Optimal Planning of Radial Distribution Networks

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

Master of Engineering
in
Power System and Electric Drives

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CERTIFICATE

I, hereby, certify that the Thesis entitled **"Optimal Planning of Radial Distribution Networks"** in the partial fulfillment of the requirement for the degree of MASTER OF ENGINEERING in POWER SYSTEM AND ELECTRIC DRIVES, submitted in the department of Electrical and Instrumentation Engineering, Thapar University, Patiala is an authentic work carried out under the guidance of Dr. SMARAJIT GHOSH, Professor and Head of EIED, Thapar University and refers other researcher's works, which are duly listed in the reference section.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any degree or diploma.

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Dedicated to My Parents

ABSTRACT

Large scale distribution system planning is a complex and reasonably difficult problem. This thesis proposes the application of simple and efficient mathematical algorithms for the optimal design of large scale distribution systems in order to provide optimal locating of the high and medium voltage (HV and MV) substations, as well as medium voltage (MV) feeders routing, using their corresponding fixed and variable costs associated with operational and technical constraints. The novel approach presented in the report solves hard optimization problems with different technical constraints in large scale distribution networks. This report presents a new concept based on **Dijkstra's Algorithm** introduced for optimal routing of MV substations, followed by new methodology based on graph theory and differential evolution for optimal locating of the substations in a real size distribution network. In the present article to reduce computational burden and avoid huge search space leading to infeasible solutions, special coding methods are generated to solve optimal feeders routing. The proposed coding methods guarantee the validity of the solution toward the global optimal solution. The developed algorithms software is tested in distribution system and the results are presented.

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LIST OF SYMBOLS

Z	Impedance Matrix Vector
S	Complex Power Matrix Vector
P_i	Net Active Power
Q_i	Net Reactive Power
V^0	Initial Voltage Vector
I^k	Branch Current of kth Iteration
T	Upper Triangular Matrix
i	Injected Quantity
D_Z	Diagonal Matrix of Vector Z
$r_i(k)$	Per Unit Resistance of Conductor ‘k’ Per Unit Length
$x_i(k)$	Per Unit Reactance of Conductor ‘k’ Per Unit Length
l_i	Length of Segment ‘i’
$I_i(k)$	Peak Current in Segment ‘i’ with Conductor ‘k’
m	Number of Segments in Radial Distribution Network
$c(k)$	Annual Capital Cost
$pp(k)$	Purchase Price of Conductor ‘k’ Per Unit Length
l_i	Length of Feeder Segment
cp	Feeder Carrying Charge Rate
$EL(k)$	Energy Loss Cost
LLF	Load Loss Factor

LF_U	Ultimate Load Factor
LF_p	Present Load Factor
C_{po}	Cost of Energy Loss
M	Planning Period
K	Type of Conductor
$C_{pn}(k)$	Cost of Energy over the Life Period of M years of the System.
$Kn(j)$	Largest Conductor Size Available for Segment ‘j’,
V(j, k)	Voltage Drop in Segment j with Conductor ‘k’.
V_{min}	Minimum Voltage
$Vmax$	Maximum Voltage Drop
iv	State Variable
$Vn(m)$	Desired Voltage Drop from the Node ‘i’ to End Point
L_j	Load Demand of Load Point ‘j’ (kVA)
V	Network Voltage
R(k)	Branch Resistance of Conductor type ‘k’ Per Unit Length
X	X-Coordinate
Y	Y-Coordinate
Cr	Crossover Probability
F	Mutation Rate
kV	Kilo Volt
kW	Kilo Watt

CHAPTER ONE

INTRODUCTION

Future development and present operation of electric power systems along with other large systems must pursue a number of different goals. Above all, the power system should be economically efficient, it should provide a reliable energy supply and should not have any detrimental impact on the environment. In addition to these global goals, there are a number of supplementary goals, objectives and criteria. At the same time, operation and development of the system are influenced by the variety of uncertain and random factors. As a result, development strategy can be chosen from a large number of possible alternatives. Thus, the complexity of the problems related to power systems planning is mainly caused by the presence of multiple objectives, uncertain information and large number of variables.

The electric utility system is usually divided into three subsystems as shown in Fig. 1.1 [**iik.ac.in**], which are generation, transmission, and distribution. A fourth division, which sometimes is made, is sub transmission. However, the latter can really be considered as a subset of transmission since the voltage levels and protection practices are quite similar.

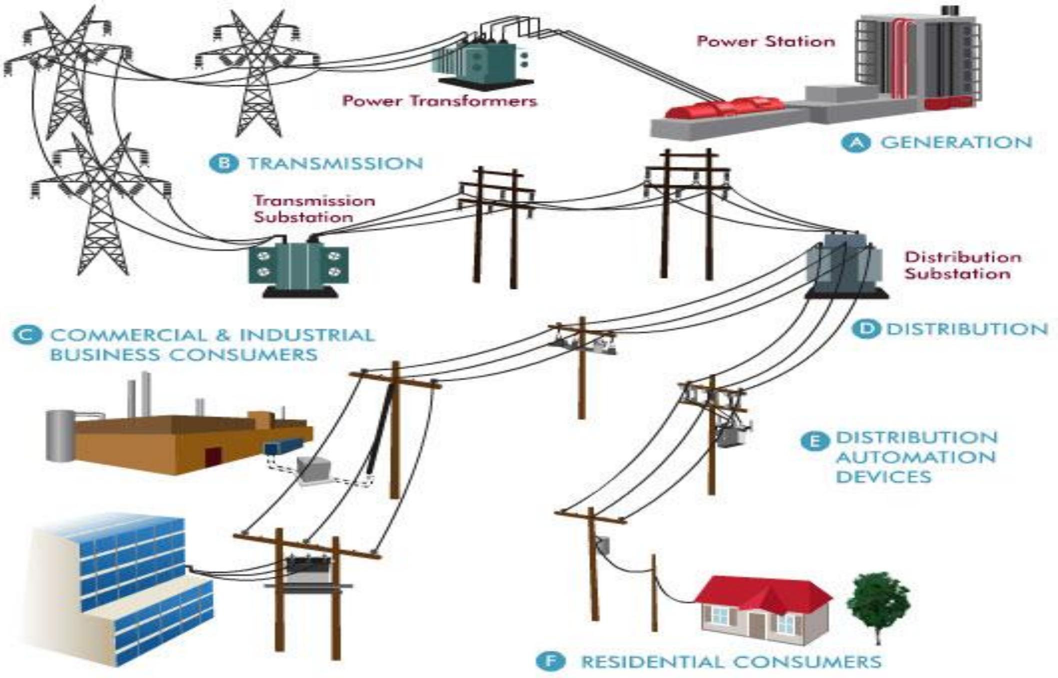

Figure 1.1 Electrical Power System layout from Generation to Consumer End

1.1 OVERVIEW ON DISTRIBUTION SYSTEM

The electrical energy produced at the generating station supplied to consumers through transmission and distribution system networks. It is often difficult to differentiate between the transmission and distribution systems of large power systems. *The part of the system, which distributes electric power for local use, is known as a distribution system.* Single line diagram of the distribution system is shown in Fig.1.2 [**intechform.com**].

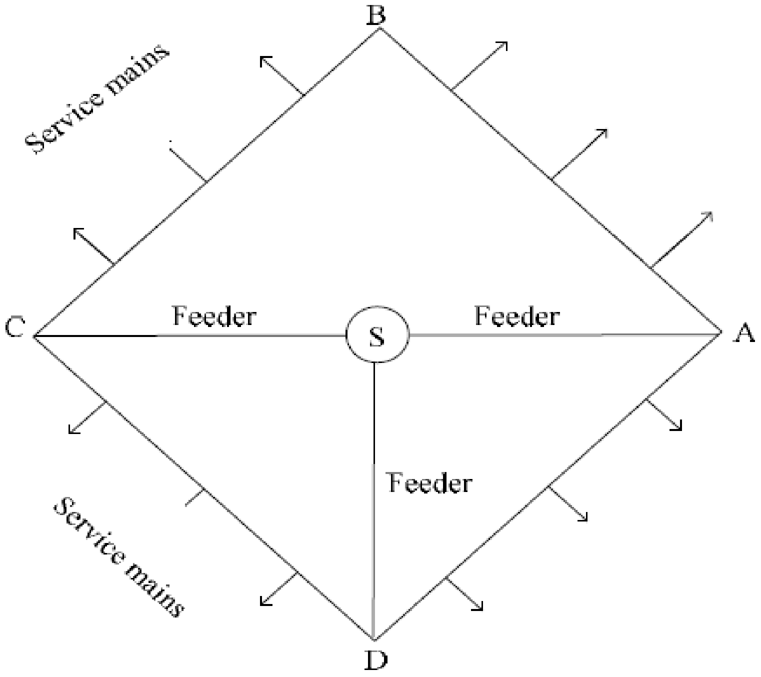

Figure 1.2 Single Line Diagram of Distribution System

Distribution networks make up the last link in the chain of supplying energy. The density and the complexity of distribution networks are usually larger than for the transmission systems, which feed them through distribution substations. Distribution networks also have specific characteristics, which distinguish them from transmission network and the most exposed to the critical observation of its users. The main differences between transmission and distribution systems are in the number of particular types of devices, multiphase possibilities and widely varying types of loads.

As the direct link to end customers, electric power distribution systems must meet customer load demands at all times in a safe and efficient way. Therefore, load information is an essential part of the power distribution system analysis. Specifically, up-to date nodal load information is required to accurately represent customers and for many operations, control and planning of power distribution systems.

The distribution system is commonly broken down into three components: distribution substation, primary distribution and secondary distribution. At the substation level, the voltage is reduced and the power is distributed in smaller amounts to the customers. Consequently, one substation will supply many customers with power. Thus, the number of transmission lines in the distribution systems is many times that of the transmission systems.

1.1.1 Distribution Substations

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

For a typical substation, the voltage of the high side bus can be anywhere from 34.5 kV all the way up to 345 kV. The average high side voltage level is approximately 6.6 kV to 66 kV. Two or more feeders are normally connected to the low voltage bus through a feeder breaker.

1.1.2 Distribution Feeders

Most distribution feeders are three-phase and four-wire. The fourth wire is the neutral wire, which is connected to the pole, usually below the phase wires, and grounded periodically. A three-phase feeder main can be fairly short, on the order of a mile or two, or it can be as long as 30 miles. Actually, the length of feeders is closely linked to load density at the location. For instance, for an area where the customer load density is strong, primary network will end very close of consumers and secondary feeders will be short. In a weak load density area, primary and secondary feeders will be longer. The distance separating substation from customers will be covered both by primary and secondary feeders in order to provide the best quality supply.

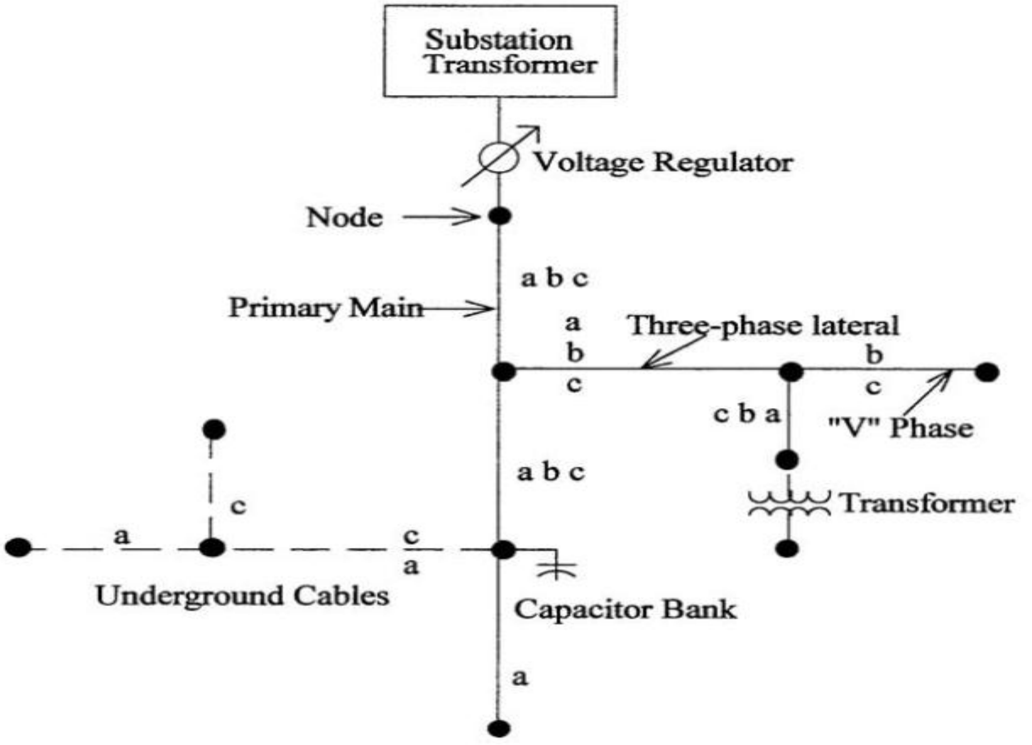

Figure 1.3 Distribution Feeder [1]

1.1.3 Distribution Transformer

The purpose of the distribution transformer is to reduce the primary voltage to a level where it can be used by the customer. Single-phase transformers range in size from 10 kVA to about 300 kVA with units in the 25 kVA and 37.5 kVA sizes being the most popular for residential areas.

The secondary voltage level in India for residential service is 220-240 V. Lower wattage devices, such as lights, are connected line-to-neutral across both sides of the transformer secondary. Higher wattage devices, such as ovens, clothes dryers, etc. are usually connected across the 240 V circuit since this has the effect of reducing voltage drop and losses.

1.2 A.C. Distribution

Now-a-days electrical energy generated, transmitted and distributed in the form of alternating current. One important reason of using AC distribution is that the AC voltage can be conveniently changed in magnitude by means of transformers at different stages. The AC distribution system is basically classified into two

(i) Primary Distribution System

(ii) Secondary Distribution System

1.2.1 Primary Distribution System

It is that part of the AC distribution system that operates on the voltage somewhat higher to utilize. The voltage used in primary distribution depends upon the amount of power to be conveyed and distance of substation to be fed. Primary distribution systems consist of feeders that deliver power from distribution substations to distribution transformers.

