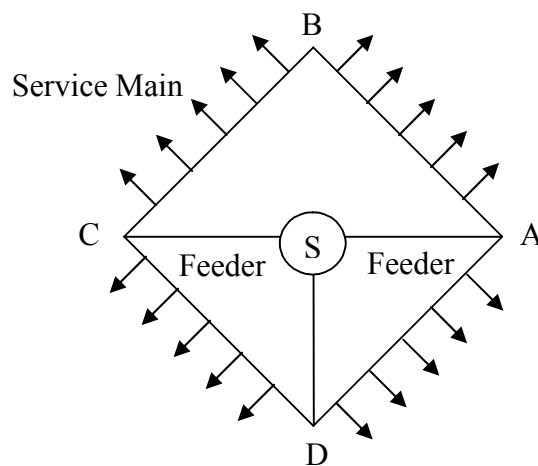


Figure 1.2 Single line diagram of a typical low tension Distribution System

Feeders: Conductors which connects the main substations to the various distribution substations. There is no tapping from the feeders. In other words, the current loading of a feeder is the same along its entire length.

Distributors: Conductors that radiate out from distribution substations to their allotted consumer areas. Various tapping are taken from the Distributors. Hence, a distributor has distributed current loading along its entire length.

Service mains: The connecting links between the distributor and the consumer terminals.

1.3 Main Components of Distribution System

A distribution system consists of all the facilities and equipment connecting a transmission system to the customer's equipment. A typical distribution system can consist of:

- 1) **Substation:** A substation is a high-voltage electric system facility. It is used to switch generators, equipment, and circuits or lines in and out of a system. It also is used to change AC voltages from one level to another, and/or change alternating current to direct current or direct current to alternating current. Some substations are small with little more than a transformer and associated switches. Others are very large with several transformers and dozens of switches and other equipment.
- 2) **Distribution feeder circuit:** Distribution feeder circuit are the connections between the output terminals of a distribution substation and the input terminals of primary circuits. The distribution feeder circuit conductors leave the substation from a circuit breaker or circuit recloser via underground cables, called substation exit cables. The underground cables connect to a nearby overhead primary circuit outside the substation. This eliminates multiple circuits on the poles adjacent to the substations thereby improving the overall appearance of the substation. Several distribution feeder circuits can leave a substation extending in different directions to serve customers. The underground cables are connected to the primary circuit via a nearby riser pole.
- 3) **Switches:** Distribution systems have switches installed at strategic locations to redirect or cut-off power flows for load balancing or sectionalizing. Also, this permits repairing of damaged lines or equipment or upgrading work on the system. The many types of switches include:
 - Circuit breaker switches
 - Single-pole disconnect switches
 - Three pole ground operated switches
- 4) **Protective Equipment:** Protective equipment in a distribution system consists of protective relays, cut out switches; disconnect switches,

lightning arresters, and fuses. These work individually or may work in concert to open circuits whenever a short circuit, lightning strikes or other disruptive event occurs. When circuit breakers open, the entire distribution circuit is deenergized. Since this can disrupt power to many customers, the distribution system is often designed with many layers of redundancy. Through redundancy, power can be shut off in portions of the system only, but not the entire system, or can be redirected to continue to serve customers. Only in extreme events, or failure of redundant systems, does an entire system become deenergized, shutting off power to large number of customers. The redundancy consists of the many fuses and fused cut outs throughout the system that can disable parts of the system but not the entire system. Lightning arresters also act locally to drain off electrical energy from a lightning strike so that the larger circuit breakers are not actuated.

- 5) **Primary Circuits:** Primary circuits are the distribution circuits that carry power from substations to local load areas. They are also called express feeders or distribution main feeders. The distribution feeder bay routes power from substation to the primary distribution feeder circuit.
- 6) **Distribution Transformers:** Distribution transformers reduce the voltage of the primary circuit to the voltage required by customers. This voltage varies and is usually:
 - 120/240 volts single phase for residential customers,
 - 480Y/277 or 208Y/120 for commercial or light industry customers.

Three phase pad mounted transformer are used with an underground primary circuit and three single-phase pole type transformers for overhead services. Network service can be provided for areas with large concentrations of businesses. These are usually transformers installed in an underground vault. Power is then sent via underground cables to the separate customers.

- 7) **Secondaries:** Secondaries are the conductors originating at the low-voltage secondary winding of a distribution transformer. Secondaries for residential service are three-wire single-phase circuits. When secondaries are strung in a vertical plane, they are directly attached to the support pole one above the other. This is in contrast to the primary lines which are often strung on a cross bar or other attachment in a horizontal or "V" shaped plane.
- 8) **Services:** The wires extending from the secondaries or distribution transformer to a customer's location are called a service. A service can be above or below ground. Underground services have a riser connection at the distribution pole. Commercial and residential services are much the same and can be either 120 or 220 or both.

1.4 Objectives of the Distribution System

- 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 with in permissible limits.
 - d) Less voltage dips.
 - e) Minimum interruption in power supply.

1.5 Requirement of a good Distribution Scheme

- 1) Reliability of supply should be maintained. If there is a breakdown, it should be for the least possible time.
- 2) The voltage drop at any consumer terminal should remain within $\pm 5\%$ of the declared voltage.
- 3) The efficiency of the system should not be less than 90%.
- 4) The insulation resistance of the system is high so that there is no leakage.

5) The system should be economical.

Function of sub transmission and distribution system is given in table 1.1.

Table 1.1 Function of Sub transmission and Distribution Network

Level title	Function	Remarks
Distribution networks 1) Primary circuit 2) Distribution transformer 3) Secondary circuits	1) To receive power from the sub transmission network. 2) To deliver power to the consumer.	Low voltage level 33kV, 11kV To reduce the voltage to 400\230V level.
Sub transmission network	1) To receive power from transmission network and other local power station. 2) To deliver power to distribution network via HV transmission lines.	1) less meshed 2) More radial Generally at high voltage AC (220 kV ,132 kV)

1.6 Classification of Distribution System

According to current the distribution systems may be classified as (1) ac distribution and (2) dc distribution. AC system is universally employed for distribution of electrical power.

According to the type of construction the distribution systems may be classified as (1) overhead distribution systems and (2) underground distribution system. Due to low cost overhead type system is usually employed. Underground distribution system is used where overhead system becomes impracticable.

1.6.1 DC Distribution System

DC distribution system may be divided into two systems known as *high voltage (or primary) distribution* and *low voltage (or secondary) distribution*.

1.6.1.1 Primary Distribution System: From generating stations the electrical power is usually transmitted to various substations through extra high tension transmission lines at voltage from 33 to 220 kV. At these substations this voltage is stepped down to 11 or 6.6 or 3.3 kV and power at this voltage is conveyed to different substations for distribution and to the bulk supply consumers. Such a system is known as high voltage or primary distribution system. The voltage employed for primary distribution system depends upon the amount of power to be conveyed and the distances of the substations required to be fed. The primary distribution voltage is usually 11kV but in case the load densities are very high (say of the order of 5 MVA/km²), as in cities like Bombay, Calcutta, Delhi, Noida, Ludhiana the primary distribution voltages may be higher (33 or 66 kV) even.

1.6.1.2 Secondary Distribution System: At distribution substations the voltage is stepped down to 400 volts. From these substations various low voltage (400 volts between phases and 230 volts between phase and neutral) distributions radiate out and feed the consumers. This system of distribution is known as low voltage or secondary distribution system.

1.6.1.3 Classification of DC Distribution System: Distribution may be classified in various ways:

According to the type of construction the distribution systems may be classified as (1) overhead distribution systems and (2) underground distribution system. Due to low cost overhead type system is usually employed. Underground distribution system is used where overhead system becomes impracticable.

According to the number of wires the distribution systems may be classified as (1) two-wire (2) three-wire and (3) four wire distribution systems. In case of dc supply 3-wire distribution system is usually employed owing to its advantages over two-wire distribution system. In case of ac supply 3-phase 3-wire system is employed for balanced loads such as power loads, 3-phase 4-wire system is employed for unbalanced loads such

as light and power loads combined and single phase 2-wire system is used for lighting and small power appliances.

According to the character of service, the distribution systems may be classified as (1) general light and power (2) industrial power (3) railway (4) street lighting etc. According to the scheme of connections the distribution systems may be classified as (1) radial (2) parallel (3) ring and (4) interconnected distribution systems and these are shown in figure 1.3.

The radial system is the simplest and lowest in first cost but has poorest service reliability. The parallel system provides improved reliability of supply, particularly if the circuits follow different routes. The ring system provides alternative supplies to a number of scattered sub stations. The interconnected networks are a common development of the simple ring system.

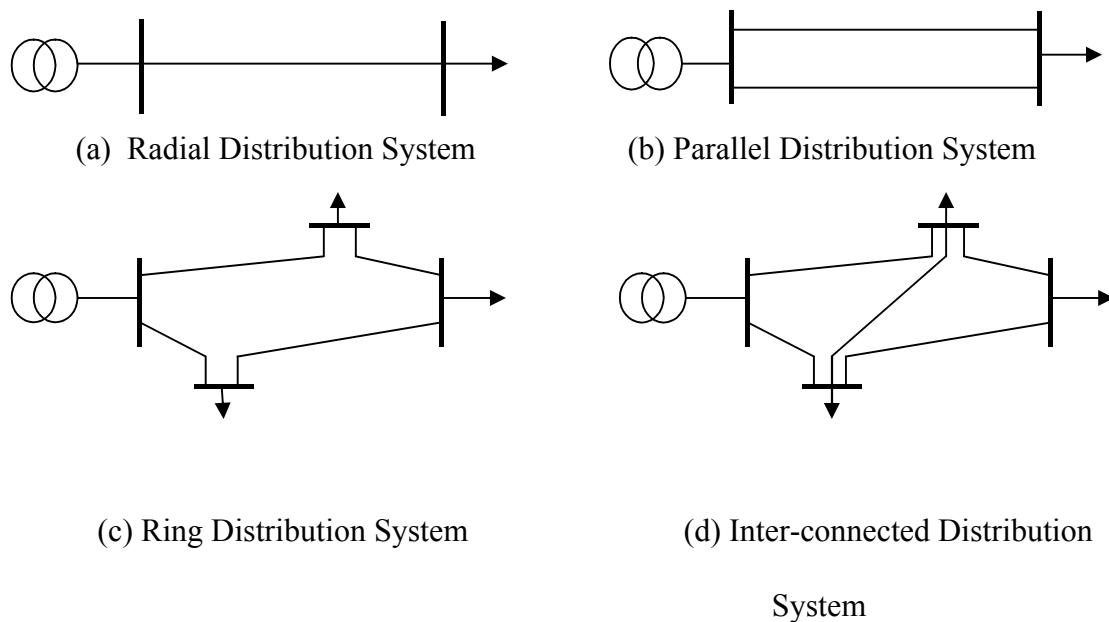


Figure 1.3 Arrangements of Feeders and Distribution System

1.6.2 AC Distribution System: AC distribution system may be divided into two systems known as *high voltage or primary distribution systems* and *low voltage or secondary distribution systems*.

1.6.2.1 Types of AC Distribution System

The distribution consists mainly of two parts: (1) primary distribution system, and (2) the secondary distribution system.

The primary distribution system would be the circuits supplying power at high voltage to large consumers such as industrial consumers and to distribution substations. The secondary distribution system would take the power to consumers such as domestic consumers at distribution voltage.

1.6.2.2 Primary Distribution System: It is that part of ac distribution system which operate at voltages (such as 3.3, 6.6, 11 kV or higher even) somewhat higher than that of general utility (400/230 V) and handle large blocks of power. The primary distribution is universally carried out by 3-phase, 3-wire system.

Electric power from the generating station is transmitted, through extra high tension transmission lines at voltages from 33-400 kV, to various substations located in or near the city. At these substations, called the secondary substations, the voltage is stepped down to 11, 6.6 or 3.3 kV with the help of power transformer for primary distribution. The primary distribution system can be classified as follows:

1) Radial System: figure 1.4 shows a radial system of distribution. The sub transmission substation supplies the primary distribution system feeders radiating from the substation bus. They feed the distribution transformer of substations which step down the voltage to distribution voltage and supply various loads through distributors. This is also shown as radial distribution and is one the secondary distribution side. Feeders are conductors that are not tapped in between the sub-transmission substation and distribution substations while distributors are conductor that are tapped throughout at all points when they are laid from substation transformers to various consumers in the area to be served. Primary feeder voltage of 11 kV and 3.3 kV are very common. The secondary distribution voltage at the consumers is 415/240 V, the system being three phase four-wire.

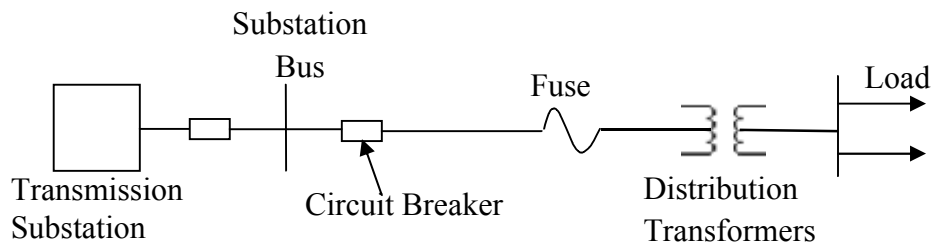


Figure 1.4 Radial System of Distribution

2) Parallel or Loop System: In a parallel feeder system, two radial feeders originating from the same or different secondary substations are run in parallel. Each feeder, though capable of supplying the entire load, shares the total load equally in normal conditions. Through this system is expensive but reliability is increased as in case of fault on one feeder, the total load can be supplied by the healthy feeder. Interruption of supply is only for the time duration that is taken in transferring the load from the faulty feeder to healthy one either by manual or automatic switches. Such a system is employed wherever the continuity of supply is of greater importance.