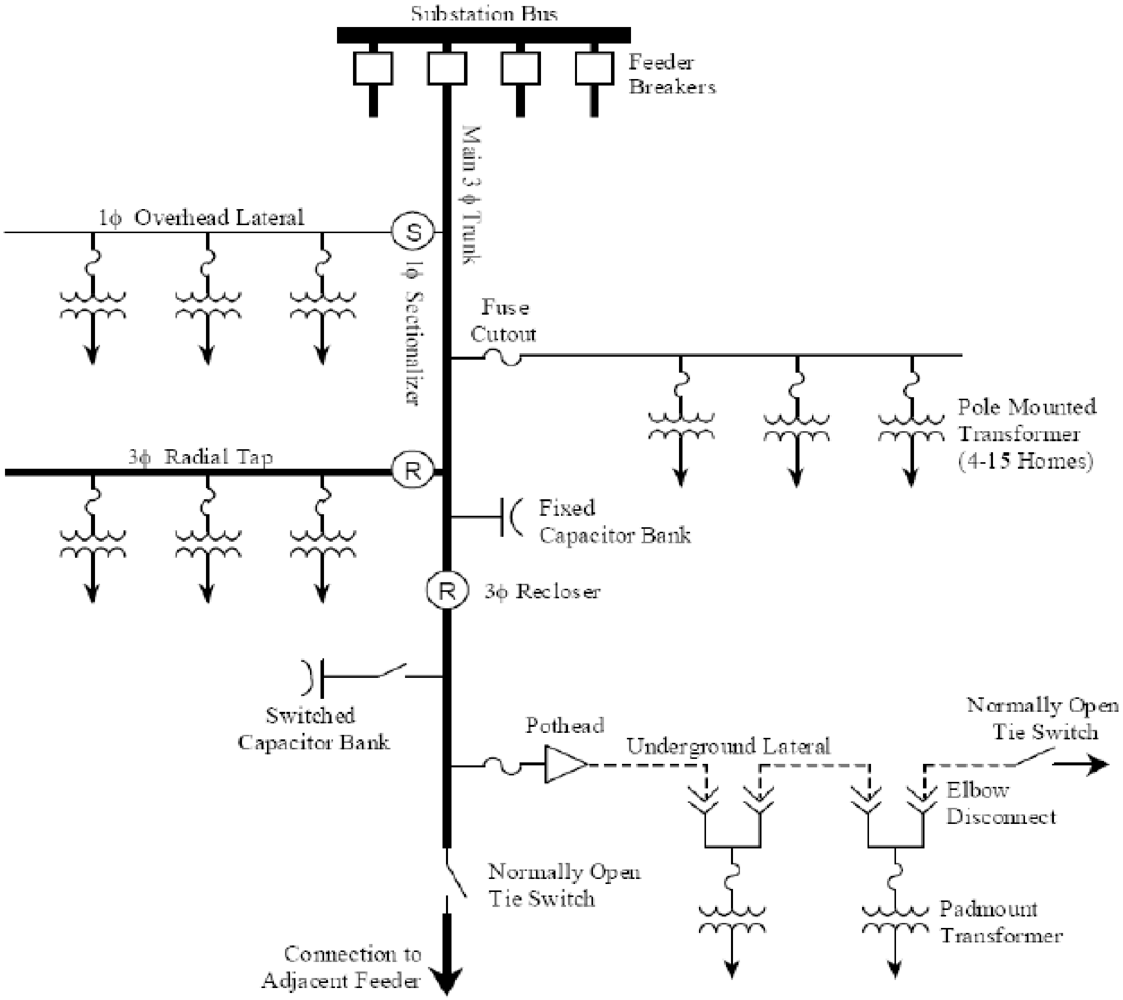

Figure 1.4 Primary Distribution System with its Major Components [1]

A feeder begins with a feeder breaker at the distribution substation. Many will exit the substation in a concrete duct bank (feeder get-away) and be routed to a nearby pole. At this point, underground cable transitions to an overhead three-phase main trunk. The main trunk is routed around the feeder service territory and may be connected to other feeders through the normally-open tie points. Underground main trunks are possible, even common in urban areas, but cost much more than overhead construction.

Figure 1.4 shows the typical primary distribution system. Electric power from generating stations transmitted at high voltage to the substation located near the loads. At this substation the voltage is stepped down to 11 kV by using step-down transformer.

1.2.1.1 Typical Configurations of Primary Distribution Systems

All distribution schemes are done by constant voltage system. In practice, following distribution circuits are generally used as shown in Fig.1.5.

(A) Tie feeder: The main function of a tie feeder is to connect two sources. It may connect two substation buses in parallel to provide service continuity for the load supplied from each bus.

(B) Loop Feeder: A loop feeder has its ends connected to a source (usually a single source), but its main function is to supply two or more load points in between. Each load point can be supplied from either direction, so it is possible to remove any section of the loop from service without causing an outage at other load points. The loop can be operated normally closed or normally open. Most loop systems are, however, operated normally open at some point by means of a switch. The operation is very similar to that of two radial feeders.

(C) Radial Feeder: A radial feeder connects between a source and a load point, and it may supply one or more additional load points between the two. Each load point can be supplied from one direction only. Radial feeders are most widely used because the circuits are simple, easy to protect, and low in cost.

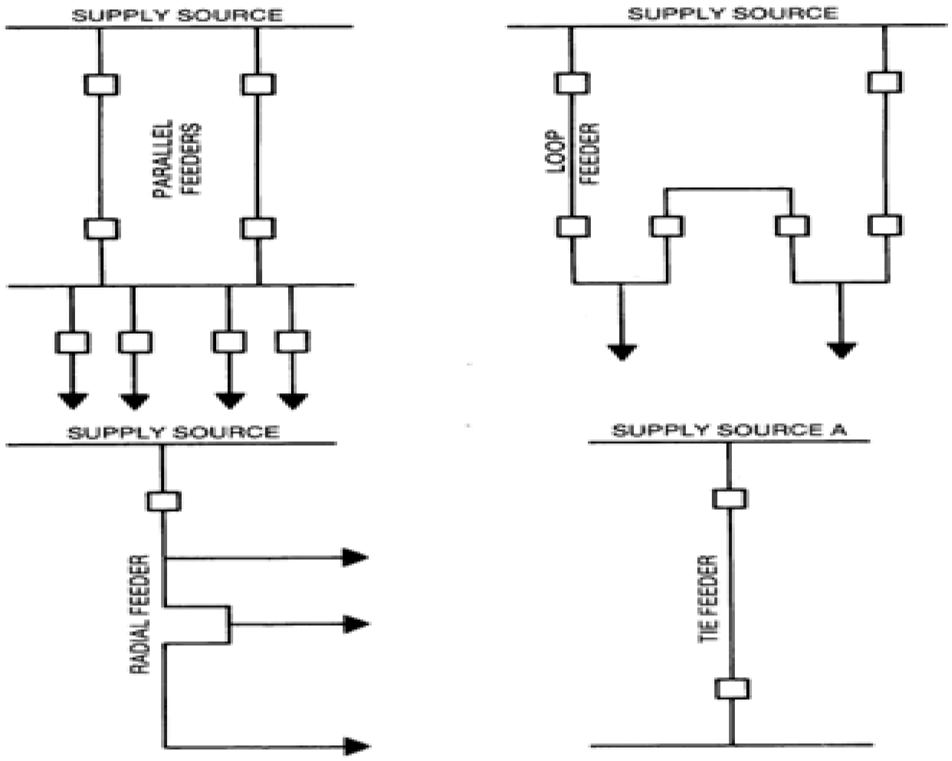

Figure 1.5 Typical Configurations of Primary Distribution System [1]

(D) Parallel Feeder: Parallel feeders connect the source and a load or load center and provide the capability of supplying power to the load through one or any number of the parallel feeders. Parallel feeders provide for maintenance of feeders (without interrupting service to load) and quick restoration of service when one of the feeders fails.

1.2.2 Secondary Distribution

The secondary distribution system is that portion of the network between the primary feeders and utilization equipment. It includes the range of voltages at which the ultimate consumers utilize the electrical energy. Residential secondary systems are predominantly single-phase, but commercial and industrial systems generally use three-phase power.

1.2.1.2 Typical Configurations of Secondary Distribution Systems

(A) Simple-Radial Distribution System: In the simple-radial system shown in Fig.1.6, distribution is at the utilization voltage. A single primary service and distribution transformer supply all the feeders. System investment is the lowest of all circuit arrangements. Operation and expansion are simple. Reliability is high if quality components are used. However, loss of a cable, primary supply, or a transformer will cut off service. Further, electrical service is interrupted when any piece of service equipment must be de-energized to perform routine maintenance and servicing.

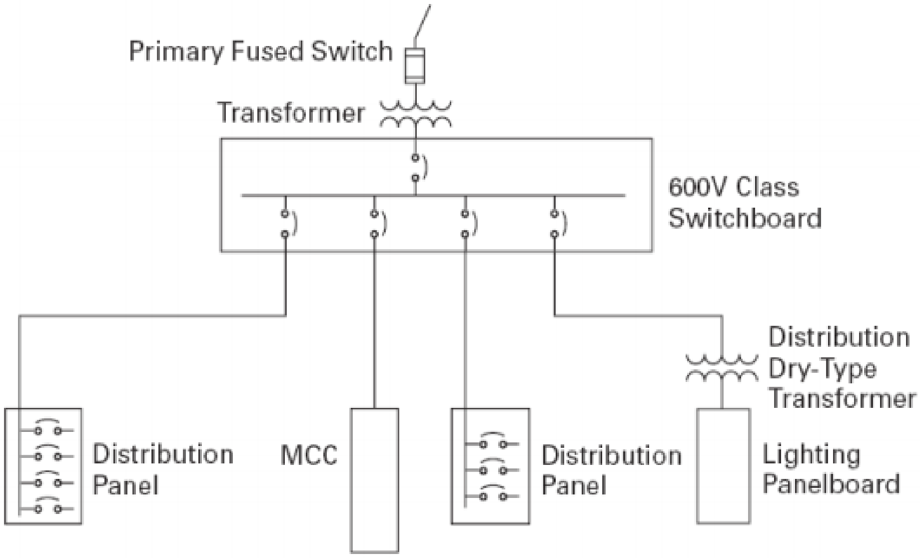

Figure 1.6 Simple Radial Distribution System [1]

(B) **Expanded Radial Distribution System:** The advantages of the radial system may be applied to larger loads by using a radial primary distribution system to supply a number of unit substations located near the load centers with radial secondary systems (Fig.1.7). The advantages and disadvantages are similar to those described in the simple radial system.

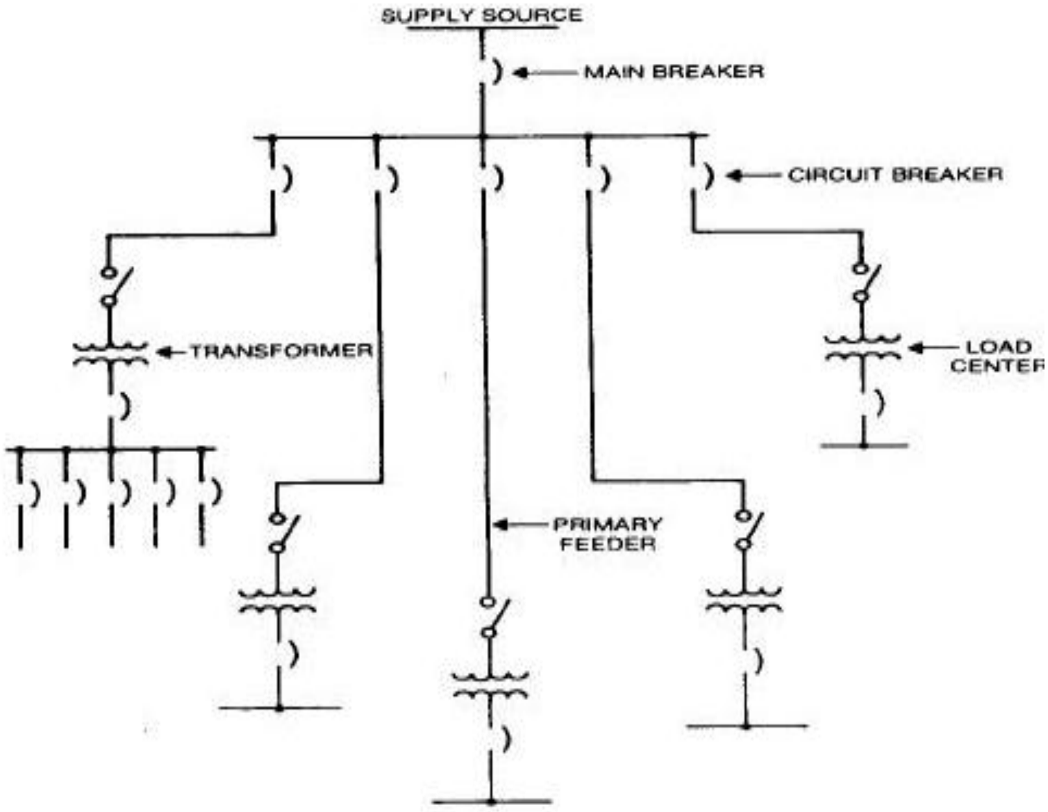

Figure 1.7 Expanded Radial Distribution System [1]

(C) Primary Selective Distribution System: Protection against loss of a primary supply can be gained through the use of a primary selective system as shown in Fig.1.8. Each unit substation is connected to two separate primary feeders through switching equipment to provide a normal and an alternate source. When the normal source feeder is out of service for maintenance or a fault, the distribution transformer is switched, either manually or automatically, to the alternate source. An interruption will occur until the load is transferred to the alternate source. The cost is somewhat higher than for a radial system because primary cable and switchgear are duplicated.

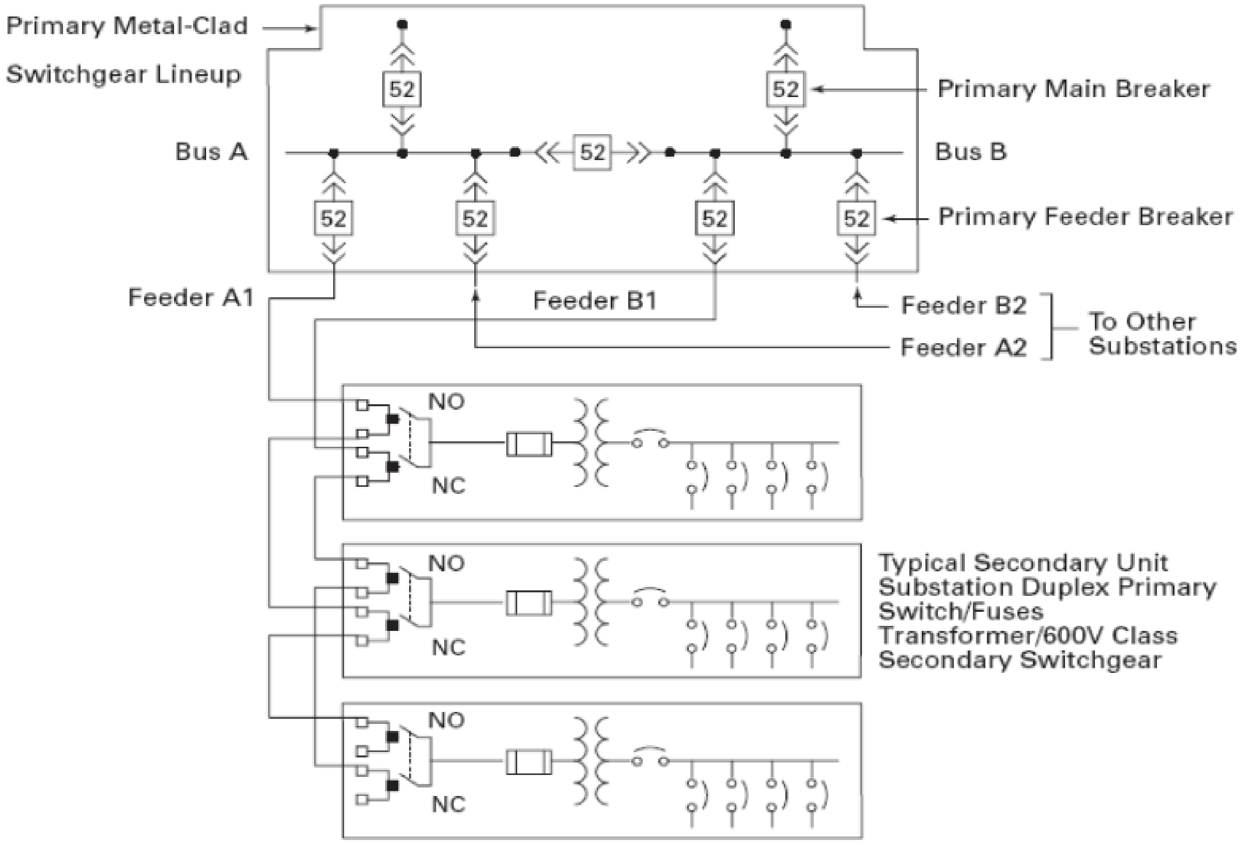

Figure 1.8 Basic Primary Selective Radial Distribution System [1]

(D) Loop Primary-Radial Distribution System. The loop primary system as shown in Fig.1.9 offers nearly the same advantages and disadvantages as the primary selective system. The failure of the normal source of a primary cable fault can be isolated and service restored by sectionalizing. Finding a cable fault in the loop, however, may be difficult and dangerous. The quickest way to find a fault is to sectionalize the loop and reclose, possibly involving several reclosing at the fault. A section may also be energized at both ends, thus, affecting another potential danger. The cost of the primary loop system may be somewhat less than that of the primary selective system. The savings may not be justified, however, in view of the disadvantages.

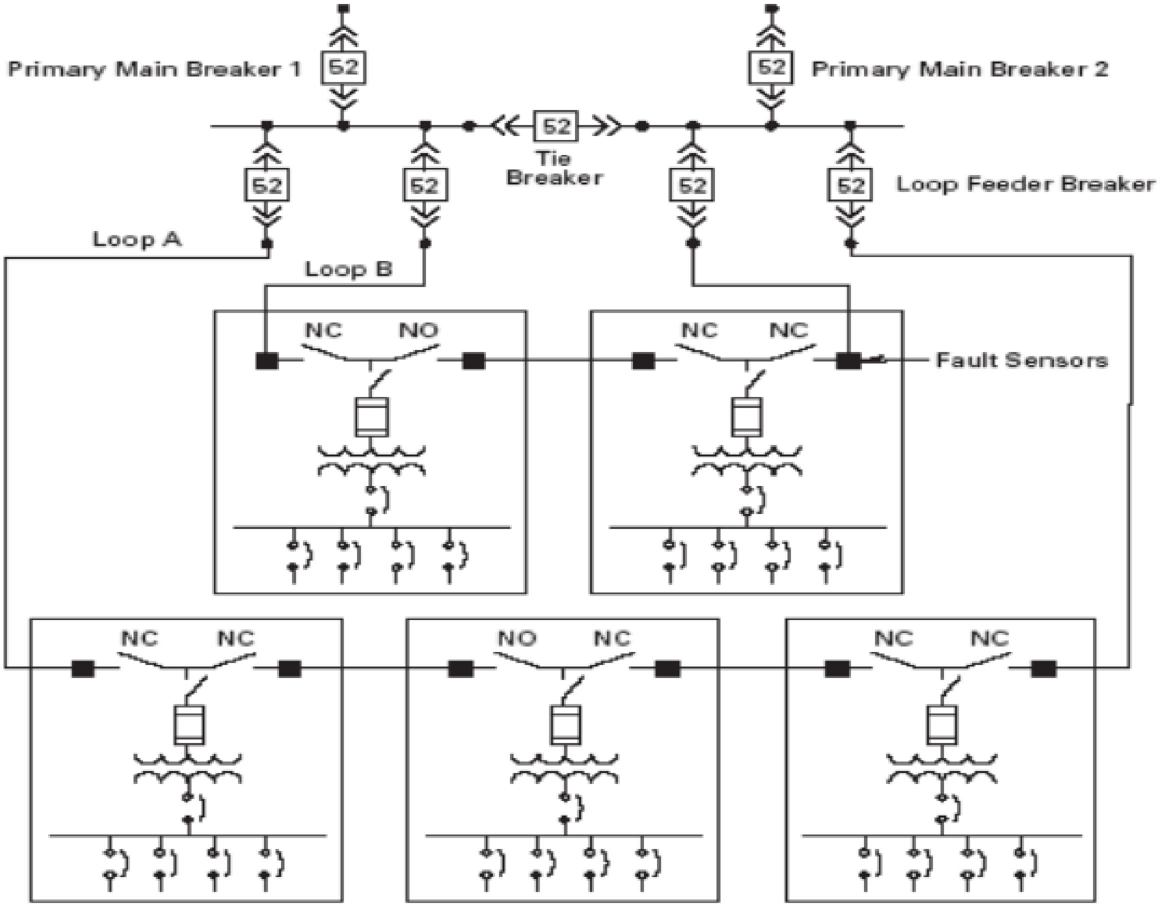

Figure1.9 Loop Primary Radial Secondary System [1]

1.3 Motivation

In the planning of electric power distribution system number of goals must be achieved and accordingly number of objectives must be optimized or in other words we can say that distribution system planning has been basically stated as a multiobjective optimization problem, in which the objective function, including the investment, operational costs and system losses related to the distribution network, should be minimized subject to technical constraints associated with the characteristics of the electric services while enhancing stability of the system, safety and power quality of the network.

The optimization of large power radial distribution system is a task of remarkable complexity. Because of the different technically feasible alternatives, powerful optimization techniques must be employed, which are leading to remarkable saving for electric utilities and investors. The problem of distribution network planning is extremely complex optimization due to:

- Dependency on load growth
- Large number of variables and constraints
- Dynamic nature of the system

One of the most powerful scheme is to reduce the complexity of the problem is to divide the complete task into several sub tasks or objectives. The planning procedure is usually divided into the following stages:

- Optimal feeder routing
- Optimal conductor selection
- Optimal substations location

It should be noted that the decomposition of complex problems in many initial specific problems for free of charges. The decision of each sub-problem should be consistent. Moreover often there is a need to solve each sub problem for several outcomes of other sub problems.

Planning of MV networks is to find placement and the rating of transformers and MV feeders. This is implemented to minimize the investment cost of these devices with the line loss. Planning of MV network is to identify the location and size of the distribution substation and MV feeders. The objective of MV network planning is to minimize the investment cost along with the line loss and reliability indices. There are several limitations, which would be satisfied during planning procedure. The bus voltage as a constraint should be maintained within a standard range.

1.3.1 Process of Planning

A starting point of radial distribution planning is the existing system network under the influence of several internal and external factors. Once the performance of the existing network is identified during the planning period, it is the time to start the planning procedure.

Planning actions may include the addition, upgradation and eliminations of the network elements. Possible planning action may include the building of new lines and changing of routes, selection between overhead lines and cables as well as different kind of conductors, providing alternate network configurations, installation of DG, capacitor banks, voltage regulators etc.

The planning procedure consists of several steps starting from the identification of problem to the development and successful implementation of the suggested methods. For instance, in [2] the planning process is formulated into the following five stages:

***Stage1*:** Identify the problem: Explicitly defines the range of application and its limits.

***Stage2*:** Determines the goals: what goals are to be achieved? What is to be optimized?

***Stage3*:** Identify the alternatives: What options are available?

***Stage4*:** Evaluate the alternatives: Evaluate all options on the sound basis.

***Stage5*:** Select the best alternatives: Select the options that best satisfies the goals with respect to the problems.

***Stage6*:** Make the final decision: Based on the result obtained on the previous stages

Distribution substation has multi-substations and multi-feeders configuration, so that any load can be supplied more than one route. In the existing radial distribution system we basically use two substation configurations, one is a primary or main substation and other is a secondary or auxiliary substation. The distribution system reconfiguration of system is applied to achieve the following objectives:

- Power (active and reactive power) loss reduction.
- Improving system stability
- Adequate reduction in installation and operating costs.

The goal of this research is to optimize the configuration of the system for cost as well as loss minimization and improving system stability by adapting different methodologies in order to accomplish most appropriate results.

The main purpose of the planning of radial distribution system reconfiguration is to quickly minimize the total real and reactive power losses of the network and at the same time to improve stability of the system with satisfying minimum cost criteria and system constraints as well. Several methods had been proposed to solve these optimization problems, some methods find suboptimal solutions rapidly and other finds optimal solutions with more computation time.

1.3.2 Objectives and Dynamics of Distribution System Planning

The objectives of the network planning may vary from one utility to another and from one plan to another and it depends upon several criteria and conditions. However, it is possible to formulate the common objectives of the planning tasks in terms of planning attributes [3], which has to be minimized. The appropriate hierarchy of the objectives of the distribution system planning is presented in Fig.1.10, more or different objectives can be added to the system depending upon the requirement.

In the Fig.1.9, shaded rectangles contain the common attributes for the radial distribution system planning problems. As a result, there are the general attributes to be minimized.

- Poser Loss
- Investment
- Stability and Reliability

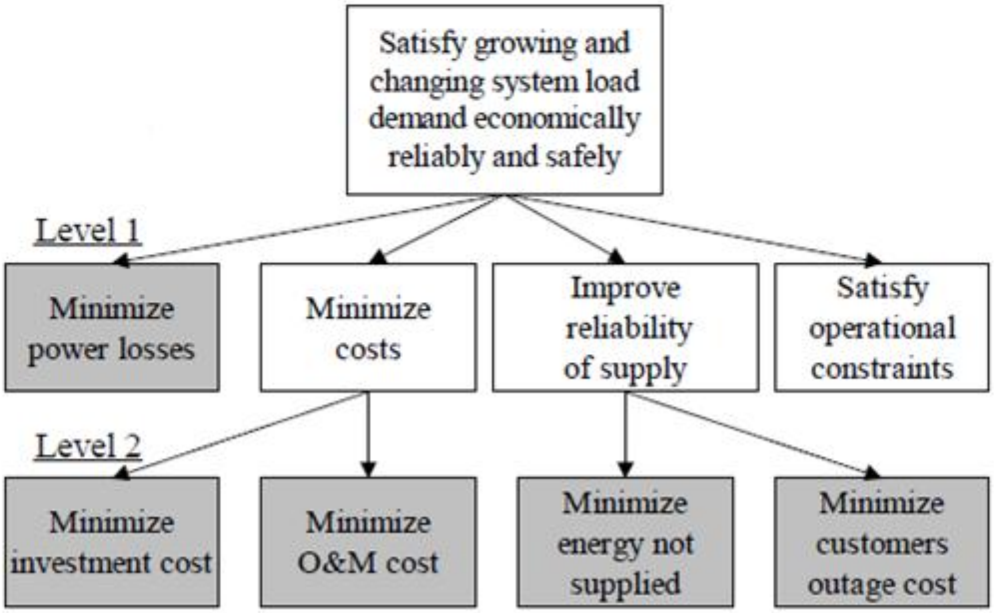

Figure 1.10 Hierarchies of Objectives of Distribution System Planning [2]

The objectives, which are the subject of optimization, are open-ended. No matter how good the plan is, the planner is challenged to do better and better. By contrast, the operational constraints must only be met, not exceeded [3].

Due to the uncertainty in the future, the planner may commit only to the planning alternatives, which have to realize in the nearest future. The planning process may be divided into two major time stages:

- Short term planning
- Long term planning

The purpose of short term planning is to make system eligible to serve the consumers load while meeting power system standers and power quality constraints. On the other hand, the purpose of long term planning is to assure all short term goals and contribute to robust system solutions.

The long term planning must contain the characteristics of promising systems from dynamic prospective. Since power system is an object, which may change continuously with the passing of the time period. Hence in the planning load growth, economic indices etc., estimation of current decision must allow for some potential additions when there will be needed at some moment in near future.

1.4 Purpose, Features and Contributions of this Thesis Work

The above mentioned problem highlights the need for the comprehensive system planning of distribution networks. This planning method should minimize the cost of the system, maximize the system stability, improve the voltage profile, support the load growth and ensure the system stability.

The major purpose of the thesis is to contribute the development of radial distribution system in order to minimize the cost as well as the total power losses in the existing and test system. To achieve the purpose of planning, the following steps were stated:

- Choose the planning objectives reflecting the planning effectiveness and contribution towards the need of the system and power utilities.
- Select the methods for assessment of the attribute corresponding to the planning objectives and organize the step by step optimization procedure. The optimization procedures adopted are different for different problems. Differential evolution technique based optimization technique is used for the distribution substation placement. Simple **Dijkstra's Algorithm** is used for the purpose of optimal feeder routing.

- Apply the suggested method to real networks and the real objectives of radial distribution planning are analyzed. Based on the analysis it is stated that the suggested methods are realistic and can be applied to the practical distribution planning problem.

1.5 Organization of the Thesis

The thesis is organized as follows:

Chapter 1 presents the introduction of the distribution system, components of the distribution system, primary and secondary distribution system. The discussion about the planning of radial distribution system and aim to do this thesis work is to primarily describe in different sections of the chapter.

Chapter 2 presents the contribution of different authors in the field of radial distribution planning as well as the fields used throughout the implementation of problem solution. This chapter basically demonstrates the motivational study to carry out this work.

Chapter 3 discusses the main body of the thesis i.e. formulation of the problem in terms of mathematical models and their solutions by using different algorithms proposed.

Chapter 4 analyses the results carried out in our thesis work using proposed and existing algorithms and comparison between them to find out the effectiveness.

Chapter 5 presents conclusions and future scope of work.

CHAPTER 2

LITERATURE REVIEW

Distribution networks are conventionally designed by planning of optimal feeder routing, optimal conductor placement, and optimal allocation of substation, transformer and distribution line for minimizing the line losses and capital and maximizing the system reliability and improve the voltage profile.

Many text resources discussed the complexity and difficulty of distribution system planning. Planning of a distribution network with minimum capital cost investment and operating cost is a complicated task due to the high number of non-linearity, time varying nature and several technical constraints. The planned project must satisfy the electric system demand with acceptable reliability, minimum cost, considering distribution substations loading levels and the current limits of feeders. Each solution should have acceptable voltage at end buses, servicing all loads and preserving the radial structure of the network [1-2].

Ponnavikko and Prakasha Rao [3] proposed an optimal conductor gradation method for radial distribution feeder planning. The objective function with the consideration of feeder cost, energy cost and voltage regulation as a function of conductor cross section, was formulated to optimize the results. The optimization procedure was to be satisfied non-uniform distribution of loads along the length of feeder and also the maximum permissible voltage drop along a feeder.

Dijikstra [4] proposed algorithm for the solution of two fundamental graph theory problems: (i) the minimum weight spanning tree problem and (ii) the shortest path problems.

Holland *et al.* [5] had proposed the optimal solutions of the complicated combinatorial problems the genetic algorithm used, which imitated the process of natural evolution.

Rao [6] proposed a novel method for determining optimal conductor cross sections for radial distribution feeders, considering several factors such as non-uniform feeder loading, load growth, allowable voltage drop etc., for the purpose of minimizing sum of capital investment cost and capitalized energy loss cost for the feeders.

Civanlar [7] developed a branch exchange method. In this method, loss reduction was achieved by exchange operation corresponds to the selection of a pair of switches, one for opening and the other for closing so that the resulting network had lower line losses while remaining connected and radial.

Hsu and Chen [8] proposed a knowledge based expert system technique for determining substation location and feeder configuration of radial distribution system using a location - allocation method.