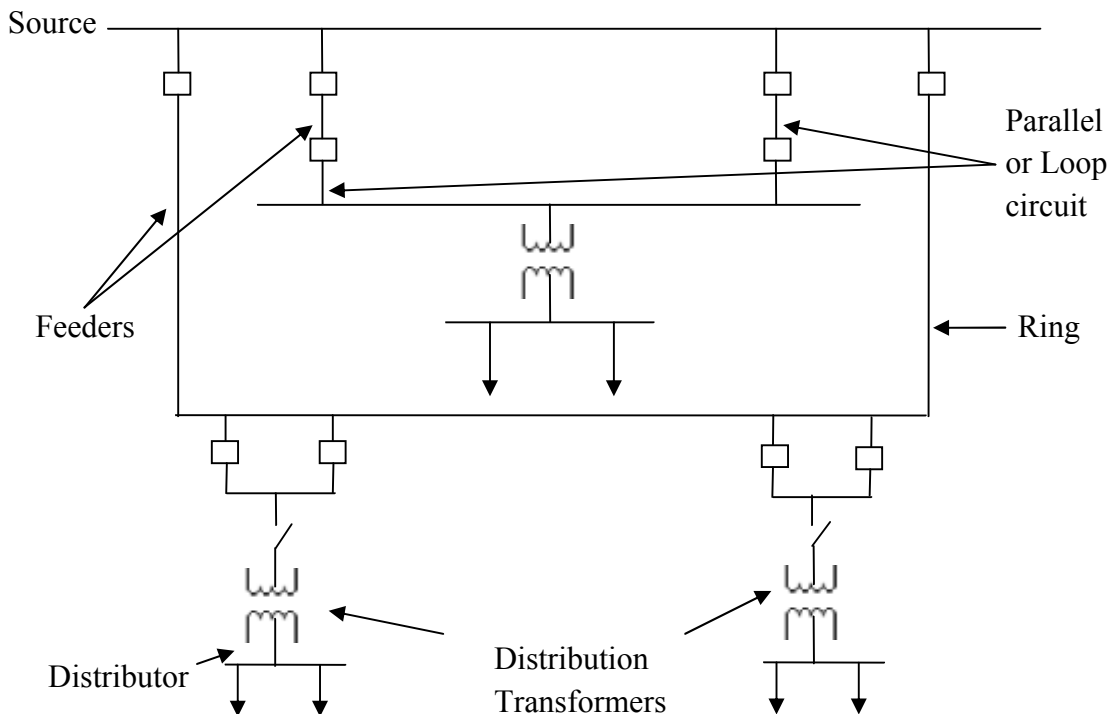


Figure 1.5 Parallel or loop distribution System

In a loop feeder system, two or more radial feeders originating from the same or different secondary substations are laid on different routes of load areas. The arrangement having the ends of two feeders tied together through normally open switching devices is called the ring main feeder or the ring loop. This system is by far the most reliable for continuity of supply and gives better voltage regulation and less power losses. The use of this system is prohibitive on account of very large investment involved. It is used where continuity of supply is the priority factor and thus large investment may be warranted. Feeders and loop components must have sufficient reserve capacity to handle the load that may be transferred under abnormal conditions. The type of the system is shown in figure 1.5.

3) Network or Grid System of Distribution: This type of system is applicable in large distribution areas with large loads and where the system has to be made more reliable for continuity of supply. This is true for primary distribution systems as well as in some applications to secondary distribution systems. A primary network is a system of interconnected primary feeders supplied by two or more sub transmission circuits through several distributions located at intersection points of the interconnected feeders. The network system is shown in figure 1.6. A network distribution system is also used where loads are heavy as in small crowded commercial areas. The network type distribution system gives the maximum possible flexibility, reliability of the continuity of the advantage of diversity between loads, etc. The network gives better voltage regulation and less possible outages of consumers. The size of the substations required is also smaller compared to that required in radial system. The circuits in the primary networks are fed at both ends and hence give better voltage regulation. In the case of radial distribution, the length of the feeders is larger than in case of network methods. The primary network has small substations; each located at or near the centre of the load of the area served by it. All the substations are interconnected. It is, therefore, possible to add or remove small increments of transformer capacity in the area under consideration. Shifting of loads or load growth in the area can be handled with minimum changes with the network distribution system

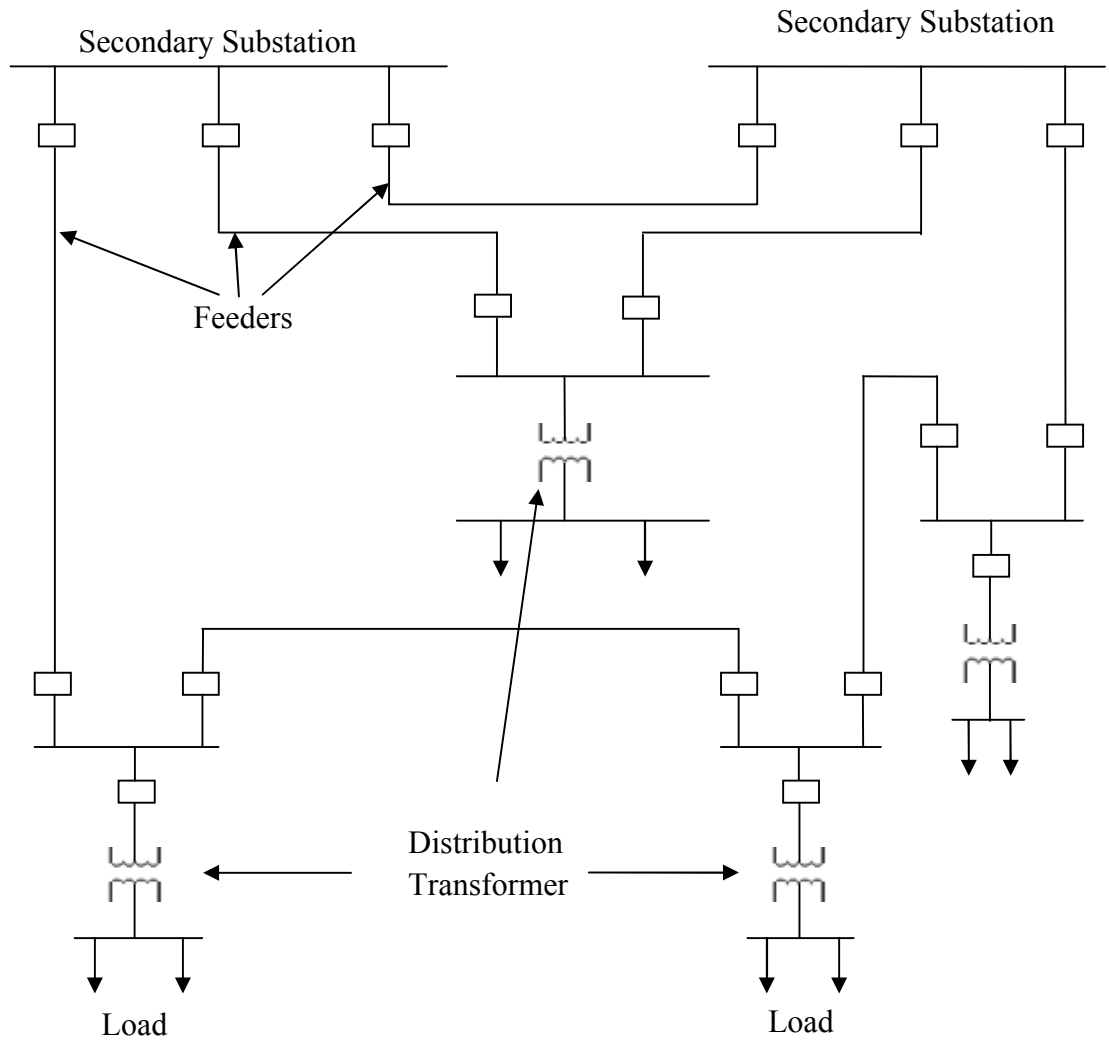


Figure 1.6 Networks or Grid System of Distribution

than with other types of distribution systems. There are not extensive reconnections or changes in circuits necessary for the purpose.

1.6.2.3 Secondary Distribution System: It is that part of ac distribution system that includes the range of voltages at which the ultimate consumer utilizes the electrical energy delivered to him. The secondary distribution employs 400/230 V, 3-phase, 4-wire system. The primary distribution circuit delivers power to various sub-stations, called distribution sub-stations. The sub-stations are situated near the consumer's localities and contain step-down transformers. At each distribution sub-station, the voltage is stepped down to 400 V and power is delivered by 3-phase, 4-wire ac system. The voltage between any two phases is 400 V and between any phase and neutral is 230. The single phase domestic loads are connected between any one phase and the neutral whereas 3-

phase 400 V motor loads are connected across 3-phase lines directly. The reference value of voltage limit in distribution is given in table 1.2.

Table 1.2 Reference value of voltage limit in distribution system

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

1.7 Design Considerations: The distribution system should be designed so as to be economical but confirming to the Indian Electricity Rules. Thus it is essential to design each distributor with the minimum volume of the conductor material consistent with the voltage regulation needs.

Both voltage drop and current rating, in addition to overall economy, are the important considerations in the design of distribution systems. The cross sectional area of feeder is determined on the basis of current to be carried and for overall economy (the minimum cost of conductor material and power losses). The consideration of voltage drop is not important in the design of feeders, because no consumer is tapped-off from it and the receiving end voltage can be raised to the desired value and kept within permissible limits.

On contrary, the voltage regulation is very important in the design of distributor. It is because of the statutory regulation giving the voltage variations permissible at the consumer's terminals.

1.8 Determination of Size of Conductor for Feeders and Distributors: In practice, ACSR conductors are universally employed for distribution systems (feeders as well as distributors). However, in case of distributors all aluminium conductors (AAC) can also be used provided the spans are small. The conductor size for a feeder is mainly governed by the current carrying capacity and overall economy. The current carrying capacity of a conductor depends on the conductor losses and surroundings. The current carrying capacity is usually determined for a maximum operating temperature of 75° (current carrying capacity for ACSR conductors of different sizes are available in IS: 398-1976). After determining the size of the conductors on the basis of current carrying capacity it should be checked that voltage drop in the feeder is not out of the range of the regulating equipment. If the voltage drop comes out to be too high, the conductor size of feeder is increased to the next higher standard value and so on till the voltage drop in the feeder comes down to reasonable value. The value of conductor size so determined now is checked for overall economy.

1.9 Nominal Voltage Levels in Transmission and Distribution Systems

3-phase, 50Hz or 60 Hz AC systems are universally used for generation, transmission and distribution of electrical power. For purpose of long distance high power transmission, voltages are stepped at generating station. The voltages are stepped down to appropriate level for sub transmission level. The voltages are again stepped down at distribution substation and deliver to the consumer. Thus, the entire power system network has several AC voltage levels obtained by means of power transformers located in substations and distribution systems voltage levels are standardized.

1.10 Type of Distributors: The distributors are of the following types:

- 1) Distributors fed at one end.
- 2) Distributors fed from both ends.
- 3) Distributors fed at centre.

4) Ring main distributor.

1) Distributors fed at one end: In this type of feeding, the distributor is connected to supply mains at one end and loads are tapped at different points along the length of the distributor, as shown in figure 1.7. In this type of distributor current in the sections away from the feeding point and voltage across the loads away from the feeding point goes on decreasing. The minimum voltage occurs in the farthest load point. If fault occurs in any section of distributor, the whole distributor is required to be disconnected from the supply mains and thus supply continuity is disturbed.

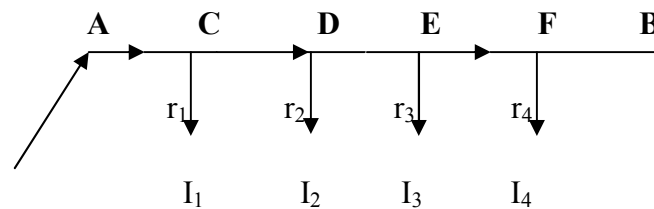


Figure 1.7 Distributor fed at one end

2) Distributor fed from both ends: In this type of feeding, the distributor is connected to supply mains at both ends, as shown in figure 1.8. The voltage at both feeding points may be different or equal. In this type of distributor, load voltage first goes on decreasing, reaches the minimum value, then starts increasing and reaches the maximum value when we reach the other feeding point while going from one load point to another load point. The point of minimum voltage is never fixed. It always shifts with the variation of load on the different sections of the distributor.

Advantages:

- 1) In case of fault in any one feeder feeding the distributor, the continuity of supply is maintained by feeding it from other end.
- 2) If any section of the distributor is isolated in case of fault, the continuity of supply is maintained to the remaining sections.
- 3) Since x-section required for doubly-fed distributors is much less as compared to singly fed one, hence it is economical.

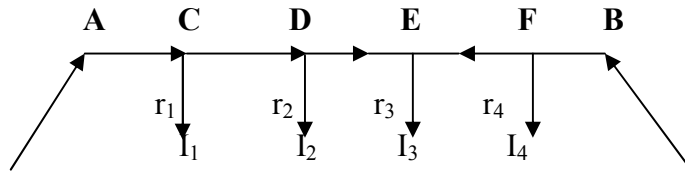


Figure 1.8 Distributor fed from both ends

3) Distributors fed at centre: In this type of feeding, the centre of the distributor is connected to the supply mains, as shown in figure 1.9. In fact this type of distributor is equivalent to two singly-fed distributors, each distributor being of one half of its total length and having common feeding point.

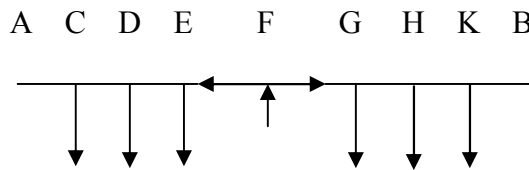


Figure 1.9 Distributor fed at the centre

4) Ring main distributor: When the two ends of a distributor fed at equal voltages brought together, then such distributor is known as ring main (figure 1.10). It has got all the advantage of doubly-fed distributor, while the feeder required is only one. Ring main may be fed at one or more points.

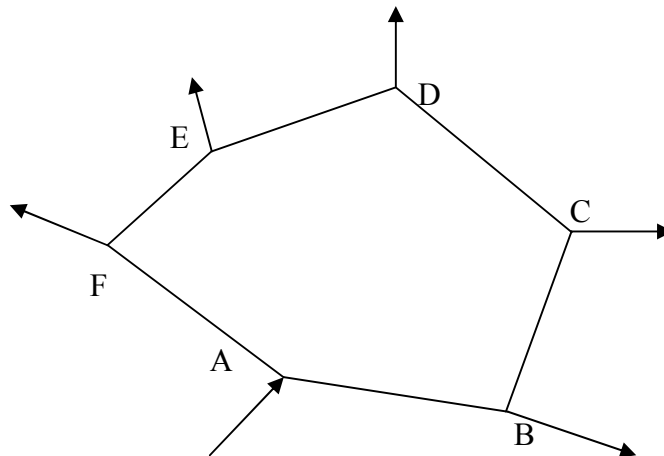


Figure 1.10 Ring main distributors

1.11 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:** Underground system is safer than overhead system.
- 2) **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 overhead system.
- 3) **Flexibility:** Overhead system is more flexible than underground system. In 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.
- 4) **Operating 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.
- 5) **Maintenance Cost:** Maintenance cost of underground system is very low in comparison with that of overhead system.
- 6) **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 very few chances of power failures or faults as compared to overhead system.
- 7) **Frequency of Accidents:** The chances of accidents in underground system are very low as compared to overhead system.
- 8) **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.

- 9) **Appearance:** Underground system of distribution or transmission is good looking because no wiring is visible. Due to its good looking, in spite of its higher cost it is adopted in modern cities like Chandigarh, Faridabad.
- 10) **Fault Location and Repairs:** Though there are very rare chances of occurring fault in underground system, but if occurs it is very difficult to locate that fault and its repair is difficult and expensive.
- 11) **Charging Current:** On account of less spacing between the conductors the cables have much capacitance, so draw higher charging current.
- 12) **Surge Effects:** In underground system surge effect is smoothened down as surge energy is absorbed by the sheath.

1.12 Distribution System Planning

Distribution systems planning heavily depend on the predicted future consumptions in the service area. When statistical data exist about past consumptions, probabilistic forecasting methods may be applied, and expected cost/benefit and risk analysis are used to decide between different solutions. In most cases, however, this strategy is not applicable, due mainly to the lack of significant data (new developing areas, rapidly changing situations) and uncertainty of economic and social factors. System planning is essential to assure that the growing demand for electricity can be satisfied by distribution system additions which are both technically adequate and reasonably economical. Even though considerable work has been done in the past on the application of some type of systematic approach to generation and transmission system planning, its application to distribution system planning has unfortunately been somewhat neglected. In the future, more than in the past, electric utilities will need a fast and economical planning tool to evaluate the consequences of different proposed alternatives and their impact on the rest of the system to provide the necessary economical, reliable and safe electrical energy to consumers.

The distribution system is particularly important to an electrical utility for two reasons: (1) its close proximity to the ultimate customer and (2) its high investment cost. Since the distribution system of a power supply system is the closest one to the customer, its

failures affect customer service more directly than, for example, failures on the transmission and generating system, which usually do not cause customer service interruptions. Therefore, distribution system planning starts at the customer level. The demand, type, load factor, and other customer load characteristic dictate the type of distribution system required. Once the customer loads are determined, they are grouped for service from secondary lines connected to distribution transformers that step down from primary voltage. The distribution transformer loads are then combined to determine the demands on the primary distribution system. The primary distribution system loads are then assigned to substations that step down from transmission voltage. The distribution system loads, in turn, determine the size and location of the substations as well as the routing and capacity of the associated transmission lines. In other words, each step in the process provides input for the step that follows.

The distribution system planner partitions the total distribution system planning problem into a set of sub problems with which can be handled by using available, usually ad hoc, methods and techniques. The planner, in the absence of accepted planning techniques, may restate the problem as an attempt to minimize the cost of sub transmission, sub stations, feeders, laterals, etc., and the cost of losses. In this process, however, the planner is usually restricted by permissible voltage values, voltage values, voltage dips, flicker, etc., as well as service continuity and reliability.

1.13 Factors Affecting System Planning

The number and complexity of the considerations affecting system planning appears initially to be staggering. Demands for ever-increasing power capacity, higher distribution voltages, more automation and greater control sophistication constitute only the beginning of a list of such factors.

1) Load Forecasting: The load growth of the geographical area served by a utility company is the most important factor influencing the expansion of distribution system. Therefore, forecasting of load increases and system reaction to these increases is essential to the planning process. There are two common time scales of importance to load forecasting; long range, with time horizons on the order of 15 or 20 years away, and short-range, with horizons of up to 5 years distant.

2) Substation Expansion: The planner makes a decision based on tangible or intangible information. For example, the forecasted load, load density, and load growth may require a sub-station expansion or a new sub-station construction. In the system expansion plan the present system configuration, capacity and the forecasted loads can play major roles.

3) Substation Site Selection: The distance from the load centres and from the existing sub transmission lines as well as other limitations, such as availability of land, its cost and land use regulations, are important. The sub-station process can be described as a screening procedure through which all possible locations for a site are passed. The service region is the area under evaluation. It may be defined as the service territory of the utility. An initial screening is applied by using a set of considerations, e.g., safety, engineering, system planning, institutional, economics, aesthetics. This stage of the site selection mainly indicates the area that is unsuitable for site development.

1.14 Literature Survey

Distribution system planning is essential to assure that the growing demand for electricity can be satisfied by distribution system additions which are both technically adequate and reasonably economical. Dale M. Crawford [1] discussed the planning of distribution substation locations, sizes, and service boundaries. The technique discussed uses operations research methods to simultaneously optimized substations sizes and service boundaries, given alternative locations for the substations and reliability constraints. The SLP procedure described was characterized by the calculation of MFD's from each sector to each substation, optimization of load and service area by the transportation algorithm, and analysis of results, making indicated changes in the system. The method didn't give an exact solution with one run of the program, but instead gives the planner a tool with which to evaluate options.

Increasing effort was focused by Carlos H. Castro [3] on automated remote control of distribution feeder deployment and sectionalizing to improve service restoration time to unfaulted feeder sections and for transferring load between feeders. Digital processor algorithms which determined fault location and generate switching instructions automatically based on tree searching techniques utilizing switch tables were described.

Simulation results for fault location, fault isolation, and service restoration, including balancing between feeders using an illustrative simplified feeder configuration were shown.

G.L. Thompson [4] formulated a distribution planning model which considered existing and potential substation locations, their capacities and costs, together with the primary feeder network represented by small area demanded locations to represent non-uniform loads, and feeder segments having variable distribution costs and limited capacities. A branch and bound search method was described which utilizes a shortest path table to obtain lower bounds and solutions from a transshipment linear programming model for upper bounds. The search process was expedited by using weak lower bounds calculated from a shortest path table and minimum feeder network cost, along with upper bounds obtained from the solutions of the transshipment model. The computational experience with realistic sized problems was encouraging. The model was not used by itself but rather to augment existing transmission planning models. The model provided the critical interface of existing and potential station sites and their loads to the transmission planning model.

D. I. Sun [6] presented the planning methodology in an application of recent advances in optimization techniques for distribution substation siting and radial feeder planning. The concept of a long range horizon year (target) was used together with a time-phased expansion process beginning with the base year and progressing to the target year. An optimal static horizon year design was determined using a fixed charge transshipment problem formulation (FCNP). The FCNP solution methodology employed the branch-and bound algorithm and includes explicit modelling of fixed charge and variable cost components for improved accuracy. The method was incorporated existing facilities in the decision process for maximum benefit.

Keinosuke Matsumoto [7] analyzed the background of power system restoration and discussed how the process might benefit from the use of knowledge-based systems. After describing the state of the art of knowledge-based systems for power system restoration, efforts were made to review knowledge based techniques to handle system restoration problems. Then the experiences of system development were reported and evaluation of the systems was addressed. Finally, some needed technological innovations were listed

that were required before knowledge-based systems which extensively be applied to power system restoration.

S. Kato [10] developed a computer-based distribution SCADA (Supervisory Control and Data Acquisition) system and a geographical display system of distribution network diagrams. The development objects, system configuration, system functions and feeder switching algorithm of the distribution SCADA system, and system configuration, software and database of the geographical display system were described. The distribution SCADA system installed in Ginza branch office had been verified for its performance and effectiveness. It had been used for daily monitor and control of the distribution network. The non-faulted out-of-service sections were restored within five minutes, 1/10 of time required by manual operation. The system had been used about 300 times for the network maintenance and extension works (re-arrangement of network configuration, installation of new large customer, etc.) since the installation.

Chen-Ching Liu [11] developed an expert system to assist in the decision-making of the reactive power/voltage control problem. The knowledge required to perform the task was identified. To alleviate a voltage problem, empirical rules were used to generate appropriate control actions when slight voltage violations occurred. Controls such as shunt capacitors, transformer tap changers and generator voltages were utilized. Theoretical justification of the empirical rules was presented. When it is judged that the voltage problem was so severe that empirical judgements were not reliable, the developed expert system was help in formulating the problem and an available application software package was effectively utilized. The production rules were proposed to perform the above functions. Numerical examples were also presented. Different scenarios of the system condition were selected to test the capability of the developed expert system.

Bruce F. Wollenberg [12] demonstrated the alarm processing which was a traditional feature of energy management systems and had not changed significantly over several generations of EMS design. Problems were obvious, however, and operations personnel had often voiced a desire for a better way to monitor a power system than provided by existing alarm processing software and hardware. The experiments reported show promise of a truly different methodology for handling alarms. This was realized through

the application of a real time expert system dedicated to continuous analysis and reporting of system conditions rather than simply printing numerous specific alarm messages. Results showed the ability of the expert system to present operators with concise alarm information extracted from a standard set of alarm messages.

Saiosh N. Talukdar [13] described two knowledge-based programs. The first simulated the behaviour of automatic protection schemes in power networks. The second was an expert system for the diagnosis of faults. Both were coded in OOPS--a widely available language for writing rule-based programs. The user and the programs communicated over a Blackboard which was a database for messages. The Blackboard had been organized so that the addition of new programs recognised. Those aids, or problem solvers, and their communication mechanism (called a blackboard) constituted the skeleton of a DPS system that was readily expandable at both the macro and micro levels. At the macro level, new problem solvers were added by giving them access to the blackboard. At the micro level, new rules and working memory-elements were added to existing problem solvers to enhance the capabilities.

Chihiro Fukui [14] discussed an expert system which estimated possible fault sections using information from protective relays and circuit breakers. The system was applicable to dispatching centres and was helpful for dispatchers to judge emergency situations as the first step in restoration procedures. When some faults occurred, the system made inferences based on both knowledge about protection systems and information on the operating protective relays and tripped circuit breakers. The system gave possible answers even in the case of multiple faults and false operations of relays and circuit breakers. The expert system was written in Programming in logic (Prolog). The knowledge and rules stored in databases were easily changed corresponding to the relays adopted in the object power system making it applicable for various kinds of power systems.

Kevin Tomsovic [15] demonstrated PSPL dispatchers which were number of times in order to evaluate the system performance. Many of the dispatchers' comments were related to the man/machine interface using familiar terminology and concise messages. In all tested scenarios, the expert system suggested a correct solution. Comments from those demonstrations resulted in adding the ability to handle multiple lines at the same

time. Dispatchers used their judgement as to which line they want to work on first. The extension was deemed necessary since the expert system was helpful during abnormal weather conditions where several faulted lines were expected.

K. Aoki [16] addressed a sub problem related to distribution automation. It outlined an algorithm and presented computer results for minimizing the losses in a loop distribution system based on the remote operation of sectionalizing switches on feeders interconnecting different substations. The minimization was carried out subject to the voltage-drop, line-capacity and substation-capacity constraints. Computational experience with a system of realistic size indicates that the procedure proposed there was valid and was effective in practical operations.

R.P. Schulte [17] described the spectrum of power system operating problems that were believed to be good candidates for Artificial Intelligence (AI) solution. The first short note listed many of those applications and discussed their characteristics and why they were candidates for AI. The second described an existing application that uses a knowledge base derived from operator experience. The third described a research project that was conducted toward solving the alarm processing problem and the last short note introduced some of the problems to be encountered in Implementing AI in an energy management system.

K.P. Wong [18] developed methods based on the set theory and the Prolog programming language by which the allocation of loads to the bus bars of distribution substations were determined automatically. Starting from the initial possible allocation of loads to the substation bus bar sections, a formulation for load allocation was first developed using set theory. The 'generate evaluate and test' technique and the depth-first search method were then applied to the solution-seeking process. The formulation was implemented and recursive search procedures were derived using the Prolog language. The structure of the Prolog program developed had the flexibility that the solution process in the solution generator is independent of the structure of the substations. The Prolog software aid developed includes a complete solution generator from which all hypothetical solutions were generated, an evaluator which prunes invalid solutions and a tester which produced feasible solutions by checking the load allocation constraints related to the firm capacity

of the distribution substations. An application of the methods developed was given for two 11 kV interconnected substations which include 5 bus bar sections and 10 ring loads.

D. T. Rizy [19] discussed the development of a distribution automation applications software package for assessing system reconfiguration opportunities and volt/var control on automated radial distribution feeders. The package, called *SYSRAP* (System Reconfiguration Analysis Program) was developed by the Oak Ridge National Laboratory as part of the Athens Automation and Control Experiment (AACE). The AACE was a large scale distribution automation research project conducted on the Athens Utilities Board (AUB) in Athens, Tennessee. *SYSRAP* was unique because it combined the power flow and short circuit analyses with data base management and was especially well suited for answering system operator questions with respect to switch orders, capacitor bank dispatch and regulator tap adjustments. The programs was run on a personal computer, executes power flow and short-circuit analyses for detailed feeder models in tens of seconds, used highly detailed feeder models including voltage sensitive loads, and was adept at reorganizing the data base to reflect switching operations and changes in the status of volt/var control equipment. Experimental observations on the AUB system had shown that voltage insensitive load models (constant power sinks) were inadequate to accurately simulate system response to system reconfiguration and volt/var control which affect feeder voltage profile.

J. S. Lawler [20] discussed the reliability effects of distribution automation on the Athens Utilities Board (AUB) in Athens, Tennessee. The investigation was part of the Athens Automation and Control Experiment sponsored by the U. S. Department of Energy, Office of Energy Storage and Distribution, Electric Energy Systems Program. In the experiment, distribution feeder equipment on twelve feeders connected to three substations was remotely controlled from a central dispatch centre. Substation and feeder monitoring and remote control of feeder circuit breakers, power recloser, and load break switches was provided by a supervisory control and data acquisition system. An analytical study was presented to show the improvement in conventional distribution system reliability indices that were achieved at AUB as a function of the penetration of automation equipment. The value of automation predicted by the study was highly sensitive to the historical outage data used in the analysis and to the economic worth of reliability assigned by the utility. Those sensitivities were well known and account, at

least in part, for the reluctance of some upper utility managers in automation systems. Operating experience with the AUB automation system had shown that there were significant intangible reliability benefits and tangible cost savings associated with automation that were outside the scope of conventional distribution reliability indices.

Yuan-Yih Hsu [22] discussed an expert system designed for determining substation locations and feeder configuration of a distribution system. To minimize the feeder losses of the distribution plan, a novel approach, usually referred to as the location-allocation method, was proposed to determine substation locations. By incorporating the heuristic rules followed by distribution engineers into the knowledge base, the expert system was benefit from system planners' experience in its problem-solving process. The expert system was implemented using the artificial language PROLOG and was designed to be used interactively.

Satish Jonnavithula [24] demonstrated a new approach for optimal network routing in distribution planning was presented in the search. The distribution network routing planning problem was formulated as a non-linear constrained, non-differentiable optimization problem. The main objective is to minimize the total cost which was the summation of reliability costs, feeder resistive loss, and investment and maintenance costs. Simulated annealing, which is a general purpose combinatorial optimization algorithm, was used to obtain a global optimum solution of the problem.

Belgin Turkey [25] presented an improved mathematical model to optimise the size and locations of substations and the network routing problem. The model was formulated to minimise the total cost of the network by determining the optima of the substation locations and power, the load transfers between the demand centres, the feeder routes and the load flow in the network subject to a set of constraints. The computational results of a devised sample problem indicate that the developed optimisation model and its code were adequate for computer aided planning of distribution systems.