Hongwei *et al.* [9] considered the problem of planning of the distribution substation and sizing and proposed a method to solve the optimal planning of distribution substations is presented. They mentioned method by using Heuristic Combinational Optimization Algorithm (HCOA) in their paper, which could automatically select the optimal sizes and locations of substations in electric distribution systems. The solution method was based on the decomposition of the original problem.

Salamat *et al.* [10] proposed a possible configuration minimizing a cost of the feeder routing problem and developed a new method for designing feeder routing of power distribution systems, which was applicable for system future expansion. They used a new two-step i.e., both the minimum spanning tree concept and mixed integer programming formulation method for designing feeder routing of power distribution systems.

Safri *et al.* [11] defined a new set of heuristic rules for distribution system reconfiguration problem. The rules had been developed with the objective of reducing losses directly and made an effort to quantize the suitability of switching options. The proposed method served as a preprocessor to a reconfiguration algorithm removing undesirable switching options without the need to perform a complex load-flow analysis.

Borozan *et al.* [12] analyzed the influence of load imbalances on the minimum loss configuration solution and a heuristic method for reconfiguration of unbalanced distribution networks in order to reduce their resistive line losses was developed. The method was a direct extension of the improved method for loss reduction in distribution networks from single to three phases.

Fan and Zhang [13] made an attempt to provide an analytical description and a systematic understanding about the single loop optimization approach via qualitative analysis. They formulated the problem of network reconfiguration for minimum loss as an integer optimization problem with a quadratic objective function, 0-1 type state variables had linear constraint equation with state dependent formulas. This non-linear integer programming problem, if it linearized, could be approximately represented by an integer linear programming (LP) problem, which led to the consideration of applying the concept of simplex method normally used for solving LP problems. That in turns led to the direct deviation of the single loop optimization approach. In addition, an efficient and simple scheme to compute load-flow and loss change in the network after a switch exchange in a loop was presented. A heuristic procedure was then proposed to obtain the optimal switch plan by eliminating those unnecessary switch operations during the iterative solution procedure of the single loop optimization approach to accomplish the transition from the initial configuration to the optimal configuration.

Khator *et al.* [14] treated the complex task of radial distribution planning in which planners ensured that there was adequate substation capacity (transformer capacity) and feeder capacity (distribution capacity) to meet the load demands. Decisions such as allocation of power flow, installation of feeders and substations, and procurement of transformers were costly ones, which would be evaluated carefully. They provided a review of research problems as well as models related to the planning of substations and/or distribution feeders.

Lin and Chin [15] developed a new approach for the distribution network reconfiguration to minimize losses. The algorithm adopted a switching index to obtain a proper set of switching operations. Switching indices were defined by using branch voltage drops and line constraints. In normal operating state, switches with the largest index in each loop were considered for switching.

Kashem *et al.* [16] proposed a new algorithm for enhancing the voltage stability by network reconfiguration. Initially, a certain number of switching combinations were generated using the combination of tie and its two neighboring switches at the best combination of switching for maximizing the voltage stability in the network among them was determined. That search was extended by considering the branches next to the open branches of the beat configuration only by one to check whether there is any other switching combination available, which gave further improvements in voltage stability.

Wang *et al.* [17] proposed simple, practical approach, which was a combination of an economic current density based approach and heuristic index directed method. In their planning approach multiselection, branching feeder model with non-uniform load distribution had been chosen for the planning purpose in which actual conditions were found in most distribution systems.

Hsiao and Chien [18] developed a fuzzy satisfied method based on EP to solve the constrained multi-objectives problem. The proposed algorithm enabled the optimal feeder reconfiguration problems to be treated with multi-objectives to obtain the optimal solution.

Skok *et al.* [19] presented an order to enhance the serviceability of the distribution system, genetic algorithm and GIS based method was proposed for planning of the distribution networks. In their method, distribution system planning was a multiojective optimization problem. The objective function included both the investment and the operational costs of the network, which was minimized subject to technical constraints.

Ranjan *et al.* [20] made an attempt to develop a new algorithm for distribution system planning, incorporating heuristic rules. They developed a generalized algorithm for planning purpose in order to meet the goal of optimal feeder path as well as the optimal substation location. The algorithm did not require any prior knowledge of the candidate substation location, it automatically selects the optimal location of the substation, feeder configuration and conductors while satisfying current capacity and voltage drop constraints.

Ming and Pengxiang [21] proposed an improved genetic algorithm (GA) using the feature of radial distribution system. A chromosome coding method and gene operation strategies were developed. Cross over operations was defined to exchange between templates. The mutation operations and inversion operations were restricted in templates. Above strategies greatly reduced the infeasible solution. Further, a simplifying power distribution method was also proposed to reduce the length of the chromosome and reciprocal value of the active power losses to be fitness function.

Tram and Wall [22] proposed a fast algorithm to select proper conductors for feeder expansion plans, minimizing capital investments and cost of feeder losses.

Gomez *et al.* [23] discussed the planning problem of electrical power distribution networks, stated as a mixed nonlinear integer optimization problem, and was solved using the Ant Colony System Algorithm (ACS). These methodologies were very flexible and computed the location and the characteristics of the circuits minimizing the investment and operation costs while enforcing the technical constraints such as the transmission capabilities and the limits on the voltage magnitudes.

Parada *et al.* [24] considered the problem to minimize both the investment cost for feeder and substations, and the power-loss cost. When the substations could already provide enough power flow, the problem reduced to minimize the total cost related to the feeders and their power-loss. They proposed a Simulated Annealing (SA) algorithm to deal with the electric power distribution problem, where the objective was to minimize the sum of the total investment cost and of the total power-loss cost.

Gomez *et al.* [25] explored the application of ant colony based metaheuristic algorithm for the purpose of primary distribution circuits. They utilized the behavior of ants for searching their food by following optimal path. The ACS methodology coupled with a conventional distribution system load-flow and computed the location and characteristics of the system while minimizing the investment and operational costs with a combination of technical constraints as well as transmission capabilities.

Hsiao [26] modeled the multiple objectives such as power loss, voltage quality, reliability and number of switching using fuzzy sets to evaluate their imprecise nature and for ease of integration. The, EP method was used to solve the constrained multiobjective problem.

Chakravorty and Das [27] proposed a new voltage stability index for identifying most sensitive load on which voltage collapse is possible. New voltage stability index was proposed for identifying the node, which is most sensitive to voltage collapse. Composite load modeling was considered for the purpose of voltage stability analysis.

Ramriez *et al.* [28] presented a new multiojective tabu search (NMTS) algorithm to solve a multiojective fuzzy model for optimal planning of distribution systems. Their method computed fuzzy economic cost, level of fuzzy reliability, and maximization of robustness, including optimal size and location of reserve feeders for maximizing the level of reliability at the lowest economic cost.

Fletcher *et al.* [29] took care of the problem of long term forecasting and an application method to enhance distribution horizon planning for a twenty year period. The optimal horizon planning model encompassed all distribution design requirements for primary and secondary systems. The proposed method was able to identify the general electrical power needs of the future consumer and approximate the lowest cost distribution system infrastructure design required to serve the future consumer.

Nahman *et al.* [30] presented a new approach of radial distribution system planning, which was a combination of the steepest descent method simulated annealing approach. They investigate the total available routes, which were to be minimized or optimized in order to reduce the total annual cost. The minimum total cost oriented solutions created by applying the steepest descent method, which further improved by a simulated annealing approach to obtain the minimum optimal total cost solution.

Najafi *et al.* [31] understood the complexity and difficulty of large distribution networks planning. The planner presented an improved genetic algorithm (GA) based solution for the optimal design of large scale distribution system in order to provide optimal sizing and location of high and medium voltage substations as well as feeder routing by incorporating their corresponding fixed and variable costs while satisfying their operational constraints. The planner took the 20 year planning period for the purpose of forecasting of loads and takes the advantage of minimum spanning tree for MV feeder routing.

Chakravorty and Ghosh [32] proposed a distribution system planning method by the means of Analytical Hierarchy Process (AHP). They took care of some reliability aspects such as miles of conductor, failures in feeder, energy interruption, relative cost for the purpose of minimizing substation construction cost.

Chakravorty and Ghosh [33] developed a method for distribution system planning in unstructured environments. The cost associated with the conductors, distance between load points and substation capacity was considered for the purpose of solving the optimal conductor layout problem of the distribution system. Combined Genetic Algorithm (GA) and Analytical Hierarchy Process (AHP) were used to determine substation location and the conductor layout.

Chakravorty and Ghosh [34] considered the problem of conductor layout in distribution system planning and proposed hybrid model which includes Taguchi and Analytical Hierarchy Process (AHP), where they took some reliability aspects into consideration as miles of conductors, feeder failure etc. The suggested method firstly decided the priority of reliability aspects and then conductor layout was decided based on these prioritized aspects.

Chakravorty *et al.* [35] proposed fuzzy logic based traditional load-flow technique such as Gauss Seidel method and Newton Rapson method. The fuzzy logic approach was used to choose the acceleration factor (α) so as to minimize the number of iteration and computational time.

Chakravorty and Ghosh [36] suggested an improved mathematical model to optimize the network routing problem in the distribution system planning by the means of a hybrid model. The hybrid model included Taguchi and Analytical Hierarchy Process (AHP) and Technique of Order Preference. Some aspects of reliability such as miles of conductor, feeder failures, customer interruption, maximum interruption, estimated relative cost were taken into consideration for constructing distribution system planning process.

Kalesar and Seifi [37] made an attempt to develop a genetic algorithm inspired method for the complex problem of optimal substation placing and feeder reconfiguration in distribution system planning. They developed a comprehensive algorithm for obtaining the optimal “number, location and service area” of HV/MV substations, and the optimal feeder path was found on the behalf of minimum loss criteria.

Samui *et al.* [38] proposed a directional approach to the optimal feeder routing problem of radial distribution system, which utilized the effectiveness of principals of optimality theorem. They took the various cost considerations such as yearly fixed cost, cost of energy and interruption cost to achieve the goal of optimal feeder path as in [31], while satisfying the various power flows, capacity, radiality and voltage drop constraints.

Samui *et al.* [39] investigated the role of reliability in distribution system planning configurations and planning cost for the radial distribution network. The concept of optimality was computed to evaluate the reliability of computationally reducing the total number of radial paths. Reliability indices were computed to evaluate the reliability of systems with different configurations. Both methods [39, 40] were similar to [34].

The above literature survey shows that a number of works have been carried out. The optimal configuration of the network obtained in [23],[34] and [38] are identical. They had used the same data but the result in each case is different.

In this thesis work, the optimal configuration for the example (23 node system) used in [23,34,38] is also used here to get the optimal structure with fixed substation location. A second example of 53 node points are taken and the optimal location of substation is found out using the proposed method and the computation of optimal location of substation is once again carried out using the method proposed in [20]. The results in each case by the proposed method with the existing methods are compared.

CHAPTER-THREE

NETWORK MODELLING, PROBLEMS FORMULATION AND PROPOSED ALGORITHMS

The main objective of radial distribution system planning is to find the optimal sizing and locating of the high and medium voltage (HV and MV) substations and optimal conductor selection and placement, as well as medium voltage (MV) feeders routing, using their corresponding fixed and variable costs associated with operational and optimization constraints.

The aim of the thesis is discussed below.

(i) To reduce the real and reactive power loss and total feeder length.

(ii) To reduce the capital cost and cost of loss as given in [30]. This has been done using 23-node points and existing substation [30].

(iii) To compute the optimal location of substation using DE algorithm and connection of load points.

(iv) To recompute the substation location [20] using the method used by them and load points have been connected.

Dijkstra's Algorithm has been used in this thesis work to connect the load points. This algorithm has been discussed in Art. 3.1.1.

(v) The sensitivity index [27] has been computed in each case.

3.1 DESCRIPTION OF OPTIMAL FEEDER ROUTING

The total annual cost of the distribution network planning basically depends on the total capital investment done in the system. There are many other cost factors, which must be accumulated for the formulation of the actual objective function of the system planning purpose. They are energy losses cost and energy interruption cost due to long energy supply route of distribution. As the distribution system is of radial configuration, the capital cost depends upon the total length of the route branches available for supply of energy to consumers. Such solutions were well known for the graph theory as the minimum spanning tree for the graph of the available routes [30]. In the radial distribution problem unfortunately the minimum spanning tree solutions are going to be failed due to several technical constraints hence the network routing algorithms must be modified to reach a feasible solution of the network reconfiguration.

3.1.1 Dijkstra’s Algorithm

Finding the shortest path is a very common problem. Dijkstra [4] made a great contribution to solve the problem with a path finding algorithm. He proposed a single source shortest path algorithm for the purpose of finding optimal path between given set of nodes in a weighted, directed graph with vertices V and edges E in a given network but the All Pair Shortest Path (APSP) problem could be solved by repeating the algorithm on every vertex in a graph.

Dijkstra’s algorithm [4] maintained a set S of vertices whose final shortest-path weights from the source ‘S’ had already been determined. For those vertices ‘V’ from S the shortest-path estimate d[v] was set to the shortest path from s to v. The algorithm repeatedly selected one of the remaining vertices not in ‘S’ with the minimum shortest-path estimate. This vertex was added to ‘S’ and all edges leaving this vertex are relaxed. Relaxing was tested whether the shortest-path estimate of a vertex could be lowered by designating the current edge as the best edge to reach this vertex. If the test was true, then the shortest path estimate d[v] was lowered and the best edge to reach this node is set to the current edge.

This algorithm was one attempt to find the shortest path from one node to all other nodes in the network. It assumed that the link lengths were always non-negative. The Dijkstra’s algorithm was comprised of the following steps:

Step-1: Source node was initialized and can be indicated as a filled circle.

Step-2: Initial path cost to neighboring nodes (adjacent nodes) or link cost was computed and these nodes are relabeled considering source node.

Step-3: Examine all adjacent nodes and find smallest label, made it permanent.

Step-4: The smallest label was now working node, then Step-2 and Step-3 are repeated till the destination node is reached.

3.1.2 Proposed Dijkstra Algorithm for Radial Distribution Network

The radial distribution system is said to be directed graph where the power directed from the source end i.e. substation to feeder and next to all loads connected in the system. A directed graph is nothing but an ordered pair D = (V, E), where ‘V’ is a set of all nodes or we can say that the co-ordinates of the substation, feeders and load points, and ‘E’ is a set of arcs or directed edges.

One of the main reasons for taking of Dijksta’s Algorithm for the purpose of solution of radial distribution feeder routing problem is that it is most important and useful algorithm available for generating (exact) optimal solutions to a large class of shortest path problems.

The radial distribution system is very much suitable for Dijkstra’s Algorithm with some changes because of the availability of one source substation with several loads and feeder points with objective function, a combination of cost and losses, as weights for the algorithm implementation requirement. Each edge in the directed graph has a combination of cost and losses associated with it. The Step by step Implementation of the algorithm is given below

Step-1: Construct graph to show all possible routes and route crossover. Compute costs and losses of each node to each rest of the nodes and draw a complete graph.

Step-2: Label a starting node. Make a substation as a staring node and mark it as first permanent node.

Step-3: Labeling of all nodes. Temporarily label all nodes connecting to the permanent labeled nodes with their distance from the starting point.

Step-4: (a) Look at the each of the arcs connecting to the starting node and choose the one of least cost and losses value arc.