Rakesh Ranjan [26] developed a new algorithm for distribution system planning. The proposed algorithm did not require prior knowledge of candidate substation location and could automatically select location of a substation, the optimal feeder configuration and the optimal sizes of branch conductors while satisfying constraints such as current

capacity, voltage drop and heuristic rules. Several algorithms were proposed for distribution systems planning. A generalized algorithm was developed for obtaining the optimal feeder path and the optimal location of substation on minimum loss criterion. Heuristic rules were incorporated. Another algorithm was also developed for branch conductor optimizations. Modified load flow method was also presented, which could handle composite load models. The load flow algorithm was used for solving radial distribution networks (RDN) and branch conductor optimization algorithm. The load flow algorithm and branch conductor optimization techniques were used as subroutine in the generalized distribution systems planning algorithm.

K.K. Li [27] demonstrated a rule-based expert system for distribution planning. By combining heuristic rules with mathematical algorithms, the proposed expert system was capable of optimizing the locations of substations and the conductor layout. A genetic algorithm approach was employed to determine the optimal sites of new substations. To determine the optimal conductor layout, a heuristic algorithm was proposed, which considers both the capital expenditure and the cost associated with power losses. The heuristic rules required in the expert system were also identified and reported in the search. The expert system had been tested to be applicable and efficient.

Ming-Yang Huang [28] demonstrated a rule-based expert system with a colored Petri net (CPN) inference model which was developed for service restoration of distribution systems with fault contingency. The CPN models of distribution components such as four-way line switches were proposed to derive the proper restoration plan after the faulted location had been identified and isolated. To assure the restoration plan could comply with the operation regulation, heuristic rules based on the standard operation procedures of Taipower distribution system were included in the best first search of the CPN. The unfaulted but out-of-service zones restored as much as possible with the proposed switching operation plan. The short-term load forecast of each service zone was also included in the restoration strategy. A Taipower distribution system with 68 feeders was selected for computer simulation to demonstrate the effectiveness of the proposed CPN model to solve the service restoration of distribution system.

Ibrahim Helal [29] presented a value-based distribution system planning procedure for large-scale agricultural real life project. The type of distribution planning was

characterized not only by high load demand but also with a huge distribution network covering the vast agricultural area. It was a planning for single type of customers who has a consistent developing policy, interest, cost damage function, together with a realistic and less uncertain data. The planning was also perceived from the consumer perspective who may even question the connection to the power utility unless it was proved as cost effective way of power supply. Macro and micro-levels planning was suggested for both overall project and farm modules, respectively. The proposed planning procedure evaluates different feasible alternatives based on life cycle cost while reliability indices and cost of interruption were taken into consideration.

1.15 Objective of the Thesis Work

The thesis work endeavours load allocation plan whose purpose is to reallocate some loads in the study system to the new substation such that certain desirable features of the distribution system such as minimum loss, minimum investment cost, high reliability, satisfactory voltage regulation, etc., can be met. The objectives are divided into the following:

- 1) To develop a rule-based expert system for the load allocation in distribution expansion planning.
- 2) An expert system is presented for feeder planning and load allocation.
- 3) The heuristic rules used by system planners are incorporated into the expert system.
- 4) An algorithm based on some heuristic rules is developed for the minimum loss design.
- 5) To compute the critical values of total real power load (TPL) and total reactive power load (TQL) of the system.

1.16 Organisation of the Thesis work

Chapter 1 has presented the introduction of distribution system, size of feeder conductor, nominal voltage level in transmission and distribution system, distribution expansion planning and the factors affecting system planning, objectives of the research and organisation of the research.

Chapter 2 presents a rule-based expert system for the load allocation in distribution expansion planning. To demonstrate the effectiveness of the proposed expert system, the expansion planning of a new substation on a distribution system is examined. The planning of the feeders for the substation and the reallocation of some loads in the present system to these new feeders is of major concern in the study. 71 node radial distribution network is selected for applying in the proposed system.

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

References present the list of previous papers published by researchers in load allocation in distribution system, optimal model for load planning radial distribution networks and reconfiguration of radial distribution system.

Appendix – A shows the line data and load data of 71 node optimum radial distribution network.

Appendix - B shows the line data and load data of 71 node radial distribution network for single feeder.

Appendix - C shows the line data and load data of 71 node radial distribution networks for double feeder.

Appendix - D shows the line data and load data of 71 node radial distribution network for three feeder.

Appendix – E shows the data for conductors.

Appendix – F shows biography of candidate.

2.1 Assumption

In this section a new load flow algorithm for radial feeders is presented. It is assumed that the three phase radial distribution feeders are balanced and can be represented by its equivalent single line diagram.

2.2 Load Allocation in Distribution Expansion Planning

Distribution network expansion planning is one of the important activities in distribution control centres [21]. Several evaluation items such as new equipment installation cost, equipment utilization rate, reliability of the distribution system, and loss minimization should be evaluated considering increase of network loads and newly installed large customer loads when planning. Recently, reduction of maintenance costs, restraining investment for equipment and energy-saving are of primary concerns in power utilities. Therefore, more efficient distribution network expansion planning is required. The reduction of maintenance costs, restraining investment for equipment and energy-saving are of primary concerns in power utilities. Therefore, more efficient distribution network expansion planning is required. Many approaches have been proposed in the expansion planning. Most of them have been developed for allocation of substations and feeders.

The purpose of a load allocation plan is to reallocate some loads in the study system to the new substation such that certain desirable features of the distribution system such as minimum loss, minimum investment cost, high reliability, satisfactory voltage regulation, etc., can be met. Several approaches based on mathematical programming have been reported in the literature for the load allocation problem [2-9]. However, these approaches require considerable computational effort and cannot take the heuristic rules used by system planners into account.

The purpose of this thesis work is to develop a rule-based expert system for the load allocation in distribution expansion planning. In the development of the expert system, C language is used because it is available for personal computers and it is an excellent language for building a rule-based expert system due to its capability of searching and

backtracking. Since the whole system is developed on a personal computer, it is very cost-effective. To demonstrate the effectiveness of the proposed expert system, the expansion planning of a new substation on a distribution system is examined. The planning of the feeders for this substation and the reallocation of some loads in the present system to these new feeders are of major concern in this study.

The main contributions of the paper are summarized as follows.

- 1) A knowledge-based expert system is developed for distribution system planning.
- 2) The heuristic rules used by system planners are incorporated into the expert system.
- 3) An algorithm based on some heuristic rules is set forth for the minimum-loss design.
- 4) An algorithm based on minimal-path criterion is developed for minimum-cost design.

2.3 Knowledge Based Expert System [22]

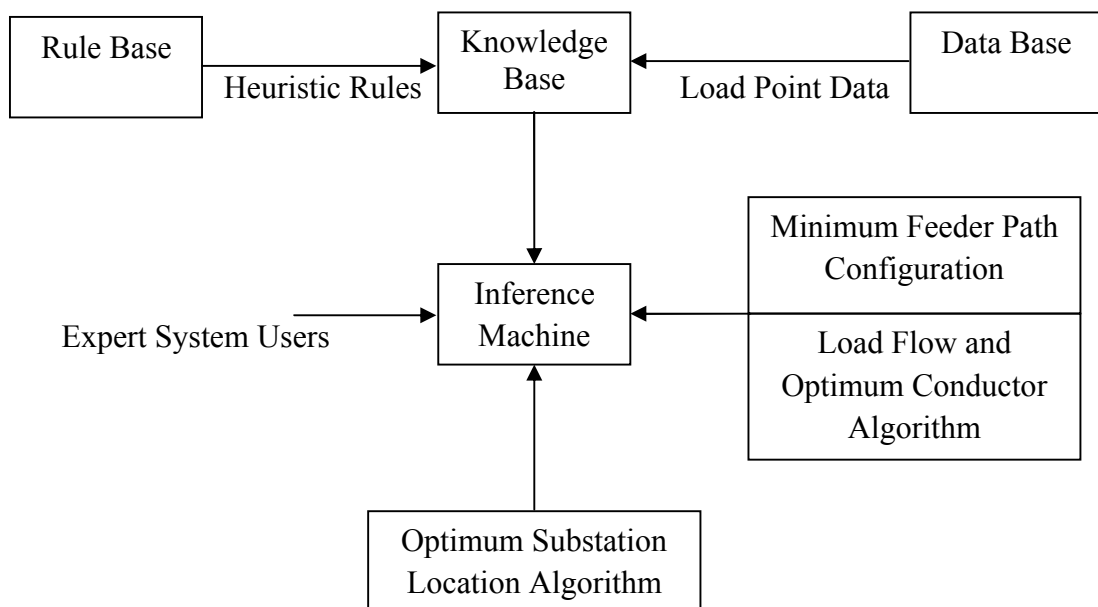


Figure 2.1 Knowledge Based Expert System [22]

Fig.2.1 shows the proposed expert system. It comprises rule base and data base. Data base includes the load data and location of load points and obstacles. Rule base includes the heuristic rules. Inference engine is designed to reach a proper distribution plan based on the data and rules in the knowledge base.

2.4 Heuristic Rules for Load Reallocation [22]

Rules for load allocation established are described below:-

1) Constraints on substations:

Rule 1: If the load of a substation is greater than 70% of the installed capacity of its main transformer, a new substation is needed.

Rule 2: If the load point of a main transformer exceeds 90% of its installed capacity and some of its feeders are overloaded, some loads on these feeders must be reallocated to a main transformer in the new substation. Otherwise, only load transfers between feeders of the same main transformer are required to alleviate feeder overload.

Rule 3: The number of feeders for each main transformer is limited. For example, a main transformer with an installed capacity of 25 MVA is restricted to have at most five feeders.

2) Constraints on feeders:

Rule 4: The current of each feeder is limited to be less than 300 A to avoid overloading.

Rule 5: The desirable peak load of each feeder is between 2800 KVA and 6300 KVA. If the load on a feeder exceeds 6300 KVA, load transfer should be performed on this feeder to reduce the load to a level less than 6300 KVA. For that part of load between 2800 KVA and 6300 KVA, load transfer is optional. If the load on an existing feeder is less than 2800 KVA, no load transfer will be considered.

Rule 6: At most two load points are allowed to connect to the same load point.

Rule 7: The voltage regulation of each load point must be within $\pm 5\%$.

Use of the first rule helps to justify the need for a new substation. Rule 2 can help to identify the main transformers which need load transfer. The loads on the feeders supplied do not need reallocation regardless of the peak loads and maximum currents of these feeders.

2.5 Minimum Power Loss Algorithm [22]

The power loss of a feeder can be expressed as

$$\text{Loss} = (P/V)^2 \times R$$

Where P = power

V = voltage

R = resistance

In reaching a minimal power loss plan for a particular load switching pattern under consideration, the load points to be reallocated to the new substation under that load switching pattern are divided into several zones according to their distances from the load points to the new substation. Figure 2.2 depicts a load switching pattern with eight load points A, B, C, C', D, E, F and G. The new substation is located at the centre of the circles. If the distance from a load point to the new substation is less than u_1 , then load point is within zone 1. If the distance is greater than u_1 and less than $2u_1$, then it is in zone 2, and so forth. Thus, among the eight load points in Figure 2.2, there are five in zone 1 (A, B, C, C', D), two in zone 2 (E and F), and one in zone 3 (G). A rule in addition to rules 3-7 must be followed in reaching a minimum power loss load allocation plan:

Rule 8: The load points, which are concerned together on the original feeder and fall within the same zone, must be connected in the load allocation plan.

For example, if load points C and C' belong to the same feeder in the original plan, they must be connected together under the new allocation plan.

The minimum power loss algorithm proceeds are follows:

Step 1: Reallocate load points in zone 1.

Connect the load points in zone 1 to the new substation forming new feeders of the new substation. The feeders should not violate any of the rules 3-8. Otherwise, the present load switching pattern will be regarded as infeasible and the minimum power loss algorithm terminates.

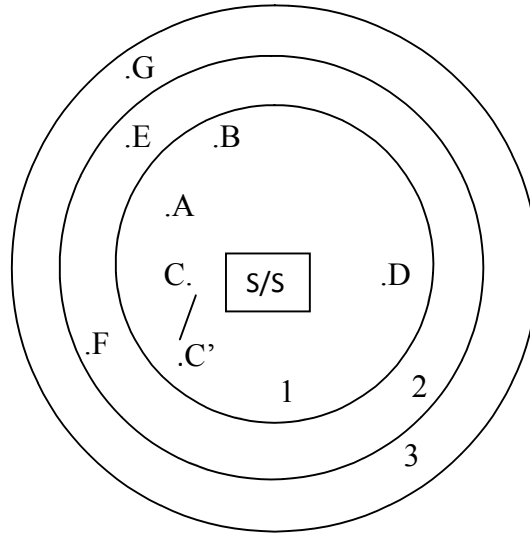


Figure 2.2 A load switching pattern with eight load points

Step 2: Reallocate load points in zone 2.

Connect each load points in zone 2 to any one of the load point in zone 1. The feasible connection which results in minimum power loss is adopted.

Step 3: Repeat the procedure in step 2 for load points in zone 3, 4, etc.

It is noted that the load points in zone ‘i’ can only be connected to a load point in zone i-1. Furthermore, rules 3-8 should not be violated in all cases.

2.6 Solution Methodology

In this work a knowledge based expert system is developed for obtaining optimal feeder path and optimal substation location and it considers all the heuristic rules. Also in this thesis work, a new load flow algorithm for solving radial distribution feeders is presented. Such a load flow algorithm is needed because of its repeated use in the optimization algorithm. Another important feature of this present work is to optimize the branch conductor size of radial distribution feeders. A branch conductor optimization algorithm is also presented based on the proposed new load flow algorithm.

Figure 2.3 shows the single line diagram of a sample radial distribution feeder. In this figure bold number shows the branch number and non bold number shows the node number. Branch number, sending end and receiving end nodes of this feeder have been given in Table-2.1.

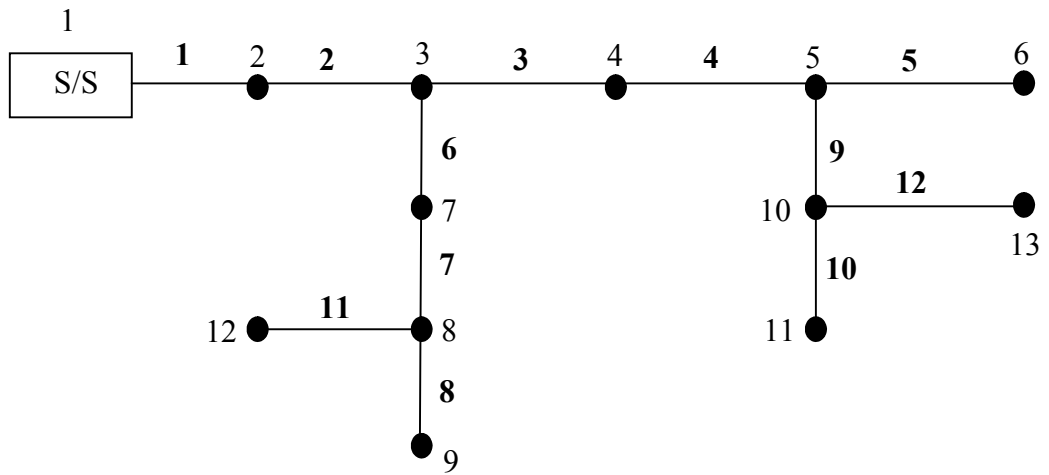


Figure 2.3 Single Line Diagram of Radial Distribution Network

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

Proper selection of branch conductors for connecting the load point is required because it reduces the planning cost also. Although uniform conductor can reduce the loss of the system, it increases the planning cost. A composite should be made between loss and cost. To select the optimum conductor selection, the formula given in [21] is used. Four different types of conductors **Squirrel, Weasel, Rabbit and Raccon** are considered in this work and the data of all conductors are given in **Appendix-E**. The general expression of branch current for branch -jj having k- type conductor is given by

$$I(jj, k) = \sum_{k=1}^{N(jj)} IL\{IE(jj, k), k\} \quad (2.1)$$

where

N (jj) is the total number of nodes beyond branch-jj,

IE(jj,k) is the receiving-end node.

The load current of node ‘i’ is given by

$$IL(i, k) = \frac{PL(i) - jQL(i)}{V^*(i, k)} \quad (2.2)$$

The voltage of node m2 is given by

$$V (m2) = V (m1) - I (jj) Z (jj) \quad (2.3)$$

where 1 = 1, 2, 3.....NB and k = 1, 2.....NTYPE

Equation (2.2) shows that as node voltage are different for different type of conductors; load currents are also different for different type of conductors.

Real and Reactive power losses of branch-jj with k-type conductor are given by:

$$LP(jj,k) = | I(jj,k)|^2 R(jj,k) \quad (2.4)$$

$$LQ(jj,k) = |I(jj,k)|^2 X(jj,k) \quad (2.5)$$

To find the cost of losses, the formula available in [21] is given by:

$$L(i,k) = 10^{-5} \times C1 \times R(k) \times \{P(i)\}^2 \quad (2.6)$$

where

C1 = composite cost of losses (Rs/kW)

R(k) = per unit resistance

L(i) = length of feeder segment i

P(i) = power flow through segment i (kVA)

To calculate the composite cost of losses (C1) the formula available in [21] is given by:

$$C1 = D \times 8760 \times LSF \times E \quad (2.7)$$

where

D = levelized annual demand cost of losses per kW

LSF = Loss factor

E = Energy cost of losses (Rs/kWh)

To calculate the cost of capital [C (i, k)], the formula available in [21] is given by:

$$C (i, k) = CC \times PP(k) \times I(i) \quad (2.8)$$

where

PP (k) = purchase price of conductor k (Rs/Unit length)

L (i) = length of feeder segment i

CC = carrying charge rate (feeders)

The objective function to be minimized is:

$$F(i,k) = L(i,k) + C(i,k) \quad (2.9)$$

The current through the feeder is compared with the maximum current carrying capacity of conductor and proper conductor is selected. The algorithm to find the optimal branch available in [21] is given below:

- Step 1 : Read real system data and assume a flat voltage start
- Step 2 : Identify the nodes beyond all branches.
- Step 3 : $IT = 1$ and $DVMAX = 0.0$
- Step 4 : Calculate the load current using equation (2.2)
- Step 5 : $jj = 1$
- Step 6 : $m1 = IR(jj)$
- Step 7 : $m2 = IS(jj)$
- Step 8 : $k = 1$
- Step 9 : Compute $I(jj, k)$ and $V(m2, k)$ using equation (2.1) and (2.3) respectively.
- Step 10 : Set
 $VV(k) = |V(m2, k)|$ and $CII(k) = |I(jj, k)|$
- Step 11 : Compute $LP(jj, k)$ using equation (2.4).
- Step 12 : Compute $L(jj, k)$ and $CC(jj, k)$ using equation (2.6) and (2.8) respectively.
- Step 13 : Compute $F(jj, k)$ using equation (2.9).
- Step 14 : Set $FN(k) = F(jj, k)$
- Step 15 : $k = k+1$
- Step 16 : If ($k \leq NTYPE$) go to step-9 otherwise go to step 17

- Step 17 : Arrange FN(k) in an ascending order for $k=1, 2, \dots$,
 NTYPE and store different k for ascending order of FN(k)
 in KS(j).
- Step 18 : J6=1
- Step 19 : M33=KS(J6)
- Step 20 : If $\{VV(M33) > V_{\min}$ and $CII(M33) \leq CMAX(M33)\}$
 Go to step 23 otherwise go to step 21
- Step 21 : J6=J6+1
- Step 22 : If $(J6 \leq NTYPE)$ go to step 19
 Otherwise go to step 21
- Step 23 : Compute receiving-end voltage using (2.3)
- Step 24 : Calculate absolute change in voltage at node m2 i.e.,
 $DV(m2) = ABS (|V(m2)| - VV(m2))$
- Step 25 : If $(DV(m2) > DVMAX)$
 $DVMAX = DV(m2)$
- Step 26 : TYPE(jj) = M33
- Step 27 : jj = jj+1
- Step 28 : If $(jj \leq LN1)$ go to step 7
 Otherwise go to step 29.
- Step 29 : If $(DVMAX < \epsilon)$ go to step 31, otherwise go to step 30
- Step 30 : If $(IT \leq ITMAX)$ go to step 6
 Otherwise print diagnostics and go to step 32

Step 31 : Solution has converged, write voltages, power losses, types of conductor for each branch, feeder losses etc.

Step 32 : Stop

2.7 Example

The example is a 71-node radial distribution network shown in Figure 2.4. In figure 2.4, 71 load points are divided into four zones. Each zone has different load points, for example, zone-1 has load points (1, 2, 3, 4....., and 14) and zone-2 has load points (15, 16, 17, 18....., and 29) and so on. In figure 2.4, there are 6 substations shown by red dots (1, 2, 3... and 6). Table 2.2 shows the comparison of investment cost, real power loss and reactive power loss between six substations.

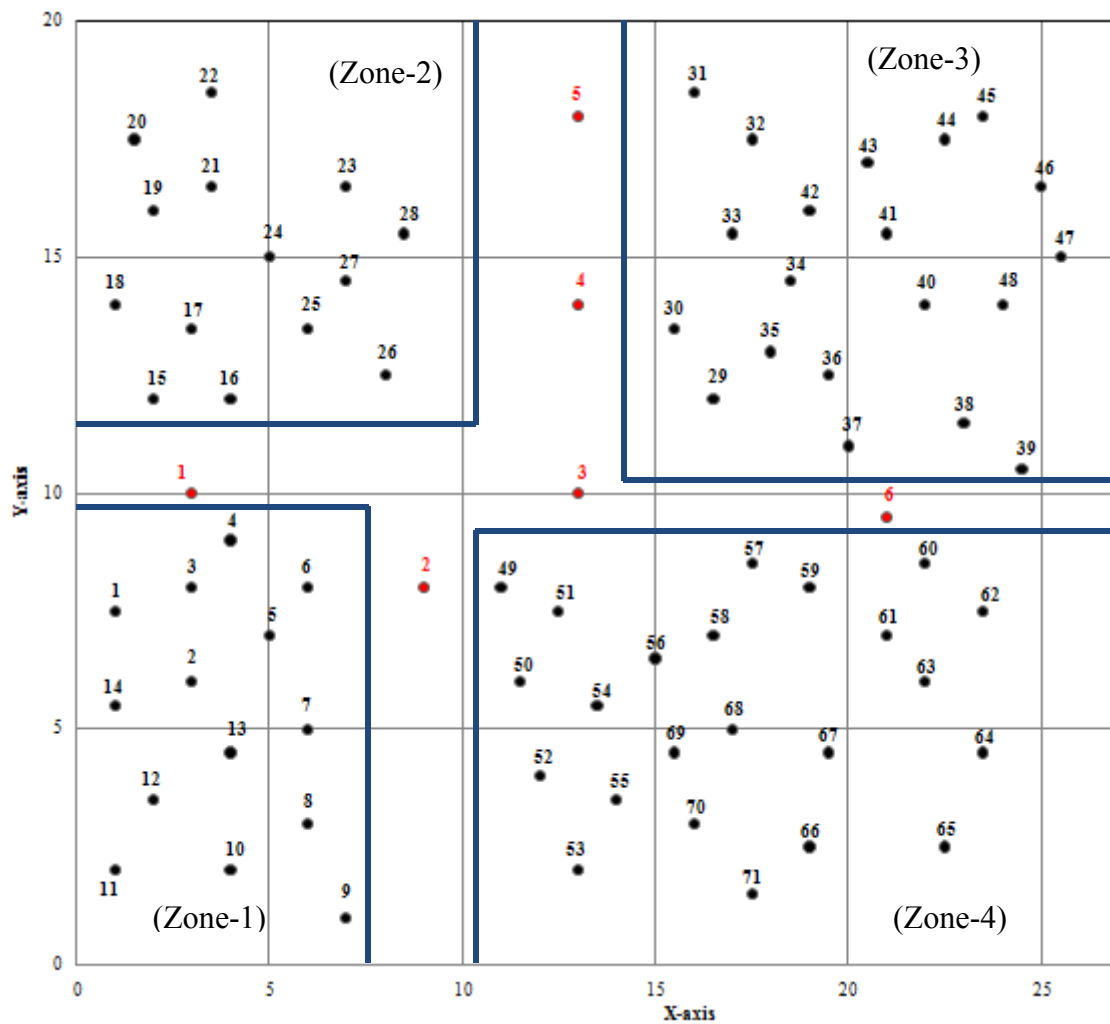


Figure 2.4 Distribution System Load Point Locations

Table 2.2 Comparison of investment cost, real power loss and reactive power loss
between substations

Substation	Coordinate of Substation (x, y) in km	Investment Cost (Rs.)	Real Power Loss (kW)	Reactive Power loss (kVAr)
1	(3, 10)	245036.531250	29.727345	27.047510
2	(9, 8)	208696.406250	23.423223	20.953062
3	(13, 10)	214014.312500	24.243145	21.753937
4	(13, 14)	360036.843750	49.067539	46.185921
5	(13, 18)	428419.812500	60.473412	57.458401
6	(21, 9.5)	239707.187500	28.449852	26.078785

From Table 2.2, it is clear that among all the substations, substation '2' has minimum investment cost, real power loss and reactive power loss. Thus substation '2' is named as new substation and taken as reference for optimum substation location, 71-node radial distribution network.

2.8 Single Feeder Case

For single feeder case it is assumed that only one feeder is emerging from the new substation. Figure 2.5 shows the 71-node radial distribution network for single feeder. Table 2.3 shows the voltage magnitude (p.u.) of 71-node radial distribution network for single feeder. Table 2.4 shows the conductor name, real power loss, reactive power loss and length of each branch of 71-node radial distribution network for single feeder. In case of single feeder total real and reactive power losses are 23.423223 kW and 20.953060 kVAr.

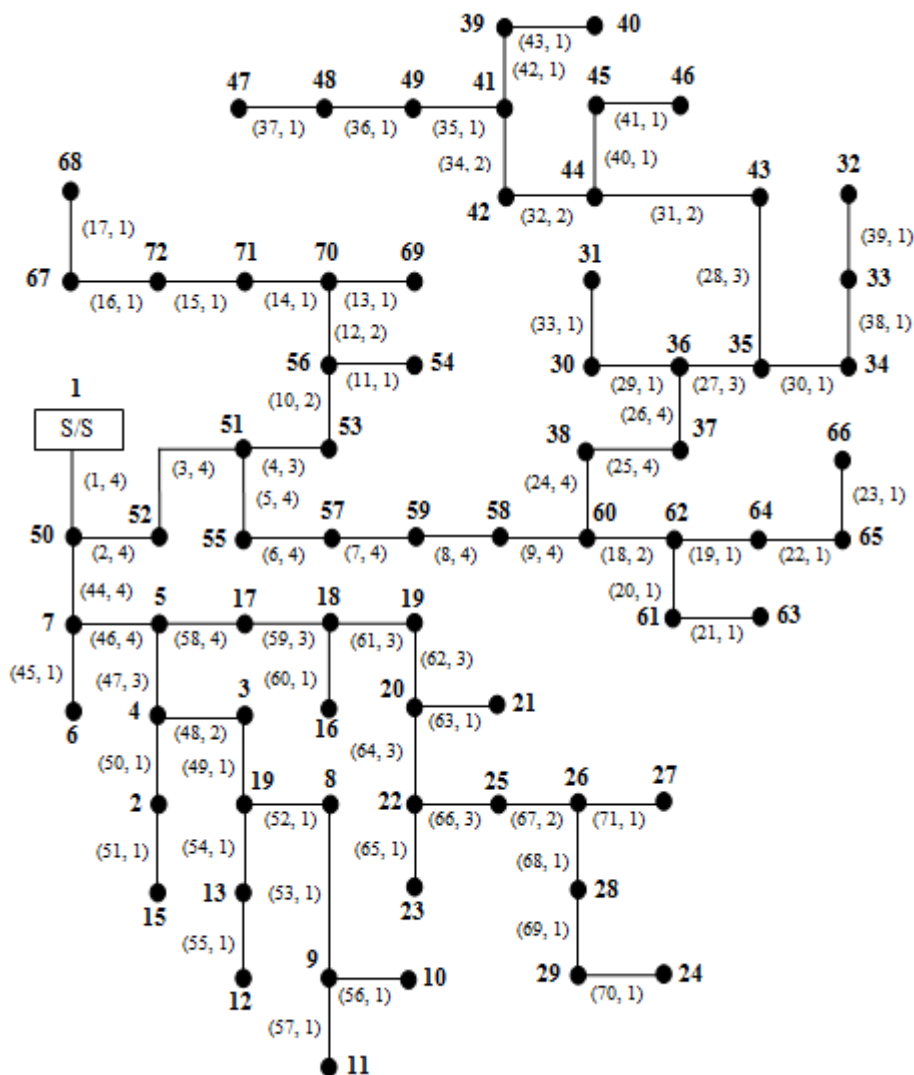


Figure 2.5 71-Nodes Radial Distribution Network for Single Feeder

Table 2.3 Voltage Magnitude of 71-Node Radial Distribution Network for

Single Feeder

Node No.	Voltage Magnitude (p.u.)	Node No.	Voltage Magnitude (p.u.)
1	1.000000	28	0.988449
2	0.992713	29	0.988159
3	0.992463	30	0.986678
4	0.992885	31	0.986544
5	0.993217	32	0.985602
6	0.994263	33	0.985739
7	0.994338	34	0.986053
8	0.991760	35	0.986393
9	0.991524	36	0.986957
10	0.991409	37	0.987518
11	0.991462	38	0.988102
12	0.991898	39	0.984479
13	0.991951	40	0.984419
14	0.992058	41	0.984635
15	0.992641	42	0.985029
16	0.991603	43	0.986011
17	0.992313	44	0.985412
18	0.991651	45	0.985202
19	0.990977	46	0.985141
20	0.990291	47	0.983864
21	0.990229	48	0.983961
22	0.989867	49	0.984206
23	0.989816	50	0.997106
24	0.988036	51	0.994249
25	0.989365	52	0.995747
26	0.988828	53	0.993718
27	0.988595	54	0.992949