(b) If a node can be reached from more than one direction, select the direction with the shortest cumulative cost.

Step-5: Chose the temporary label of least value and give the least value node as a permanent label and covert it as a new source node.

Step-6: Repeat steps 3 - 5 until all nodes have a permanent label.

Step-7: Retrace the shortest route backwards through the network back to your start node. You've found the path of least weight.

3.2 LOAD-FLOW ANALYSIS

The power flow study is the basic computation used to determine the state of a given power system operating at steady-state under the specified conditions of power input, power demand, and network configuration. Power flow or load-flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing systems. The principal information obtained from the power flow study is the magnitude and phase angle of the voltage at each bus, and the real and reactive power flowing in each line.

In the network reconfiguration problem the load-flow study is used to compute the overall real and reactive power loss of each branch for a given system configuration in order to rank it against other configurations. The results of the load-flow are also used in the evaluation of the electrical, load, and operational constraints.

In ref. [22] a simple and efficient load flow technique for radial distribution networks has been presented. For the purpose of getting load flow solutions, this load flow technique will be explained in brief:

The receiving end node voltage in branch 1 in radial distribution network can be written by using KVL equation as

$$V(2) = V(1) - I(1)Z(1) \tag{3.1}$$

Similarly for branch 2,

$$V(3) = V(2) - I(2)Z(2) \tag{3.2}$$

As the substation voltage $V(1)$ is known, so if $I(1)$ is known, it is easy to calculate $V(2)$ from eqn. 1.

Similarly, voltages of nodes 3, 4, 5... NB can easily be calculated if all the branch currents are known. Hence the generalized equation can be written as

$$V(m2) = V(m1) - I(jj)Z(jj) \tag{3.3}$$

m2 = $IR(jj)$ = receving end node of branch *jj*

m1 = $IS(jj)$= sending end node of branch *jj*

Current in branch *jj* is equal to the sum of load currents of all the nodes beyond selected node plus sum of all the nodes beyond branch *jj*, i.e.

$$I(jj) = \sum_{i=jj+1}^{LN1} IL(i) - \sum_{i=jj+1}^{LN1} IC(i) \tag{3.4}$$

The load current of node *i* is

$$IL(i) = \frac{PL(i) - j\,QL(i)}{V^*(i)} \qquad i = 2, 3\ldots NB \tag{3.5}$$

The charging current at node *i* is given by

$$IC(i) = y_0\, V(i) \qquad i = 2, 3, \ldots, NB \tag{3.6}$$

Since the load currents and charging currents are computed through iterative process using equation 5 and 6 respectively, hence a flat voltage of all nodes is assumed. After calculating initial load and charging current the branch current have been calculated by the expression given below:

$$I(jj) = \sum_{i=1}^{N(jj)} IL\{IE(jj,i)\} + \sum_{i=1}^{N(jj)} IC\{IE(jj,i)\} \tag{3.7}$$

The real and reactive power loss of branch jj is given by:

$$LP(jj) = |I(jj)|^2\, R(jj) \tag{3.8}$$

$$LQ(jj) = |I(jj)|^2\, X(jj) \tag{3.9}$$

For every new set of values of the voltages of all nodes, the convergence criterion of solution is checked.

3.3 Mathematical Modeling

The annual total network cost of rural networks considerably depends on the capital cost. The load delivery interruptions and power losses may also be cost effective to some extent due to long supply routes and, therefore, must be taken into account in optimization. As the capital cost is prevailing in most cases, the optimal network configuration is usually radial with a minimal total length of branches. The network capital cost is decreased step by step by removing the most capital cost effective branches among the available set of branches if this removal keeps the feasibility of the solution. A solution is feasible if it satisfies the imposed technical constraints and keeps the connectivity of the network. If this is not the case, the selected branch is kept included and the next most capital cost effective branch among the remaining branches is removed. This removal procedure is continued until any further removal of a branch produces an unfeasible solution. As the network during this minimization procedure changes from meshed to radial configurations, general methods for load flow and connectivity analyses should be provided applicable to all possible network structures created in various steps of this process.

3.3.1 Capital Investment Cost

The annual capital cost of any segment I with conductor k is given by-

$$C_c = g\ \sum_{i=1}^{m} c_k \tag{3.10}$$

where g capital recovery rate

c_k cost of branch k.

Cost of branch going from the source substation included both line and corresponding substation costs. By M the set of branches in the network configuration under consideration is denoted.

3.3.2 Cost of interruption

In radial networks there are no supply routes and the outage of a branch interrupts the delivery to all consumers supplied through this branch. Thus the cost of supply interruption can be calculated using the expression

$$C_i = c_i \alpha d \sum_{k \in M} \lambda_k\, Re\{I_k\} \sqrt{3} U_r \tag{3.11}$$

Where, c_i energy not delivered

α load factor

d repair duration

λ_k branch failure rate

I_k branch current

U_r network rated voltage

3.3.3 Cost of Energy Loss

The cost of energy losses equals

$$C_l = 8760 c_l \beta \sum_{k \in M} r_k |I_k|^2 \quad (3.12)$$

$$\beta = o.15\alpha + 0.85\alpha^2 \quad (3.13)$$

c_l	cost per unit of energy lost
β	loss factor
r_k	branch resistance

3.3.4 Objective Function

The overall objective function of the optimal conductor selection problem is given by

$$Min.Z = C_c + C_i + C_l \quad (3.14)$$

OPERATIONAL CONSTRAINTS

1. Economic capacity of conductor selected for the segment must meet the power flow on that segment of the network.
2. Feeder voltage at every point of the network must be more than acceptable voltage.
3. The system should take care of over voltage.
4. Conductor close to source substation will have a bigger conductor than which is farthest.
5. Load demand constraint.

3.4 DISTRIBUTION SUBSTATION PLACEMENT

The distribution system service area is fed through HV/MV substations. Hence the optimal substation location is an important part of distribution system planning to minimize the feeder losses and costs associated with the network. Optimal location of a substation is computed through an iterative algorithm. By minimizing power losses of the system, the optimal location of the substation {X (s), Y (s)} for substation ‘S’, can be computed through an iterative algorithm [37].

The initial location of the substation can be found by using the following equations

$$X(0) = \frac{\sum_{j=1}^{n} \frac{L_j^2 R(k) X_j}{V^2}}{\sum_{j=1}^{n} \frac{L_j^2 R}{V^2}} \tag{3.15}$$

$$Y(0) = \frac{\sum_{j=1}^{n} \frac{L_j^2 R(k) Y_j}{V^2}}{\sum_{j=1}^{n} \frac{L_j^2 R}{V^2}} \tag{3.16}$$

where, L_j Load demand of load point j (kVA)

V Network voltage

R(k) Branch resistance of conductor type ‘k’ per unit length

The location of the substation is to be calculated by minimizing the feeder loss (FL). The mathematical model of feeder loss of the system is given by

$$FL = \sum_{j=1}^{n} R(k) d_j \left(\frac{L_j}{V}\right)^2 \tag{3.17}$$

By minimizing FL, the optimal location for substation can be computed through the following equations with conductor type ‘k’ is given by

$$X(s) = \frac{\sum_{j=1}^{n} \frac{L_j^2 R(k) X_j}{d_j V^2}}{\sum_{j=1}^{n} \frac{L_j^2 R}{d_j V^2}} \tag{3.18}$$

$$Y(s) = \frac{\sum_{j=1}^{n} \frac{L_j^2 R(k) Y_j}{d_j V^2}}{\sum_{j=1}^{n} \frac{L_j^2 R}{d_j V^2}} \tag{3.19}$$

$$d_j = [\left(X(s) - X_j\right)^2 + (Y(s) - Y_j)^2]^{0.5} \tag{3.20}$$

3.4.1 Description of the Algorithm for Optimal Substation Placement

Substation placement is the last step of planning procedure in order to meet the consumer demand by minimizing the cost criteria.

3.4.1.1 Basics of Differential Evolution Algorithm

Ston and Price (1995) proposed a new evolutionary algorithm named as Differential Evolution, similar to other evolutionary algorithms especially genetic algorithm (GA) in the sense that it uses similar operators' mutation, recombination and selection. DE is a method of multidimensional mathematical optimization, tries to find out optimum of the problem by iteratively improving the solutions with respect to value of the objective function.

DE differs from Genetic Algorithms (GA) in that mutation is applied first to generate a trial vector, which is then used within the crossover operator to produce one offspring, and mutation step sizes are not sampled from a prior known probability distribution function. DE is a simpler technique than GA because it requires only three control variables Population (NP), crossover rate (CR) and weight factor (F).

The basic operations of DE are as follows:

A. *Initialization of population.* The initial population can be constructed using a random number generator under following formula:

$$x_{j,i,0} = rand_j(0,1)\left(x_{max,j} - x_{min,j}\right) + x_{min,j} \tag{3.21}$$

where, *i* = 0, 1, 2… NP-1;

$rand_j(0,1)$ The random generator produces uniformly distributed random numbers from the range (0, 1).

B. *Mutation operation.* Every evolutionary technique has its own type of mutation which is applied to every population member of the current population to produce intimate population. DE mutation procedure is as follows:

$$V_{i,g} = x_{best,g} + F.\left(x_{r1,g} - x_{r2,g}\right) \tag{3.22}$$

where, r1 and r2 are two different randomly chosen numbers corresponding to indexes in current population which differ from the index of target vector. The selected two vectors, $x_{r1,g}$ and $x_{r2,g}$are used as differential variation for mutation. The vector $x_{best,g}$ is the best solution of current generation. And $V_{i,g}$ are the best target vector and mutation vector of current generation.

Weight factor F is the real value between 0 to 1 and it controls the amplification of the differential variation between the two random vectors. There are many mutation variants are available shown in Table 4.1.

Table 3.1 Mutation Mechanism of DE

Mechanism	Mathematical expression
Best /1/ exp	$V_{i,g} = x_{best,g} + F.\left(x_{r1,g} - x_{r2,g}\right)$
Rand /1/ exp	$V_{i,g} = x_{r3,g} + F.\left(x_{r1,g} - x_{r2,g}\right)$
Best / 2 / exp	$V_{i,g} = x_{i,g} + F.\left(x_{r1,g} + x_{r2,g} - x_{r13g} - x_{r4,g}\right)$
Rand–to–Best	$V_{i,g} = x_{i,g} + F.\left(x_{r1,g} - x_{r2,g}\right)$
Rand / 2 / exp	$V_{i,g} = x_{r5,g} + F.\left(x_{r1,g} + x_{r2,g} - x_{r13g} - x_{r4,g}\right)$

C. *Crossover*. Crossover is an essential part of every EA methods, which is responsible for recombination of current with mutant population to produce trial population. Similarly to mutation, crossover mechanism is applied to every element in the intermediate population in current generation g. Classical DE provides uniform crossover procedure according following mathematical formula:

$$u_{i,g} = u_{j,i,g} = \begin{cases} V_{j,i,g}, \ rand_j \leq CR \\ x_{j,i,g}, \ Otherwise \end{cases} \tag{3.23}$$

Parameter Cr here is the crossover probability which is user defined parameter controlling fraction of parameters inherited from the mutant. In order to determine which source contributes a given parameter, a uniformly randomly-generated number is compared with the crossover probability.

D. *Selection.* After the mutation and crossover operator, all trial vectors have found. Procedure of surviving the fittest is realized in DE according to the value of objective functions for giving trial and current vectors. Thus, every trial vector is compared with current vector element wise and in the case when the objective function value of trial vector is lower or equal to such value of current vector, it replaces the current vector in the next generation. This procedure can be explained by the following formula given below:

$$x_{i,g+1} = \begin{cases} u_{i,g}, & if\ f(u_{i,g}) \le f(x_{i,g}) \\ x_{i,g}, & Otherwise \end{cases} \tag{3.24}$$

Once the next generation is fully constructed, whole process starting from mutation to selection is repeated with selected populations until the optimum is located or specified termination condition is satisfied. There are two most common termination criteria used, given as:

1. An objective met.
2. Limit on Number of Objective Function Evaluations (Maximum iteration count reach).

3.4.1.2 Proposed DE for Substation Location Optimization

The basic procedure of DE is summarized as follows.

Step-1: Randomly initialize the population of individual for DE using equation (3.21)

Step-2: Evaluate the objective values (Cost and loss functions) described in equation (3.14) of all individuals, and determine the best individual.

Step-3: Perform mutation operation for each individual according to Eq. (3.22) in order to obtain each individual corresponding mutant vector.

Step-4: Perform crossover operation between each individual and its corresponding mutant vector in order to obtain each individual trial vector using equation (3.23).

Step-5: Evaluate the objective values of the trial vectors.

Step-6: Perform selection operation between each individual and its corresponding trial vector according to Eq. (3.24) so as to generate the new individual for the next generation.

Step-7: Determine the best individual of the current new population with the best objective value then updates best individual and its objective value.

Step-8: If a stopping criterion is met, Print the global best particle and the corresponding fitness function value i.e. location of substation otherwise go to step 3.

The complete flow-chart for the thesis work is shown in Fig. 3.1.

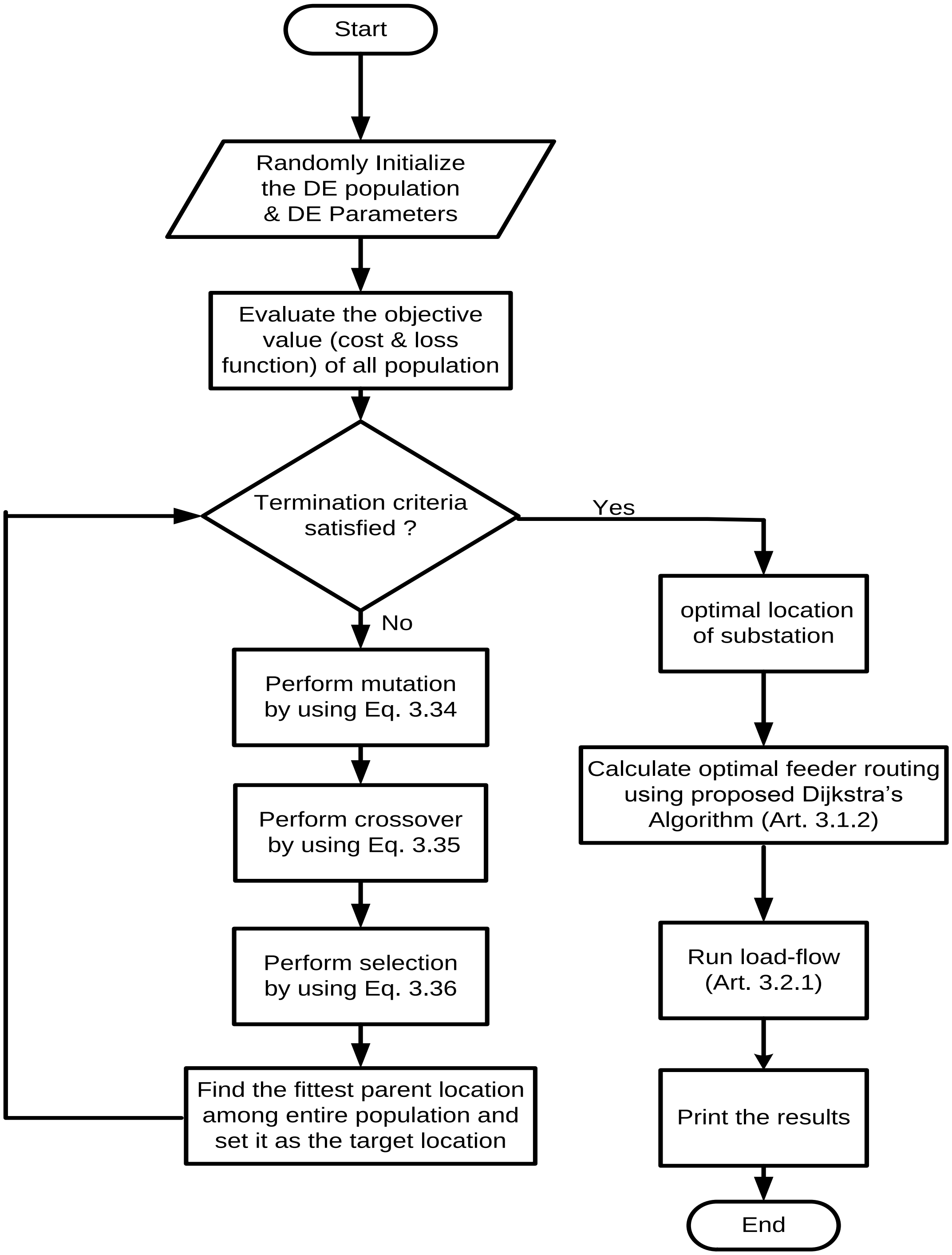

Figure 3.1 Complete Flow-Chart of the Proposed work

CHAPTER-FOUR

RESULTS AND DISCUSSIONS

The aim of this chapter is to present the result and discuss the results. Two examples have been considered. First example is 21-load points excluding substation [30]. The base values are 34.5kV and 10MVA. Figure 4.1 shows the load points of 23-node radial distribution network. The line data and load data have been shown in Appendix-A.