55	0.993026	65	0.987957
56	0.993067	66	0.987782
57	0.992004	67	0.991777
58	0.990140	68	0.991705
59	0.991125	69	0.992560
60	0.989298	70	0.992653
61	0.988561	71	0.992328
62	0.988703	72	0.991983
63	0.988518		
64	0.988315		

Table 2.4 Conductor Name, Real power loss, Reactive power loss and Length of 71-Node Radial Distribution Network for Single Feeder

Branch No.	Conductor Name	Real Power Loss (kW)	Reactive Power Loss (kVAr)	Length
1	4---->RACCON	6.385481	6.249285	2.000000
2	4---->RACCON	1.783015	1.744985	1.581139
3	4---->RACCON	1.897145	1.856681	1.802776
4	3---->RABBIT	0.191511	0.129282	2.061553
5	4---->RACCON	1.107148	1.083534	2.061553
6	4---->RACCON	0.883750	0.864900	1.802776
7	4---->RACCON	0.744369	0.728493	1.581139
8	4---->RACCON	0.821452	0.803931	1.802776
9	4---->RACCON	0.684686	0.670083	1.581139
10	2---->WEASEL	0.233242	0.097236	2.061553
11	1---->SQUIRREL	0.006989	0.001979	1.802776
12	2---->WEASEL	0.108375	0.045180	1.802776
13	1---->SQUIRREL	0.004869	0.001379	1.581139

14	1---->SQUIRREL	0.060070	0.017008	1.581139
15	1---->SQUIRREL	0.050397	0.014269	2.121320
16	1---->SQUIRREL	0.021343	0.006043	1.802776
17	1---->SQUIRREL	0.002227	0.000631	2.061553
18	2---->WEASEL	0.179330	0.074760	2.236068
19	1---->SQUIRREL	0.095989	0.027178	1.414214
20	1---->SQUIRREL	0.010154	0.002875	1.802776
21	1---->SQUIRREL	0.000932	0.000264	1.802776
22	1---->SQUIRREL	0.054605	0.015461	2.121320
23	1---->SQUIRREL	0.012234	0.003464	2.236068
24	4---->RACCON	0.689337	0.674634	3.162278
25	4---->RACCON	0.328413	0.321408	1.581139
26	4---->RACCON	0.303531	0.297057	1.581139
27	3---->RABBIT	0.281522	0.190044	1.581139
28	3---->RABBIT	0.129089	0.087143	1.581139
29	1---->SQUIRREL	0.038942	0.011026	1.802776
30	1---->SQUIRREL	0.057783	0.016361	1.802776
31	2---->WEASEL	0.225811	0.094138	1.802776
32	2---->WEASEL	0.105498	0.043981	1.581139
33	1---->SQUIRREL	0.008997	0.002547	1.802776
34	2---->WEASEL	0.098072	0.040885	1.802776
35	1---->SQUIRREL	0.082689	0.023413	2.000000
36	1---->SQUIRREL	0.030045	0.008507	1.802776
37	1---->SQUIRREL	0.005368	0.001520	1.581139
38	1---->SQUIRREL	0.043244	0.012244	2.061553
39	1---->SQUIRREL	0.009307	0.002635	1.802776
40	1---->SQUIRREL	0.019391	0.005490	2.061553
41	1---->SQUIRREL	0.002948	0.000835	1.118034
42	1---->SQUIRREL	0.008088	0.002290	2.692582
43	1---->SQUIRREL	0.001843	0.000522	1.802776
44	4---->RACCON	2.336812	2.286970	5.000000
45	1---->SQUIRREL	0.003660	0.001036	1.414214

46	4---->RACCON	0.858241	0.839936	2.236068
47	3---->RABBIT	0.108608	0.073317	1.414214
48	2---->WEASEL	0.101229	0.042201	2.000000
49	1---->SQUIRREL	0.081867	0.023180	1.802776
50	1---->SQUIRREL	0.012953	0.003667	2.061553
51	1---->SQUIRREL	0.002308	0.000654	2.000000
52	1---->SQUIRREL	0.038793	0.010984	2.061553
53	1---->SQUIRREL	0.025197	0.007134	2.000000
54	1---->SQUIRREL	0.004595	0.001301	2.236068
55	1---->SQUIRREL	0.001447	0.000410	1.802776
56	1---->SQUIRREL	0.005315	0.001505	2.236068
57	1---->SQUIRREL	0.001520	0.000431	2.236068
58	4---->RACCON	0.414962	0.406111	3.000000
59	3---->RABBIT	0.340216	0.229666	1.802776
60	1---->SQUIRREL	0.001121	0.000317	1.802776
61	3---->RABBIT	0.308212	0.208062	2.061553
62	3---->RABBIT	0.293683	0.198253	2.236068
63	1---->SQUIRREL	0.002219	0.000628	1.581139
64	3---->RABBIT	0.159326	0.107555	1.581139
65	1---->SQUIRREL	0.001137	0.000322	2.000000
66	3---->RABBIT	0.165825	0.111942	2.121320
67	2---->WEASEL	0.181581	0.075699	1.802776
68	1---->SQUIRREL	0.091807	0.025994	1.414214
69	1---->SQUIRREL	0.041892	0.011861	1.802776
70	1---->SQUIRREL	0.007581	0.002147	1.802776
71	1---->SQUIRREL	0.021882	0.006196	2.236068

2.9 Double Feeder Case

For double feeder case it is assumed that two feeders are emerging from the new substation. Figure 2.6 shows the 71-node radial distribution network for double feeder. Table 2.5 shows the voltage magnitude (p.u.) of 71-node radial distribution network for double feeder. Table 2.6 shows the conductor name, real power loss, reactive power loss

and length of each branch of 71-node radial distribution network for double feeder. In case of double feeder total real and reactive power losses are 18.540833 kW and 16.115341 kVAr.

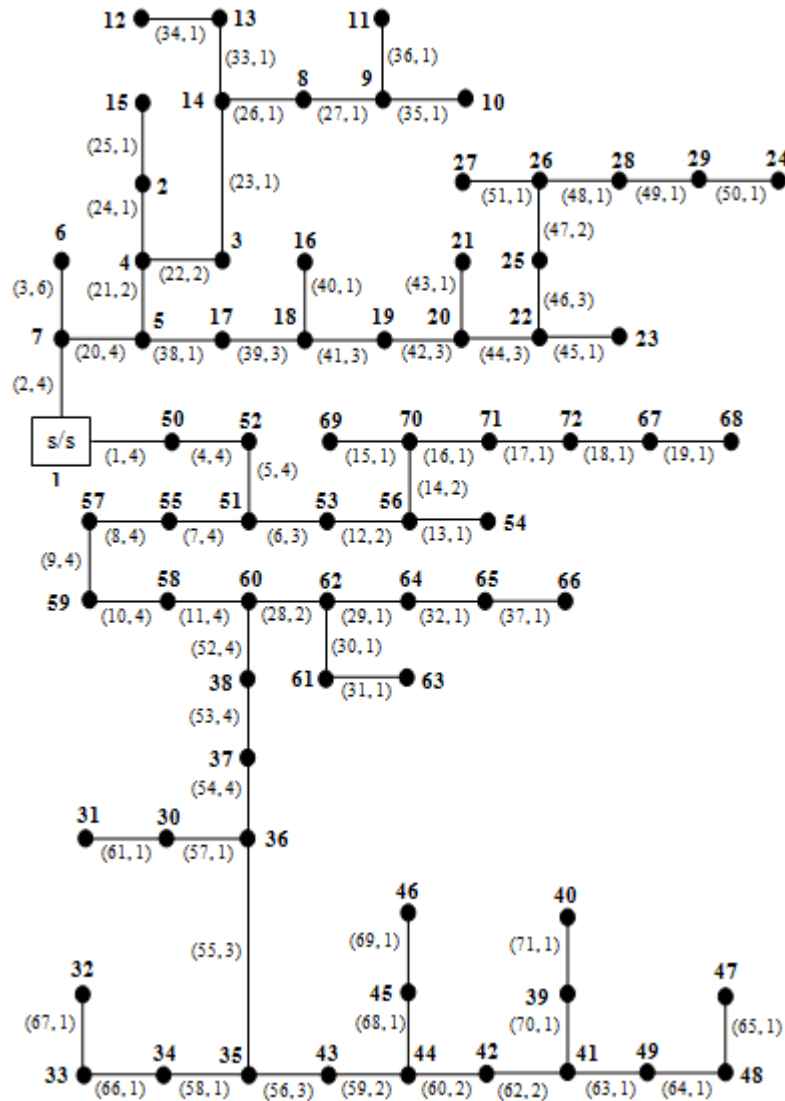


Figure 2.6 71 - Node Radial Distribution Network for Double Feeder

Table 2.5 Voltage Magnitude (p.u.) of 71-Node Radial Distribution Network for

Double Feeder

Node No.	Voltage Magnitude (p.u.)	Node No.	Voltage Magnitude (p.u.)
1	1.000000	27	0.992626
2	0.996583	28	0.992480
3	0.996334	29	0.992192
4	0.996755	30	0.987799
5	0.997229	31	0.987665
6	0.998270	32	0.986724
7	0.998346	33	0.986861
8	0.995634	34	0.987175
9	0.995399	35	0.987514
10	0.995284	36	0.988078
11	0.995337	37	0.988638
12	0.995771	38	0.989221
13	0.995825	39	0.985603
14	0.995931	40	0.985542
15	0.996512	41	0.985758
16	0.995622	42	0.986152
17	0.996329	43	0.987133
18	0.995669	44	0.986535
19	0.994998	45	0.986324
20	0.994315	46	0.986264
21	0.994253	47	0.984988
22	0.993892	48	0.985085
23	0.993842	49	0.985330
24	0.992069	50	0.998215
25	0.993393	51	0.995362
26	0.992858	52	0.996857

53	0.994831	63	0.989636
54	0.994063	64	0.989434
55	0.994140	65	0.989076
56	0.994181	66	0.988902
57	0.993119	67	0.992892
58	0.991257	68	0.992820
59	0.992241	69	0.993674
60	0.990415	70	0.993767
61	0.989680	71	0.993442
62	0.989822	72	0.993098

Table 2.6 Conductor Name, Real Power Loss, Reactive Power Loss and Length of 71-Node Radial Distribution Network for Double Feeder

Branch No.	Conductor Name	Real Power Loss (kW)	Reactive Power Loss (kVAr)	Length
1	4---->RACCON	2.428541	2.376743	2.000000
2	4---->RACCON	1.390910	1.361244	3.000000
3	1---->SQUIRREL	0.003631	0.001028	1.414214
4	4---->RACCON	1.778988	1.741044	1.581139
5	4---->RACCON	1.892859	1.852486	1.802776
6	3---->RABBIT	0.191082	0.128992	2.061553
7	4---->RACCON	1.104638	1.081077	2.061553
8	4---->RACCON	0.881745	0.862938	1.802776
9	4---->RACCON	0.742680	0.726840	1.581139
10	4---->RACCON	0.819588	0.802107	1.802776
11	4---->RACCON	0.683132	0.668562	1.581139
12	2---->WEASEL	0.232719	0.097018	2.061553
13	1---->SQUIRREL	0.006973	0.001974	1.802776

14	2---->WEASEL	0.108132	0.045079	1.802776
15	1---->SQUIRREL	0.004858	0.001376	1.581139
16	1---->SQUIRREL	0.059935	0.016970	1.581139
17	1---->SQUIRREL	0.050284	0.014237	2.121320
18	1---->SQUIRREL	0.021296	0.006030	1.802776
19	1---->SQUIRREL	0.002222	0.000629	2.061553
20	4---->RACCON	0.851404	0.833244	2.236068
21	2---->WEASEL	0.180395	0.075204	1.414214
22	2---->WEASEL	0.100443	0.041873	2.000000
23	1---->SQUIRREL	0.081231	0.023000	1.802776
24	1---->SQUIRREL	0.012852	0.003639	2.061553
25	1---->SQUIRREL	0.002290	0.000648	2.000000
26	1---->SQUIRREL	0.038492	0.010899	2.061553
27	1---->SQUIRREL	0.025001	0.007079	2.000000
28	2---->WEASEL	0.178924	0.074591	2.236068
29	1---->SQUIRREL	0.095772	0.027117	1.414214
30	1---->SQUIRREL	0.010131	0.002868	1.802776
31	1---->SQUIRREL	0.000930	0.000263	1.802776
32	1---->SQUIRREL	0.054481	0.015426	2.121320
33	1---->SQUIRREL	0.004559	0.001291	2.236068
34	1---->SQUIRREL	0.001436	0.000407	1.802776
35	1---->SQUIRREL	0.005274	0.001493	2.236068
36	1---->SQUIRREL	0.001509	0.000427	2.236068
37	1---->SQUIRREL	0.012207	0.003456	2.236068
38	4---->RACCON	0.411605	0.402826	3.000000
39	3---->RABBIT	0.337463	0.227808	1.802776
40	1---->SQUIRREL	0.001112	0.000315	1.802776
41	3---->RABBIT	0.305717	0.206377	2.061553
42	3---->RABBIT	0.291304	0.196648	2.236068
43	1---->SQUIRREL	0.002201	0.000623	1.581139
44	3---->RABBIT	0.158035	0.106683	1.581139
45	1---->SQUIRREL	0.001128	0.000319	2.000000

46	3---->RABBIT	0.164481	0.111035	2.121320
47	2---->WEASEL	0.180109	0.075085	1.802776
48	1---->SQUIRREL	0.091062	0.025783	1.414214
49	1---->SQUIRREL	0.041553	0.011765	1.802776
50	1---->SQUIRREL	0.007520	0.002129	1.802776
51	1---->SQUIRREL	0.021704	0.006145	2.236068
52	4---->RACCON	0.687770	0.673100	3.162278
53	4---->RACCON	0.327666	0.320677	1.581139
54	4---->RACCON	0.302841	0.296382	1.581139
55	3---->RABBIT	0.280881	0.189612	1.581139
56	3---->RABBIT	0.128795	0.086944	1.581139
57	1---->SQUIRREL	0.038853	0.011001	1.802776
58	1---->SQUIRREL	0.057652	0.016324	1.802776
59	2---->WEASEL	0.225297	0.093923	1.802776
60	2---->WEASEL	0.105257	0.043880	1.581139
61	1---->SQUIRREL	0.008976	0.002542	1.802776
62	2---->WEASEL	0.097849	0.040792	1.802776
63	1---->SQUIRREL	0.082501	0.023359	2.000000
64	1---->SQUIRREL	0.029976	0.008487	1.802776
65	1---->SQUIRREL	0.005356	0.001516	1.581139
66	1---->SQUIRREL	0.043146	0.012216	2.061553
67	1---->SQUIRREL	0.009286	0.002629	1.802776
68	1---->SQUIRREL	0.019347	0.005478	2.061553
69	1---->SQUIRREL	0.002941	0.000833	1.118034
70	1---->SQUIRREL	0.008070	0.002285	2.692582
71	1---->SQUIRREL	0.001839	0.000521	1.802776

2.10 Three Feeder Case

For three feeder case it is assumed that three feeders are emerging from the new substation. Figure 2.7 shows the 71-node radial distribution network for three feeders. Table 2.7 shows the voltage magnitude (p.u.) of 71-node radial distribution network for three feeders. Table 2.8 shows the conductor name, real power loss, reactive power loss

and length of each branch of 71-node radial distribution network for three feeders. In case of three feeders total real and reactive power losses are 15.809650 kW and 13.410593 kVAr.