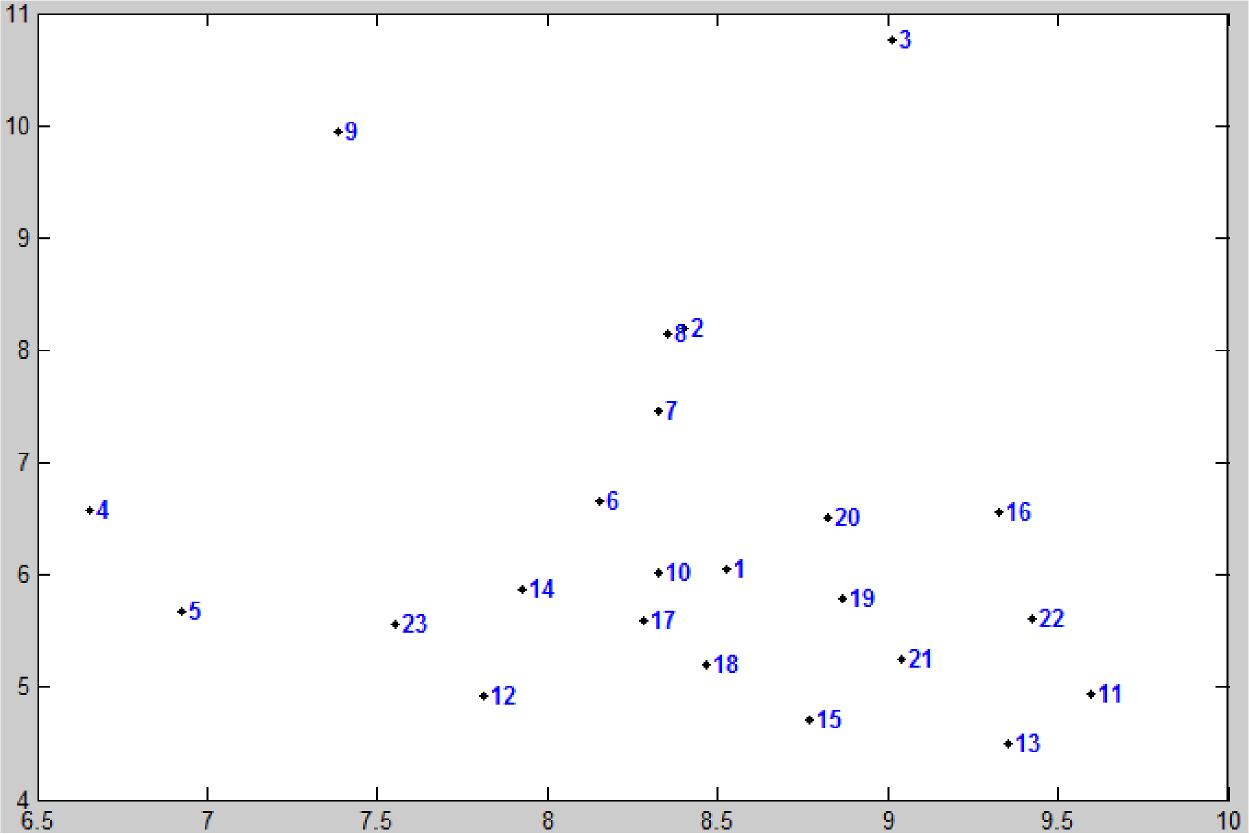

Figure 4.1 23-Load Point Radial Distribution Systems

4.1.1 EXAMPLE-1 USING PROPOSED ALGORITHM

The first example is a 23 load point radial distribution system; optimal feeder routing is shown in Fig.4.2 using the proposed method. In a first test system only single feeder case is considered and assumes that the point number 1 represents the Primary substation and 2 is a backup substation.

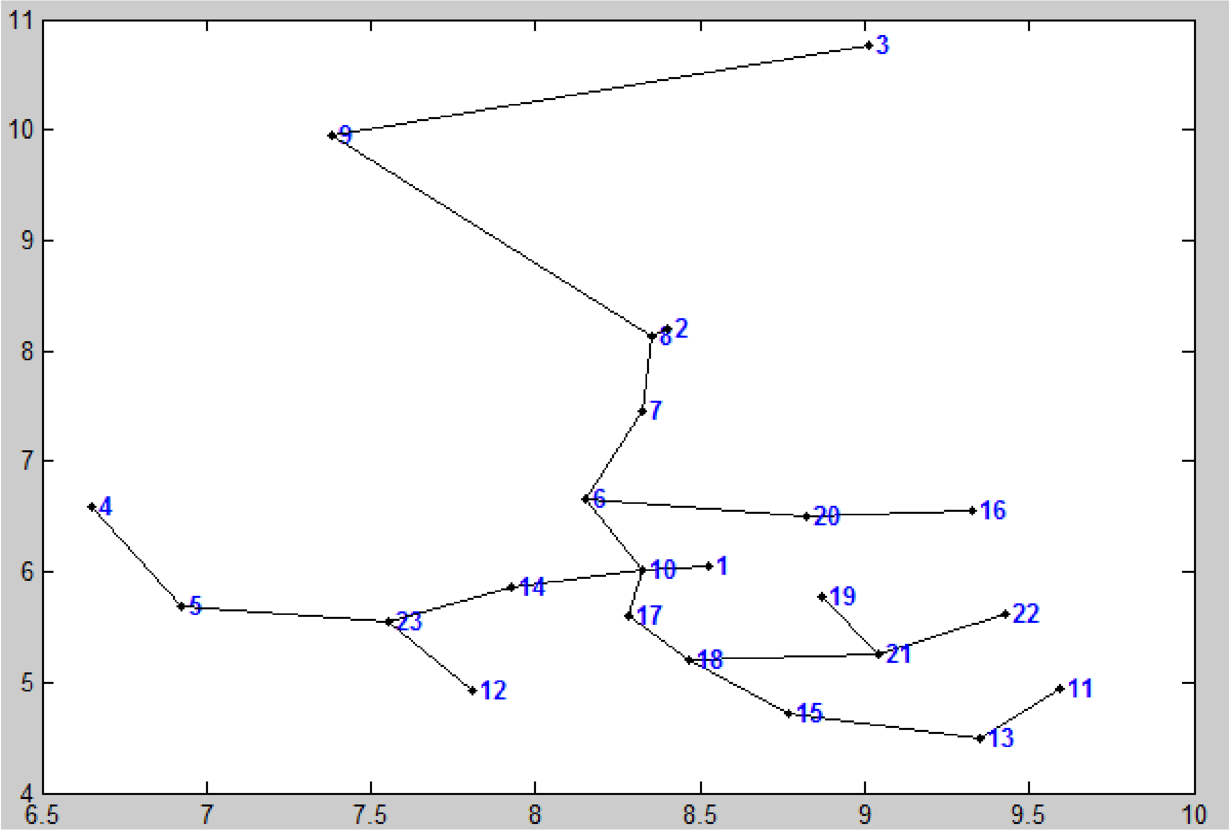

Figure 4.2 23-Load Point Radial Distribution Systems Optimal Feeder Configuration using Proposed Algorithm

Table 4.1, 4.2, 4.3 and 4.4 shows the feeder routing and their respective length, each node voltage, per branch real and reactive power loss and sensitivity index at each load point respectively.

Table 4.1 Routing of 23 Load Point Radial Distribution System and their Length (Km.) using the Proposed Method

Branch Number	Sending-end node	Receiving-end node	Length of each branch (Km.)
1	1	10	0.202091
2	10	14	0.429708
3	10	17	0.430155
4	17	18	0.441131
5	14	23	0.486042
6	18	15	0.571135
7	18	21	0.573837
8	21	22	0.525781
9	21	19	0.555000
10	15	13	0.622913
11	13	11	0.505270
12	23	5	0.640912
13	10	6	0.650864
14	23	12	0.678552
15	6	20	0.685860
16	20	16	0.501846
17	6	7	0.818072
18	7	8	0.686613
19	8	2	0.075604
20	5	4	0.940204
21	8	9	2.056600
22	9	3	1.820159

Table 4.2 Voltage Magnitude (p.u.) for Each Node in 23-Node Radial Distribution System using the Proposed Algorithm

Node Number	Voltage at Each Node (p.u.)
1 (S/S)	1.000000
2	0.998300
3	0.997288
4	0.998891
5	0.998988
6	0.999005
7	0.998583
8	0.998300
9	0.997663
10	0.999542
11	0.998512
12	0.999050
13	0.998564
14	0.999321
15	0.998693
16	0.998812
17	0.999187
18	0.998869
19	0.998635
20	0.998864
21	0.998692
22	0.998638
23	0.999120

Table 4.3 Real Power Loss (kW) and Reactive Power Loss (kVAr) of Each Branch in 23-Node Radial Distribution System using the Proposed Algorithm

Branch number	Real Power Loss (kW)	Reactive Power Loss (kVAr)
1	2.316113	2.625773
2	0.254168	0.288150
3	0.651803	0.738948
4	0.511838	0.580270
5	0.184016	0.208618
6	0.121733	0.138009
7	0.122293	0.138644
8	0.012451	0.014115
9	0.013143	0.014900
10	0.059015	0.066905
11	0.011968	0.013568
12	0.060671	0.068783
13	0.987220	1.119209
14	0.016055	0.018202
15	0.064939	0.073622
16	0.011880	0.013468
17	0.485091	0.549946
18	0.260668	0.295519
19	0.000000	0.000000
20	0.022253	0.025228
21	0.439381	0.498125
22	0.172873	0.195985

Table 4.4 Sensitivity Index at Each Node in 23-Node Radial Distribution System using the Proposed Method

Node Number	Sensitivity Index
2	0.993217
3	0.989195
4	0.995573
5	0.996222
6	0.997901
7	0.995690
8	0.994063
9	0.992373
10	0.999917
11	0.994062
12	0.996207
13	0.994525
14	0.997992
15	0.995250
16	0.995257
17	0.997992
18	0.996572
19	0.994550
20	0.995744
21	0.995248
22	0.994562
23	0.997085

4.1.2 EXAMPLE-1 USING EXISTING METHOD

Figure 4.3 represents the 23-load point radial distribution system optimal routing using existing method. The main substation is shown as the point no.1.

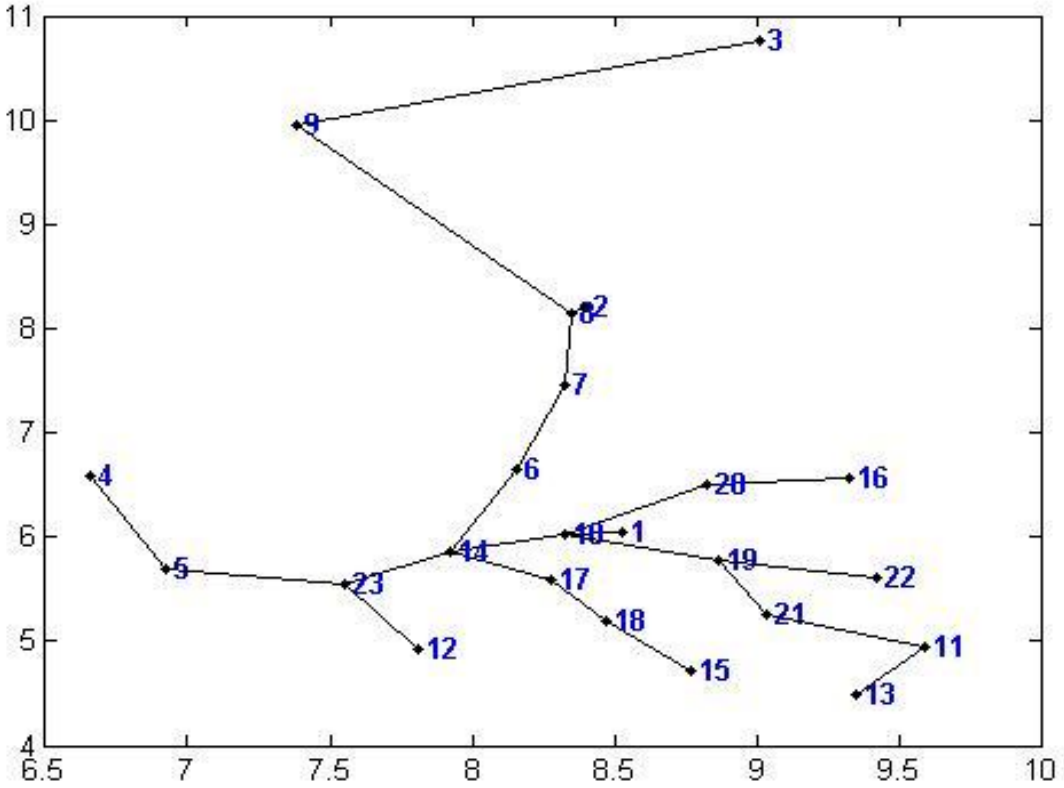

Figure 4.3 23-Load Point Radial Distribution System Routing using Existing Algorithm [30]

Table 4.5, 4.6, 4.7 and 4.8 shows the feeder routing and their respective length, each node voltage, per branch real and reactive power loss and sensitivity index at each load point respectively.