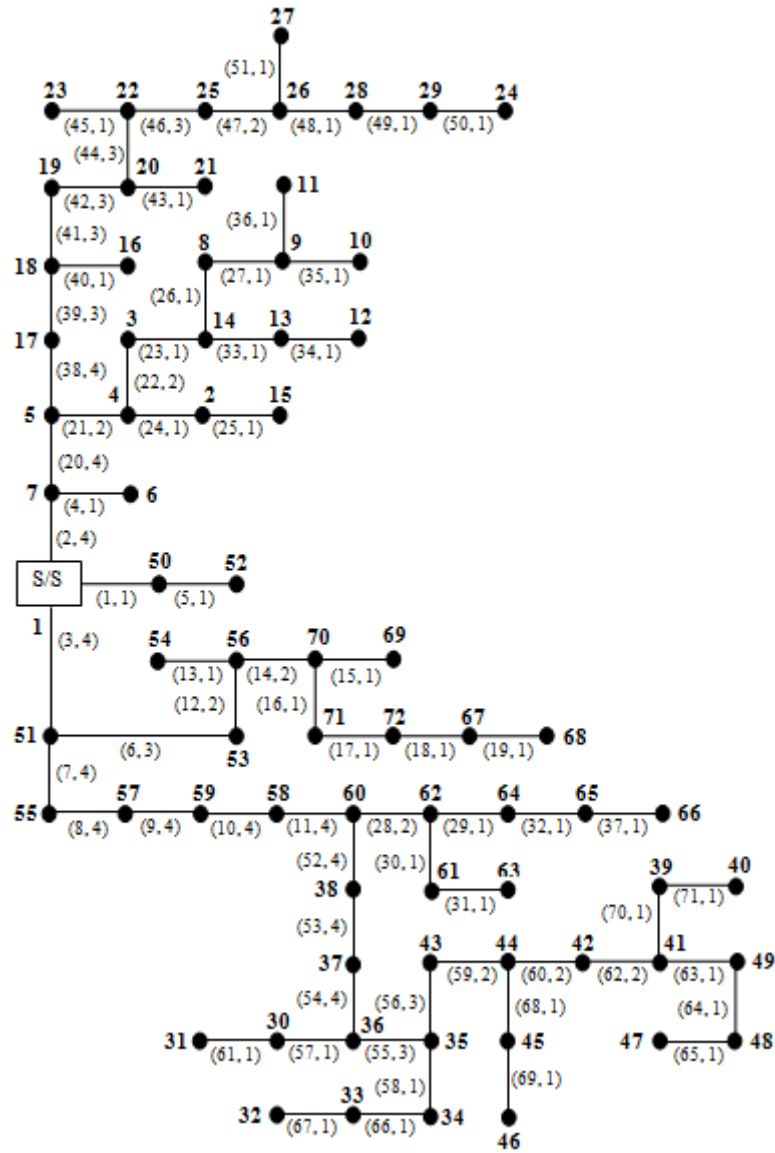


Figure 2.7 71-Nodes Radial Distribution Network for Three Feeders

Table 2.7 Voltage Magnitude (p.u.) of 71-Node Radial Distribution Network
for Three Feeders

Node No.	Voltage Magnitude (p.u.)	Node No.	Voltage Magnitude (p.u.)
1	1.000000	28	0.992480
2	0.996583	29	0.992192
3	0.996334	30	0.989802
4	0.996755	31	0.989668
5	0.997229	32	0.988729
6	0.998270	33	0.988865
7	0.998346	34	0.989179
8	0.995634	35	0.989518
9	0.995399	36	0.990080
10	0.995284	37	0.990639
11	0.995337	38	0.991221
12	0.995771	39	0.987610
13	0.995825	40	0.987549
14	0.995931	41	0.987765
15	0.996512	42	0.988158
16	0.995622	43	0.989137
17	0.996329	44	0.988540
18	0.995669	45	0.988330
19	0.994998	46	0.988270
20	0.994315	47	0.986997
21	0.994253	48	0.987093
22	0.993892	49	0.987338
23	0.993842	50	0.999685
24	0.992069	51	0.997349
25	0.993393	52	0.999569
26	0.992858	53	0.996819
27	0.992626	54	0.996053

55	0.996129	67	0.994884
56	0.996171	68	0.994813
57	0.995111	69	0.995665
58	0.993253	70	0.995757
59	0.994235	71	0.995434
60	0.992413	72	0.995090
61	0.991678		
62	0.991821		
63	0.991635		
64	0.991434		
65	0.991076		
66	0.990902		

Table 2.8 Conductor Name, Length Real Power Loss and Reactive Power

Loss of 71-Node Radial Distribution Network for Three Feeders

Branch No.	Conductor Name	Real Power Loss (kW)	Reactive Power Loss (kVAr)	Length
1	1---->SQUIRREL	0.044735	0.012666	2.000000
2	4---->RACCON	1.390910	1.361244	3.000000
3	4---->RACCON	3.348006	3.276597	3.201562
4	1---->SQUIRREL	0.003631	0.001028	1.414214
5	1---->SQUIRREL	0.007686	0.002176	1.581139
6	3---->RABBIT	0.190319	0.128477	2.061553
7	4---->RACCON	1.100175	1.076709	2.061553
8	4---->RACCON	0.878181	0.859450	1.802776
9	4---->RACCON	0.739678	0.723901	1.581139
10	4---->RACCON	0.816274	0.798863	1.802776
11	4---->RACCON	0.680369	0.665858	1.581139
12	2---->WEASEL	0.231790	0.096630	2.061553
13	1---->SQUIRREL	0.006945	0.001966	1.802776
14	2---->WEASEL	0.107700	0.044899	1.802776
15	1---->SQUIRREL	0.004839	0.001370	1.581139
16	1---->SQUIRREL	0.059695	0.016902	1.581139
17	1---->SQUIRREL	0.050083	0.014180	2.121320
18	1---->SQUIRREL	0.021210	0.006005	1.802776
19	1---->SQUIRREL	0.002214	0.000627	2.061553
20	4---->RACCON	0.851404	0.833244	2.236068
21	2---->WEASEL	0.180395	0.075204	1.414214
22	2---->WEASEL	0.100443	0.041873	2.000000
23	1---->SQUIRREL	0.081231	0.023000	1.802776
24	1---->SQUIRREL	0.012852	0.003639	2.061553
25	1---->SQUIRREL	0.002290	0.000648	2.000000
26	1---->SQUIRREL	0.038492	0.010899	2.061553

27	1---->SQUIRREL	0.025001	0.007079	2.000000
28	2---->WEASEL	0.178203	0.074291	2.236068
29	1---->SQUIRREL	0.095386	0.027008	1.414214
30	1---->SQUIRREL	0.010090	0.002857	1.802776
31	1---->SQUIRREL	0.000927	0.000262	1.802776
32	1---->SQUIRREL	0.054261	0.015364	2.121320
33	1---->SQUIRREL	0.004559	0.001291	2.236068
34	1---->SQUIRREL	0.001436	0.000407	1.802776
35	1---->SQUIRREL	0.005274	0.001493	2.236068
36	1---->SQUIRREL	0.001509	0.000427	2.236068
37	1---->SQUIRREL	0.012157	0.003442	2.236068
38	4---->RACCON	0.411605	0.402826	3.000000
39	3---->RABBIT	0.337463	0.227808	1.802776
40	1---->SQUIRREL	0.001112	0.000315	1.802776
41	3---->RABBIT	0.305717	0.206377	2.061553
42	3---->RABBIT	0.291304	0.196648	2.236068
43	1---->SQUIRREL	0.002201	0.000623	1.581139
44	3---->RABBIT	0.158035	0.106683	1.581139
45	1---->SQUIRREL	0.001128	0.000319	2.000000
46	3---->RABBIT	0.164481	0.111035	2.121320
47	2---->WEASEL	0.180109	0.075085	1.802776
48	1---->SQUIRREL	0.091062	0.025783	1.414214
49	1---->SQUIRREL	0.041553	0.011765	1.802776
50	1---->SQUIRREL	0.007520	0.002129	1.802776
51	1---->SQUIRREL	0.021704	0.006145	2.236068
52	4---->RACCON	0.684984	0.670374	3.162278
53	4---->RACCON	0.326339	0.319378	1.581139
54	4---->RACCON	0.301614	0.295181	1.581139
55	3---->RABBIT	0.279742	0.188843	1.581139
56	3---->RABBIT	0.128272	0.086591	1.581139
57	1---->SQUIRREL	0.038696	0.010956	1.802776
58	1---->SQUIRREL	0.057418	0.016257	1.802776

59	2---->WEASEL	0.224383	0.093542	1.802776
60	2---->WEASEL	0.104830	0.043702	1.581139
61	1---->SQUIRREL	0.008940	0.002531	1.802776
62	2---->WEASEL	0.097451	0.040626	1.802776
63	1---->SQUIRREL	0.082165	0.023264	2.000000
64	1---->SQUIRREL	0.029855	0.008453	1.802776
65	1---->SQUIRREL	0.005334	0.001510	1.581139
66	1---->SQUIRREL	0.042971	0.012167	2.061553
67	1---->SQUIRREL	0.009248	0.002619	1.802776
68	1---->SQUIRREL	0.019268	0.005456	2.061553
69	1---->SQUIRREL	0.002929	0.000829	1.118034
70	1---->SQUIRREL	0.008037	0.002276	2.692582
71	1---->SQUIRREL	0.001831	0.000518	1.802776

2.11 Final Results

Table 2.9 shows the comparison of the investment cost, real and reactive power losses between single feeder case, double feeder case and three feeder case. The number of iterations for single feeder case, double feeder case and three feeder case are three. The result shows that real and reactive power losses are reduced of the radial distribution network. The result also shows that there is a reduction in investment cost of the radial distribution network.

Table 2.9 Comparison of Investment Cost, Real and Reactive Power Losses

	Number of Iterations	Investment Cost (Rs.)	Real Power Loss (kW)	Reactive Power Loss (kVAr)
Single Feeder Case	3	208696.406250	23.423223	20.953060
Double Feeder Case	3	178003.250000	18.540833	16.115341
Three Feeder Case	3	160938.343750	15.809650	13.410593

CHAPTER - 3 CONCLUSION AND FUTURE SCOPE OF THE WORK

3.1 Conclusion

An attempt has been made to develop a knowledge based expert system for distribution system planning. New algorithms have been developed to obtain optimum feeder path configuration and optimum location of substation based on minimum loss criteria. Proposed distribution system planning algorithm can handle all the heuristic rules. A new load flow algorithm for solving radial distribution feeders has also been proposed which helps to find out the optimal size of branch conductor and optimal location of substation.

3.2 Future Scope of the Work

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

- Evolutionary algorithms for power distribution network expansion planning problems using the edge-set encoding technique.
- PSO based planning of distribution systems.

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Appendix A

Table A Load Point Data of 71-Node Optimum Radial Distribution System

Load Points	Coordinates (x, y)	Load Points	Coordinates (x, y)
1	(1, 7.5)	17	(3, 13.5)
2	(3, 6)	18	(1, 14)
3	(3, 8)	19	(2, 16)
4	(4, 9)	20	(1.5, 17.5)
5	(5, 7)	21	(3.5, 16.5)
6	(6, 8)	22	(3.5, 18.5)
7	(6, 5)	23	(7, 16.5)
8	(6, 3)	24	(5, 15)
9	(7, 1)	25	(6, 13.5)
10	(4, 2)	26	(8, 12.5)
11	(1, 2)	27	(7, 14.5)
12	(2, 3.5)	28	(8.5, 15.5)
13	(4, 4.5)	29	(16.5, 12)
14	(1, 5.5)	30	(15.5, 13.5)
15	(2, 12)	31	(16, 18.5)
16	(4, 12)	32	(17.5, 17.5)

33	(17, 15.5)	53	(13, 2)
34	(18.5, 14.5)	54	(13.5, 5.5)
35	(18, 13)	55	(14, 3.5)
36	(19.5, 12.5)	56	(15, 6.5)
37	(20, 11)	57	(17.5, 8.5)
38	(23, 11.5)	58	(16.5, 7)
39	(24.5, 10.5)	59	(19, 8)
40	(22, 14)	60	(22, 8.5)
41	(21, 15.5)	61	(21, 7)
42	(19, 16)	62	(23.5, 7.5)
43	(20.5, 17)	63	(22, 6)
44	(22.5, 17.5)	64	(23.5, 4.5)
45	(23.5, 18)	65	(22.5, 2.5)
46	(25, 16.5)	66	(19, 2.5)
47	(25.5, 15)	67	(19.5, 4.5)
48	(24, 14)	68	(17, 5)
49	(11, 8)	69	(15.5, 4.5)
50	(11.5, 6)	70	(16, 3)
51	(12.5, 7.5)	71	(17.5, 1.5)
52	(12, 4)		

Appendix B

Table B.1 Line Data of 71 Node Radial Distribution Network for Single Feeder

Branch No.	Sending End Node	Receiving End Node	Resistance (p.u.)	Reactance (p.u.)
1	1	50	0.067163	0.065730
2	50	52	0.053097	0.051964
3	52	51	0.060540	0.059248
4	51	53	0.103002	0.069532
5	51	55	0.069230	0.067753
6	55	57	0.060540	0.059248
7	57	59	0.053097	0.051964
8	59	58	0.060540	0.059248
9	58	60	0.053097	0.051964
10	53	56	0.172421	0.071880
11	56	54	0.227789	0.064496
12	56	70	0.150778	0.062857
13	70	69	0.199784	0.056567
14	70	71	0.199784	0.056567
15	71	72	0.268038	0.075892
16	72	67	0.227789	0.064496
17	67	68	0.260486	0.073754
18	60	62	0.187017	0.077965
19	62	64	0.178692	0.050595
20	62	61	0.227789	0.064496
21	61	63	0.227789	0.064496
22	64	65	0.268038	0.075892
23	65	66	0.282537	0.079997
24	60	38	0.106193	0.103928
25	38	37	0.053097	0.051964
26	37	36	0.053097	0.051964
27	36	35	0.078999	0.053329