Table 4.5 Routing of 23-Load Point Radial Distribution System and their Length (Km.) in Existing Method [30]

Branch Number	Sending-End Node	Receiving-End Node	Length of Each Branch (Km.)
1	1	10	0.202100
2	10	20	0.697300
3	20	16	0.501800
4	10	14	0.429700
5	14	17	0.448200
6	17	18	0.441100
7	18	15	0.571100
8	14	23	0.486000
9	23	5	0.640900
10	5	4	0.940200
11	23	12	0.678600
12	14	6	0.817700
13	6	7	0.818100
14	7	8	0.686600
15	8	2	0.075600
16	8	9	2.056700
17	9	3	1.820200
18	10	19	0.594900
19	19	22	0.582700
20	19	21	0.555000
21	21	11	0.639400
22	11	13	0.505300

Table 4.6 Voltage Magnitude (p.u.) for Each Node in 23-Node Radial Distribution System in Existing Method [30]

Node Number	Voltage at Each Node (p.u.)
1 (S/S)	1.000000
2	0.997710
3	0.996697
4	0.998492
5	0.998589
6	0.998415
7	0.997993
8	0.997710
9	0.997073
10	0.999542
11	0.998932
12	0.998651
13	0.998880
14	0.998922
15	0.998633
16	0.999347
17	0.998783
18	0.998692
19	0.999235
20	0.999398
21	0.999064
22	0.999175
23	0.998721

Table 4.7 Real Power Loss (kW) and Reactive Power Loss (kVAr) for Each Node in the 23-Node Radial Distribution System in Existing Method [30]

Branch number	Real power loss (kW)	Reactive power loss (kVAr)
1	2.316818	2.626571
2	0.065952	0.074770
3	0.011866	0.013452
4	1.996330	2.263234
5	0.095509	0.108278
6	0.041779	0.047365
7	0.013524	0.015332
8	0.184146	0.208766
9	0.060718	0.068836
10	0.022271	0.025248
11	0.016069	0.018217
12	0.698762	0.792185
13	0.485679	0.550614
14	0.260971	0.295862
15	0.000000	0.000000
16	0.439920	0.498737
17	0.173081	0.196221
18	0.351889	0.398936
19	0.013784	0.015627
20	0.118207	0.134011
21	0.060532	0.068625
22	0.011960	0.013559

Table 4.8 Sensitivity Index at Each Node in the 23-Node Radial Distribution System in Existing Method [30]

Node Number	Sensitivity Index
2	0.990871
3	0.986853
4	0.993983
5	0.994632
6	0.995357
7	0.993341
8	0.991716
9	0.990028
10	0.999917
11	0.995998
12	0.994616
13	0.995528
14	0.997992
15	0.994544
16	0.997389
17	0.995509
18	0.994960
19	0.997924
20	0.997882
21	0.996717
22	0.996706
23	0.995494

Table 4.9 shows the comparison between the existing method and Proposed method with a criteria of cost, voltage and sensitivity.

Table 4.9 Comparison of Cost, Minimum Voltage and Sensitivity Index between Proposed Method and Existing Method

Methods	Node Number	Minimum Voltage (p.u.)	Total Length (Km.)	Sensitivity Index	Fixed Loss	Cost Of Interruption (US$)	Cost of Loss (US$)	Total Cost (US$)
Proposed Method	3	0.997288	14.8683	0.989195	34266.20	773085.81	2351.81	809703.81
Existing Method	3	0.996697	16.8384	0.986853	34935.16	764250.68	2580.83	801766.69

4.2 EXAMPLE-2

The second example is a 53-lode points excluding substation [20]. The base values 11 kV and 100 MVA. Figure 4.4 show, the load points. The line data and load data have been shown in Appendix-B. In this example single feeder, double feeder and three feeder configurations are solved using proposed algorithm whose results are tabulated in Table 4.10-4.18 and results are compared with the existing methods shown in Table 4.19- 4.27.

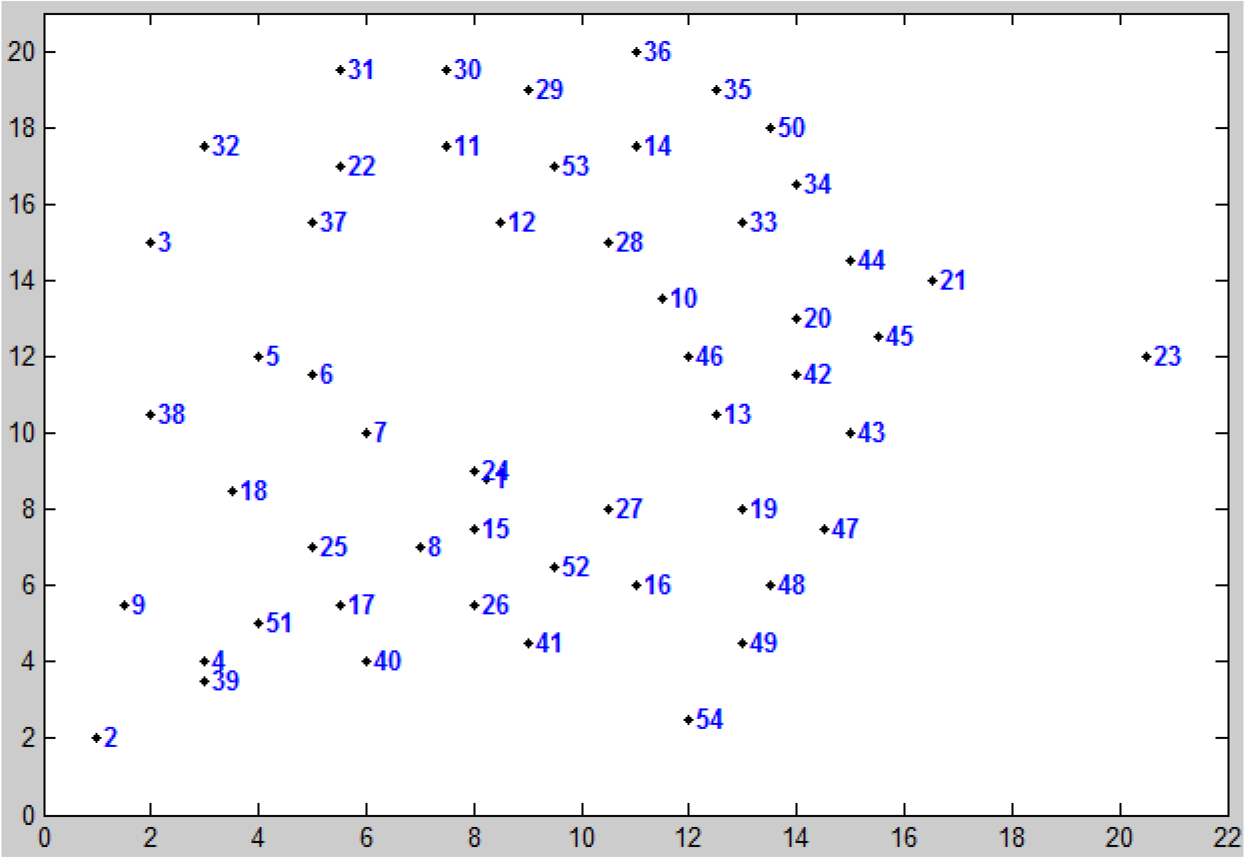

Figure 4.4 53-Load Point Radial Distribution Systems

4.2.1 Single Feeder Case using Proposed Algorithm

In single feeder case, there is only one feeder is emerging from the new candidate substation found by the algorithm proposed in chapter 3. Figure 4.4 shows the 53-load point radial distribution network with a single feeder configuration with a substation placed on a point no. 1 whose coordinates given in appendix B.1.

Table 4.10 shows the feeder routing of the system using the proposed algorithm. In Table 4.11 voltage magnitude of each load point (p.u.) is represented whereas the Table 4.12 demonstrates the severity index at each node point in order to find out the stability of the system.

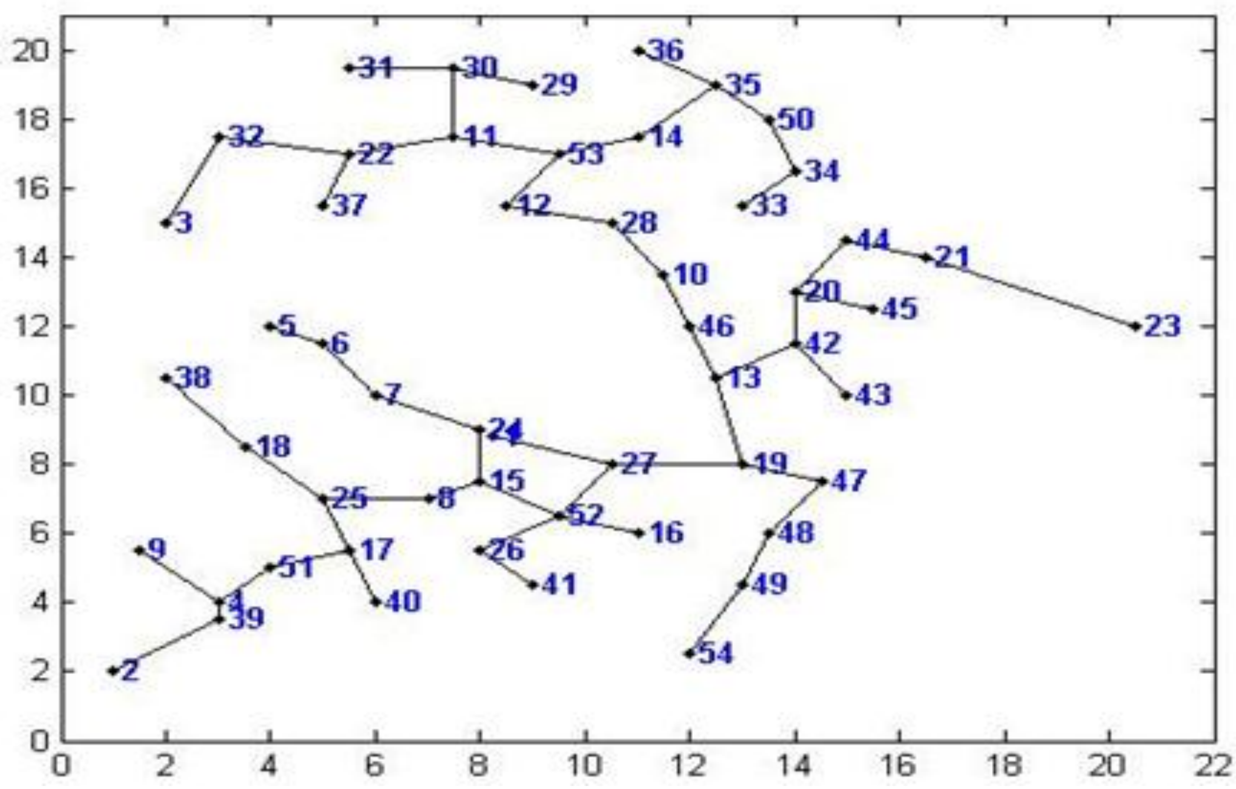

Figure 4.5 Optimal Feeder Configuration (Single Feeder Case) using the Proposed Method

Table 4.10 53-load Point Radial Distribution System Feeder Routing for Single Feeder Case using Proposed Algorithm

Branch Number	Sending-End Node	Receiving-End Node	Length of Each Branch (Km.)
1	1	27	0.671863
2	27	52	1.802776
3	52	16	1.581139
4	52	15	1.802776
5	15	8	1.118034
6	15	24	1.500000
7	52	26	1.802776
8	26	41	1.414214
9	8	25	2.000000
10	25	17	1.581139
11	17	40	1.581139
12	17	51	1.581139
13	51	4	1.414214
14	4	39	0.500000
15	25	18	2.121320
16	4	9	2.121320
17	24	7	2.236068
18	7	6	1.802776
19	6	5	1.118034
20	27	19	2.500000
21	19	47	1.581139
22	47	48	1.802776
23	48	49	1.581139
24	49	53	2.236068
25	39	2	2.500000

26	18	38	2.500000
27	19	13	2.539510
28	13	46	1.581139
29	46	10	1.581139
30	13	42	1.802776
31	42	20	1.500000
32	20	45	1.581139
33	10	28	1.802776
34	42	43	1.802776
35	20	44	1.802776
36	44	21	1.581139
37	28	12	2.061553
38	12	53	1.802776
39	53	14	1.581139
40	53	11	2.061553
41	11	30	2.000000
42	30	29	1.581139
43	30	31	2.000000
44	11	22	2.061553
45	22	37	1.581139
46	14	35	2.121320
47	35	50	1.414214
48	50	34	1.581139
49	34	33	1.414214
50	35	36	1.802776
51	22	32	2.539510
52	32	3	2.692582
53	21	23	4.472136

Table 4.11 Voltage (p.u.) of Each Node in 53-Load Point Radial Distribution System for Single Feeder Case using Proposed Algorithm

Node Number	Voltage of Each Node
1 (S/S)	1.000000
2	0.977461
3	0.952716
4	0.977826
5	0.980973
6	0.981164
7	0.981858
8	0.983006
9	0.977644
10	0.967900
11	0.954302
12	0.959860
13	0.975291
14	0.955143
15	0.984610
16	0.989143
17	0.979375
18	0.980000
19	0.984490
20	0.972536
21	0.971507
22	0.953399
23	0.970738
24	0.983200
25	0.980478
26	0.988514

27	0.994957
28	0.963982
29	0.953105
30	0.953244
31	0.952802
32	0.952952
33	0.952532
34	0.952780
35	0.953909
36	0.953752
37	0.953122
38	0.979573
39	0.977675
40	0.979240
41	0.988394
42	0.973506
43	0.973197
44	0.971916
45	0.972400
46	0.971424
47	0.983661
48	0.983103
49	0.982748
50	0.953334
51	0.978493
52	0.989277
53	0.956412
53	0.982367

Table 4.12 Sensitivity Index at Each Node in 53-Load Point Radial Distribution System for Single Feeder Case in Proposed Method

Node Number	Sensitivity Index of Each Node
2	0.912848
3	0.823860
4	0.916256
5	0.926037
6	0.927919
7	0.932651
8	0.939121
9	0.913531
10	0.890185
11	0.836314
12	0.862887
13	0.937733
14	0.835499
15	0.956304
16	0.957274
17	0.923844
18	0.923732
19	0.979449
20	0.896964
21	0.891808
22	0.828732
23	0.887984
24	0.937900
25	0.931152
26	0.955430
27	0.999550

28	0.876523
29	0.825207
30	0.827825
31	0.824155
32	0.825451
33	0.823223
34	0.825040
35	0.831641
36	0.827447
37	0.825264
38	0.920761
39	0.913807
40	0.919510
41	0.954379
42	0.903621
43	0.897020
44	0.894018
45	0.894088
46	0.903501
47	0.938095
48	0.935645
49	0.933778
50	0.827721
51	0.919510
52	0.979596
53	0.848294
53	0.931310

4.2.2 Two Feeder Case using Proposed Algorithm

In single feeder case, there is only one feeder is emerging from the new candidate substation found by the algorithm proposed in chapter 3. Figure 4.5 shows the 53-load point radial distribution network with a single feeder configuration with a substation placed on a point no. 1 whose coordinates given in appendix B.1.

Table 4.13 shows the feeder routing of the system using the proposed algorithm. In Table 4.14 voltage magnitude of each load point (p.u.) is represented whereas the Table 4.15 demonstrates the severity index at each node point in order to find out the stability of the system.