28	35	43	0.078999	0.053329
29	36	30	0.227789	0.064496
30	35	34	0.227789	0.064496
31	43	44	0.150778	0.062857
32	44	42	0.132241	0.055129
33	30	31	0.227789	0.064496
34	42	41	0.150778	0.062857
35	41	49	0.252709	0.071552
36	49	48	0.227789	0.064496
37	48	47	0.199784	0.056567
38	34	33	0.260486	0.073754
39	33	32	0.227789	0.064496
40	44	45	0.260486	0.073754
41	45	46	0.141269	0.039999
42	41	39	0.340220	0.096330
43	39	40	0.227789	0.064496
44	50	7	0.167906	0.164325
45	7	6	0.178692	0.050595
46	7	5	0.075090	0.073488
47	5	4	0.070659	0.047699
48	4	3	0.167273	0.069734
49	3	14	0.227789	0.064496
50	4	2	0.260486	0.073754
51	2	15	0.252709	0.071552
52	14	8	0.260486	0.073754
53	8	9	0.252709	0.071552
54	14	13	0.282537	0.079997
55	13	12	0.227789	0.064496
56	9	10	0.282537	0.079997
57	9	11	0.282537	0.079997
58	5	17	0.100744	0.098595
59	17	18	0.090073	0.060804

60	18	16	0.227789	0.064496
61	18	19	0.103002	0.069532
62	19	20	0.111721	0.075419
63	20	21	0.199784	0.056567
64	20	22	0.078999	0.053329
65	22	23	0.252709	0.071552
66	22	25	0.105988	0.071548
67	25	26	0.150778	0.062857
68	26	28	0.178692	0.050595
69	28	29	0.227789	0.064496
70	29	24	0.227789	0.064496
71	26	27	0.282537	0.079997

Table B.2 Load Data of 71 Node Radial Distribution Network for Single Feeder

Node No.	Real Power (MW)	Reactive Power (MVar)
2	53.249998	46.962086
3	46.499999	41.009145
4	55.499998	48.946397
5	47.249999	41.670582
6	42.000000	37.040521
7	18.000000	15.874508
8	14.249999	12.567319
9	21.750000	19.181697
10	15.000001	13.228758
11	33.000001	29.103263
12	41.250000	36.379081
13	33.750001	29.764703
14	36.750000	32.410453
15	26.999999	23.811762
16	30.000001	26.457515
17	50.249998	44.316333
18	21.750000	19.181697
19	8.250000	7.275816
20	66.000002	58.206526
21	34.500001	30.426140
22	15.000001	13.228758
23	56.999997	50.269277
24	48.749999	42.993459
25	14.249999	12.567319
26	22.500000	19.843136
27	21.000000	18.520260
28	24.749999	21.827448
29	12.750000	11.244443
30	50.249998	44.316333

31	22.500000	19.843136
32	13.499999	11.905881
33	20.250000	17.858822
34	46.499999	41.009145
35	18.750000	16.535945
36	48.749999	42.993459
37	46.499999	41.009145
38	38.250000	33.733330
39	47.999999	42.332019
40	47.249999	41.670582
41	30.000001	26.457515
42	33.750001	29.764703
43	15.000001	13.228758
44	21.000000	18.520260
45	48.749999	42.993459
46	33.750001	29.764703
47	26.249999	23.150323
48	56.249998	49.607840
49	42.000000	37.040521
50	20.250000	17.858822
51	30.000001	26.457515
52	22.500000	19.843136
53	16.500000	14.551631
54	24.749999	21.827448
55	11.250000	9.921567
56	18.750000	16.535945
57	32.250001	28.441829
58	17.250000	15.213070
59	20.250000	17.858822
60	33.750001	29.764703
61	16.500000	14.551631
62	25.499999	22.488886

63	22.500000	19.843136
64	24.749999	21.827448
65	23.999999	21.166010
66	15.750001	13.890195
67	36.000001	31.749016
68	23.999999	21.166010
69	67.500002	59.529406
70	57.749997	50.930714
71	42.750000	37.701958
72	65.250002	57.545089

Appendix C

Table C.1 Line Data of 71 Node Radial Distribution Network for Double Feeder

Branch No.	Sending End Node	Receiving End Node	Resistance (p.u.)	Reactance (p.u.)
1	1	50	0.067163	0.065730
2	1	7	0.100744	0.098595
3	7	6	0.178692	0.050595
4	50	52	0.053097	0.051964
5	52	51	0.060540	0.059248
6	51	53	0.103002	0.069532
7	51	55	0.069230	0.067753
8	55	57	0.060540	0.059248
9	57	59	0.053097	0.051964
10	59	58	0.060540	0.059248
11	58	60	0.053097	0.051964
12	53	56	0.172421	0.071880
13	56	54	0.227789	0.064496
14	56	70	0.150778	0.062857
15	70	69	0.199784	0.056567
16	70	71	0.199784	0.056567
17	71	72	0.268038	0.075892
18	72	67	0.227789	0.064496
19	67	68	0.260486	0.073754
20	7	5	0.075090	0.073488
21	5	4	0.118280	0.049309
22	4	3	0.167273	0.069734
23	3	14	0.227789	0.064496
24	4	2	0.260486	0.073754
25	2	15	0.252709	0.071552
26	14	8	0.260486	0.073754
27	8	9	0.252709	0.071552

28	60	62	0.187017	0.077965
29	62	64	0.178692	0.050595
30	62	61	0.227789	0.064496
31	61	63	0.227789	0.064496
32	64	65	0.268038	0.075892
33	14	13	0.282537	0.079997
34	13	12	0.227789	0.064496
35	9	10	0.282537	0.079997
36	9	11	0.282537	0.079997
37	65	66	0.282537	0.079997
38	5	17	0.100744	0.098595
39	17	18	0.090073	0.060804
40	18	16	0.227789	0.064496
41	18	19	0.103002	0.069532
42	19	20	0.111721	0.075419
43	20	21	0.199784	0.056567
44	20	22	0.078999	0.053329
45	22	23	0.252709	0.071552
46	22	25	0.105988	0.071548
47	25	26	0.150778	0.062857
48	26	28	0.178692	0.050595
49	28	29	0.227789	0.064496
50	29	24	0.227789	0.064496
51	26	27	0.282537	0.079997
52	60	38	0.106193	0.103928
53	38	37	0.053097	0.051964
54	37	36	0.053097	0.051964
55	36	35	0.078999	0.053329
56	35	43	0.078999	0.053329
57	36	30	0.227789	0.064496
58	35	34	0.227789	0.064496
59	43	44	0.150778	0.062857

60	44	42	0.132241	0.055129
61	30	31	0.227789	0.064496
62	42	41	0.150778	0.062857
63	41	49	0.252709	0.071552
64	49	48	0.227789	0.064496
65	48	47	0.199784	0.056567
66	34	33	0.260486	0.073754
67	33	32	0.227789	0.064496
68	44	45	0.260486	0.073754
69	45	46	0.141269	0.039999
70	41	39	0.340220	0.096330
71	39	40	0.227789	0.064496

Table C.2 Load Data of 71 Node Radial Distribution Network for Double Feeder

Node No.	Real Power (MW)	Reactive Power (MVar)
2	53.249998	46.962086
3	48.749999	42.993459
4	33.750001	29.764703
5	46.499999	41.009145
6	55.499998	48.946397
7	47.249999	41.670582
8	42.000000	37.040521
9	18.000000	15.874508
10	14.249999	12.567319
11	21.750000	19.181697
12	15.000001	13.228758
13	33.000001	29.103263
14	41.250000	36.379081
15	33.750001	29.764703
16	36.750000	32.410453
17	26.999999	23.811762
18	30.000001	26.457515
19	50.249998	44.316333
20	21.750000	19.181697
21	26.249999	23.150323
22	56.249998	49.607840
23	42.000000	37.040521
24	20.250000	17.858822
25	30.000001	26.457515
26	22.500000	19.843136
27	16.500000	14.551631
28	24.749999	21.827448
29	8.250000	7.275816
30	66.000002	58.206526

31	34.500001	30.426140
32	15.000001	13.228758
33	56.999997	50.269277
34	11.250000	9.921567
35	18.750000	16.535945
36	32.250001	28.441829
37	17.250000	15.213070
38	48.749999	42.993459
39	20.250000	17.858822
40	33.750001	29.764703
41	16.500000	14.551631
42	25.499999	22.488886
43	22.500000	19.843136
44	24.749999	21.827448
45	23.999999	21.166010
46	15.750001	13.890195
47	36.000001	31.749016
48	23.999999	21.166010
49	67.500002	59.529406
50	57.749997	50.930714
51	42.750000	37.701958
52	65.250002	57.545089
53	14.249999	12.567319
54	22.500000	19.843136
55	21.000000	18.520260
56	24.749999	21.827448
57	12.750000	11.244443
58	50.249998	44.316333
59	22.500000	19.843136
60	13.499999	11.905881
61	20.250000	17.858822
62	46.499999	41.009145

63	18.750000	16.535945
64	48.749999	42.993459
65	46.499999	41.009145
66	38.250000	33.733330
67	47.999999	42.332019
68	47.249999	41.670582
69	30.000001	26.457515
70	33.750001	29.764703
71	15.000001	13.228758
72	21.000000	18.520260

Appendix D

Table D.1 Line Data of 71 Node Radial Distribution Network for Three Feeder

Branch No.	Sending End Node	Receiving End Node	Resistance (p.u.)	Reactance (p.u.)
1	1	50	0.252709	0.071552
2	1	7	0.100744	0.098595
3	1	51	0.107513	0.105219
4	7	6	0.178692	0.050595
5	50	52	0.199784	0.056567
6	51	53	0.103002	0.069532
7	51	55	0.069230	0.067753
8	55	57	0.060540	0.059248
9	57	59	0.053097	0.051964
10	59	58	0.060540	0.059248
11	58	60	0.053097	0.051964
12	53	56	0.172421	0.071880
13	56	54	0.227789	0.064496
14	56	70	0.150778	0.062857
15	70	69	0.199784	0.056567
16	70	71	0.199784	0.056567
17	71	72	0.268038	0.075892
18	72	67	0.227789	0.064496
19	67	68	0.260486	0.073754
20	7	5	0.075090	0.073488
21	5	4	0.118280	0.049309
22	4	3	0.167273	0.069734
23	3	14	0.227789	0.064496
24	4	2	0.260486	0.073754
25	2	15	0.252709	0.071552
26	14	8	0.260486	0.073754
27	8	9	0.252709	0.071552

28	60	62	0.187017	0.077965
29	62	64	0.178692	0.050595
30	62	61	0.227789	0.064496
31	61	63	0.227789	0.064496
32	64	65	0.268038	0.075892
33	14	13	0.282537	0.079997
34	13	12	0.227789	0.064496
35	9	10	0.282537	0.079997
36	9	11	0.282537	0.079997
37	65	66	0.282537	0.079997
38	5	17	0.100744	0.098595
39	17	18	0.090073	0.060804
40	18	16	0.227789	0.064496
41	18	19	0.103002	0.069532
42	19	20	0.111721	0.075419
43	20	21	0.199784	0.056567
44	20	22	0.078999	0.053329
45	22	23	0.252709	0.071552
46	22	25	0.105988	0.071548
47	25	26	0.150778	0.062857
48	26	28	0.178692	0.050595
49	28	29	0.227789	0.064496
50	29	24	0.227789	0.064496
51	26	27	0.282537	0.079997
52	60	38	0.106193	0.103928
53	38	37	0.053097	0.051964
54	37	36	0.053097	0.051964
55	36	35	0.078999	0.053329
56	35	43	0.078999	0.053329
57	36	30	0.227789	0.064496
58	35	34	0.227789	0.064496
59	43	44	0.150778	0.062857

60	44	42	0.132241	0.055129
61	30	31	0.227789	0.064496
62	42	41	0.150778	0.062857
63	41	49	0.252709	0.071552
64	49	48	0.227789	0.064496
65	48	47	0.199784	0.056567
66	34	33	0.260486	0.073754
67	33	32	0.227789	0.064496
68	44	45	0.260486	0.073754
69	45	46	0.141269	0.039999
70	41	39	0.340220	0.096330
71	39	40	0.227789	0.064496

Table D.2 Load Data of 71 Node Radial Distribution Network for Three Feeder

Node No.	Real Power (MW)	Reactive Power (MVar)
2	53.249998	46.962086
3	48.749999	42.993459
4	55.499998	48.946397
5	33.750001	29.764703
6	46.499999	41.009145
7	47.249999	41.670582
8	42.000000	37.040521
9	18.000000	15.874508
10	14.249999	12.567319
11	21.750000	19.181697
12	15.000001	13.228758
13	33.000001	29.103263
14	41.250000	36.379081
15	33.750001	29.764703
16	36.750000	32.410453
17	26.999999	23.811762
18	30.000001	26.457515
19	50.249998	44.316333
20	21.750000	19.181697
21	26.249999	23.150323
22	56.249998	49.607840
23	42.000000	37.040521
24	20.250000	17.858822
25	30.000001	26.457515
26	22.500000	19.843136
27	16.500000	14.551631
28	24.749999	21.827448
29	8.250000	7.275816
30	66.000002	58.206526

31	34.500001	30.426140
32	15.000001	13.228758
33	56.999997	50.269277
34	11.250000	9.921567
35	18.750000	16.535945
36	32.250001	28.441829
37	17.250000	15.213070
38	48.749999	42.993459
39	20.250000	17.858822
40	33.750001	29.764703
41	16.500000	14.551631
42	25.499999	22.488886
43	22.500000	19.843136
44	24.749999	21.827448
45	23.999999	21.166010
46	15.750001	13.890195
47	36.000001	31.749016
48	23.999999	21.166010
49	67.500002	59.529406
50	57.749997	50.930714
51	42.750000	37.701958
52	65.250002	57.545089
53	14.249999	12.567319
54	22.500000	19.843136
55	21.000000	18.520260
56	24.749999	21.827448
57	12.750000	11.244443
58	50.249998	44.316333
59	22.500000	19.843136
60	13.499999	11.905881
61	20.250000	17.858822
62	46.499999	41.009145

63	18.750000	16.535945
64	48.749999	42.993459
65	46.499999	41.009145
66	38.250000	33.733330
67	47.999999	42.332019
68	47.249999	41.670582
69	30.000001	26.457515
70	33.750001	29.764703
71	15.000001	13.228758
72	21.000000	18.520260

Appendix E

Data for conductors [21]

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)
Squirrel	12.90	1.3760	0.3896	70.0	2880
Weasel	19.35	0.9810	0.3797	100.0	4338
Rabbit	32.26	0.5441	0.3673	148.0	7306
Raccon	48.39	0.3657	0.3579	200.0	10950
$LSF = 0.20$ $CC = 0.10$ $V_{\min} = 0.95$					

Appendix F

Biography of Candidate

Personal Information

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Academic Qualification

- M.E in Power Systems and Electric Drives from Thapar University, securing 7.44 CGPA.
- B.Tech in Electrical Engg. from Giani Zail Singh College of Engg. & Technology, Bathinda (Punjab Technical university), in 2007 securing 65.55%.
- High School from P. S. E. Board in 2001.

Placement

Lovely Professional University.