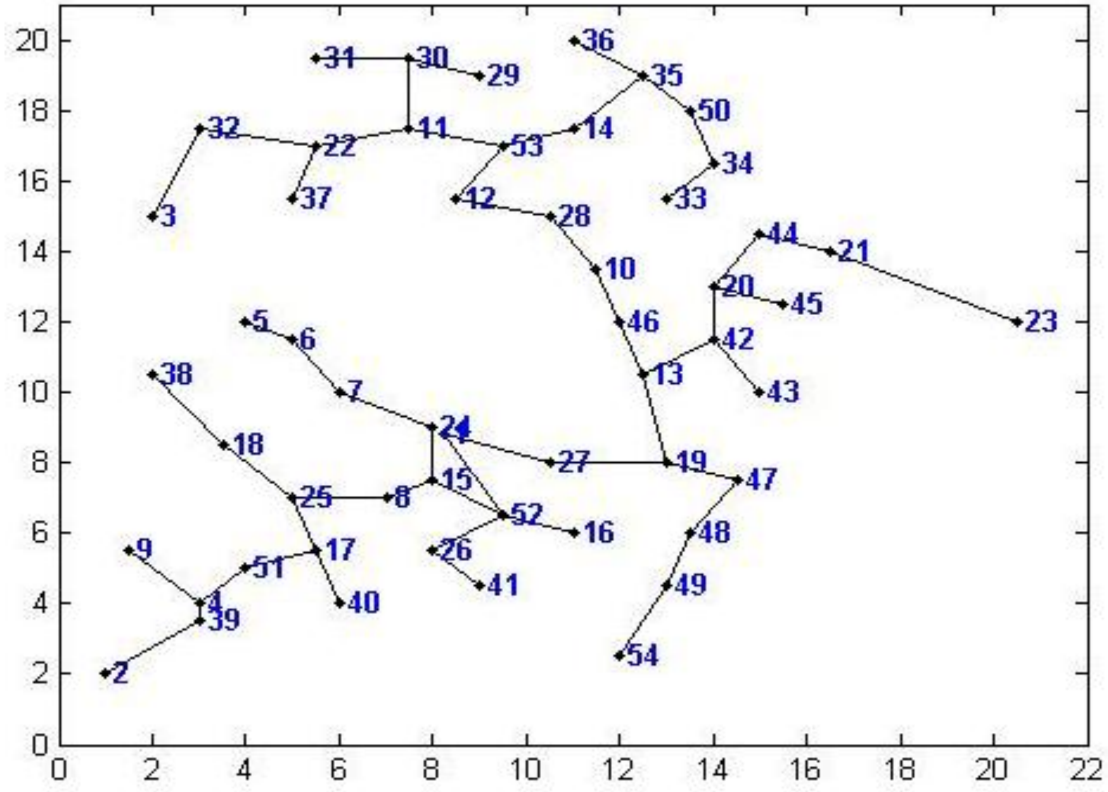

Figure 4.6 Optimal Feeder Configuration (Double Feeder Case) using the Proposed Method

Table 4.13 53-Load Point Radial Distribution System Feeder Routing for Double Feeder Case using the Proposed Method

Branch Number	Sending-End Node	Receiving-End Node	Length of Each Branch (Km.)
1	1	27	0.671863
2	1	52	2.368840
3	52	16	1.581139
4	52	15	1.802776
5	15	8	1.118034
6	15	24	1.500000
7	52	26	1.802776
8	26	41	1.414214
9	8	25	2.000000
10	25	17	1.581139
11	17	40	1.581139
12	17	51	1.581139
13	51	4	1.414214
14	4	39	0.500000
15	25	18	2.121320
16	4	9	2.121320
17	24	7	2.236068
18	7	6	1.802776
19	6	5	1.118034
20	27	19	2.500000
21	19	47	1.581139
22	47	48	1.802776
23	48	49	1.581139
24	49	53	2.236068
25	39	2	2.500000

26	18	38	2.500000
27	19	13	2.539510
28	13	46	1.581139
29	46	10	1.581139
30	13	42	1.802776
31	42	20	1.500000
32	20	45	1.581139
33	10	28	1.802776
34	42	43	1.802776
35	20	44	1.802776
36	44	21	1.581139
37	28	12	2.061553
38	12	53	1.802776
39	53	14	1.581139
40	53	11	2.061553
41	11	30	2.000000
42	30	29	1.581139
43	30	31	2.000000
44	11	22	2.061553
45	22	37	1.581139
46	14	35	2.121320
47	35	50	1.414214
48	50	34	1.581139
49	34	33	1.414214
50	35	36	1.802776
51	22	32	2.539510
52	32	3	2.692582
53	21	23	4.472136

Table 4.14 Voltage (p.u.) of Each Node in 53-Load Point Radial Distribution System for Double Feeder Case in the Proposed System

Node Number	Voltage of Each Node (p.u.)
1 (S/S)	1.000000
2	0.980783
3	0.954931
4	0.981146
5	0.984283
6	0.984473
7	0.985166
8	0.986310
9	0.980965
10	0.970082
11	0.956513
12	0.962059
13	0.977457
14	0.957353
15	0.987909
16	0.992427
17	0.982690
18	0.983313
19	0.986635
20	0.974708
21	0.973681
22	0.955612
23	0.972913
24	0.986503
25	0.983790
26	0.991800

27	0.997080
28	0.966173
29	0.955319
30	0.955457
31	0.955016
32	0.955166
33	0.954747
34	0.954994
35	0.956121
36	0.955964
37	0.955336
38	0.982888
39	0.980996
40	0.982556
41	0.991681
42	0.975676
43	0.975367
44	0.974089
45	0.974572
46	0.973598
47	0.985809
48	0.985251
49	0.984897
50	0.955548
51	0.981812
52	0.992560
53	0.958618
53	0.984517

Table 4.15 Sensitivity Index at Each Node in 53-Load Point Radial Distribution System for Double Feeder Case in the Proposed Method

Node Number	Sensitivity Index of Each Node
2	0.925319
3	0.831547
4	0.928752
5	0.938600
6	0.940495
7	0.945260
8	0.951774
9	0.926007
10	0.898182
11	0.844061
12	0.870759
13	0.945943
14	0.843241
15	0.969074
16	0.970051
17	0.936391
18	0.936279
19	0.987839
20	0.904992
21	0.899812
22	0.836443
23	0.895971
24	0.950545
25	0.943750
26	0.968195
27	0.999550

28	0.884457
29	0.832900
30	0.835531
31	0.831844
32	0.833145
33	0.830907
34	0.832733
35	0.839366
36	0.835152
37	0.832958
38	0.933288
39	0.926285
40	0.932028
41	0.967136
42	0.911679
43	0.905048
44	0.902032
45	0.902103
46	0.911558
47	0.946306
48	0.943846
49	0.941970
50	0.835426
51	0.932028
52	0.999493
53	0.856097
53	0.939491

4.2.3 Three Feeder Case using Proposed Algorithm

In Three feeder case, there is three feeders is emerging from the new candidate substation found by the algorithm proposed in chapter 3. Figure 4.5 shows the 53-load point radial distribution network with a single feeder configuration with a substation placed on a point no. 1 whose coordinates given in appendix B.

Table 4.16 shows the feeder routing of the system using the proposed algorithm. In Table 4.17 voltage magnitude of each load point (p.u.) is represented whereas the Table 4.18 demonstrates the severity index at each node point in order to find out the stability of the system.

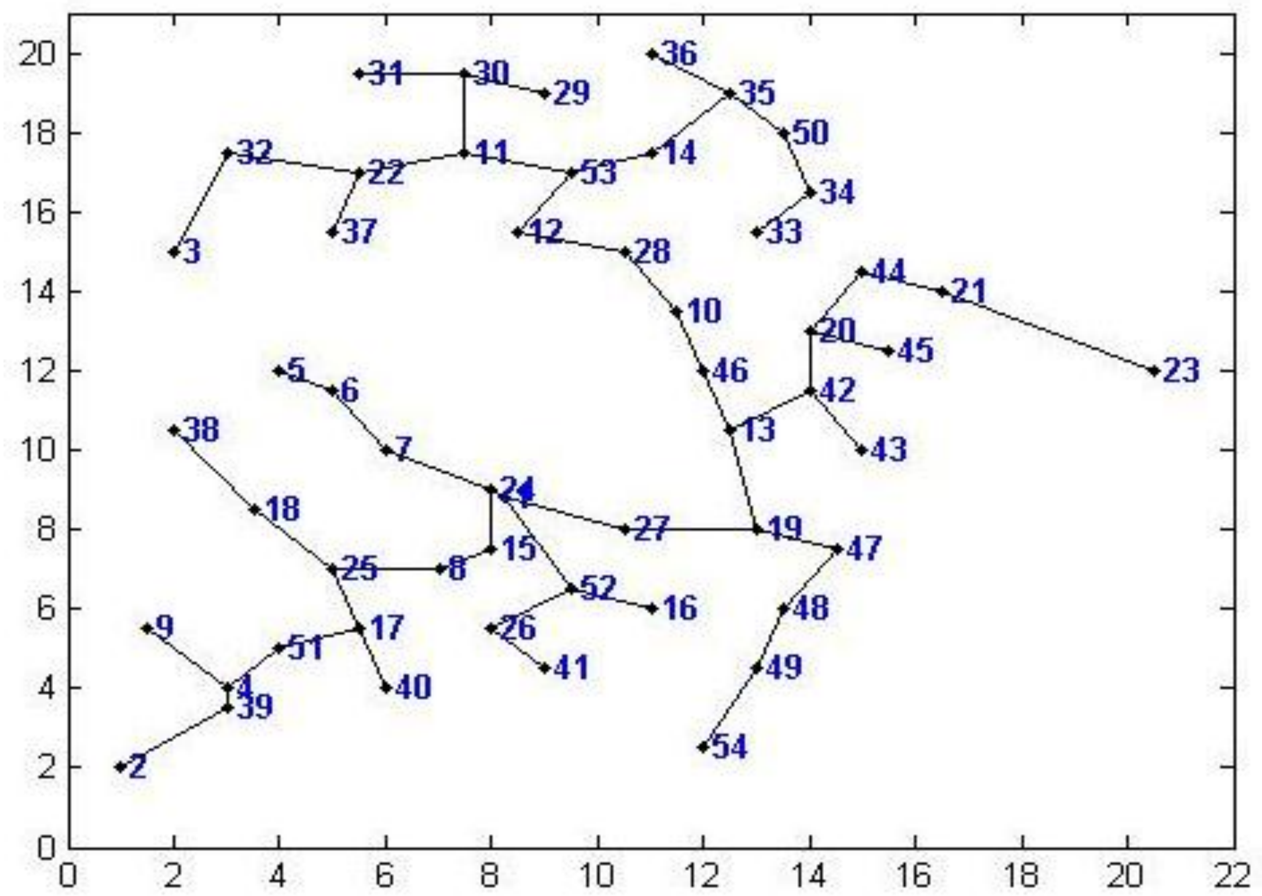

Figure 4.7 Optimal Feeder Configurations for 53-Load Point (Three Feeder Case) using the Proposed Method

Table 4.16 53-Load Point Radial Distribution System Feeder Routing for Three Feeder Case using the Proposed Method

Branch No.	Sending-End Node	Receiving-End Node	Length of Each Branch (Km.)
1	1	27	0.671863
2	1	52	2.368840
3	1	24	2.472124
4	24	15	1.500000
5	15	8	1.118034
6	52	16	1.581139
7	52	26	1.802776
8	26	41	1.414214
9	8	25	2.000000
10	25	17	1.581139
11	17	40	1.581139
12	17	51	1.581139
13	51	4	1.414214
14	4	39	0.500000
15	25	18	2.121320
16	4	9	2.121320
17	24	7	2.236068
18	7	6	1.802776
19	6	5	1.118034
20	27	19	2.500000
21	19	47	1.581139
22	47	48	1.802776
23	48	49	1.581139
24	49	53	2.236068
25	39	2	2.500000

26	18	38	2.500000
27	19	13	2.539510
28	13	46	1.581139
29	46	10	1.581139
30	13	42	1.802776
31	42	20	1.500000
32	20	45	1.581139
33	10	28	1.802776
34	42	43	1.802776
35	20	44	1.802776
36	44	21	1.581139
37	28	12	2.061553
38	12	53	1.802776
39	53	14	1.581139
40	53	11	2.061553
41	11	30	2.000000
42	30	29	1.581139
43	30	31	2.000000
44	11	22	2.061553
45	22	37	1.581139
46	14	35	2.121320
47	35	50	1.414214
48	50	34	1.581139
49	34	33	1.414214
50	35	36	1.802776
51	22	32	2.539510
52	32	3	2.692582
53	21	23	4.472136

Table 4.17 Voltage (p.u.) of Each Node in 53-Load Point Radial Distribution System for Three Feeder Case in Proposed Method

Node No.	Voltage at Each Node (p.u.)
1 (S/S)	1.000000
2	0.984091
3	0.954931
4	0.984453
5	0.991447
6	0.991635
7	0.992323
8	0.989600
9	0.984273
10	0.970082
11	0.956513
12	0.962059
13	0.977457
14	0.957353
15	0.991194
16	0.998549
17	0.985993
18	0.986614
19	0.986635
20	0.974708
21	0.973681
22	0.955612
23	0.972913
24	0.993650
25	0.987088
26	0.997926

27	0.997080
28	0.966173
29	0.955319
30	0.955457
31	0.955016
32	0.955166
33	0.954747
34	0.954994
35	0.956121
36	0.955964
37	0.955336
38	0.986189
39	0.984304
40	0.985858
41	0.997807
42	0.975676
43	0.975367
44	0.974089
45	0.974572
46	0.973598
47	0.985809
48	0.985251
49	0.984897
50	0.955548
51	0.985117
52	0.998682
53	0.958618
53	0.984517

Table 4.18 Sensitivity Index at Each Node in 53-Load Point Radial Distribution System for Three Feeder Case in Proposed Method

Node No.	Sensitivity Index
2	0.937868
3	0.831547
4	0.941324
5	0.966223
6	0.968146
7	0.972981
8	0.964502
9	0.938561
10	0.898182
11	0.844061
12	0.870759
13	0.945943
14	0.843241
15	0.973594
16	0.994209
17	0.949015
18	0.948903
19	0.987839
20	0.904992
21	0.899812
22	0.836443
23	0.895971
24	0.996691
25	0.956424
26	0.992330
27	0.999550

28	0.884457
29	0.832900
30	0.835531
31	0.831844
32	0.833145
33	0.830907
34	0.832733
35	0.839366
36	0.835152
37	0.832958
38	0.945891
39	0.938840
40	0.944622
41	0.991259
42	0.911679
43	0.905048
44	0.902032
45	0.902103
46	0.911558
47	0.946306
48	0.943846
49	0.941970
50	0.835426
51	0.944622
52	0.999493
53	0.856097
53	0.939491

4.2.4 Single Feeder Case using Existing Algorithm

In single feeder case, there is only one feeder is emerging from the candidate substation found by the algorithm proposed by Ranjan and Das [20]. Figure 4.6 shows the 53-load point radial distribution network with a single feeder configuration with a substation placed on a point no. 1 whose coordinates are (10.50, 8.70).

Table 4.19 shows the feeder routing of the system using the proposed algorithm. In Table 4.20 voltage magnitude of each load point (p.u.) is represented whereas the Table 4.21 demonstrates the severity index at each node point in order to find out the stability of the system.

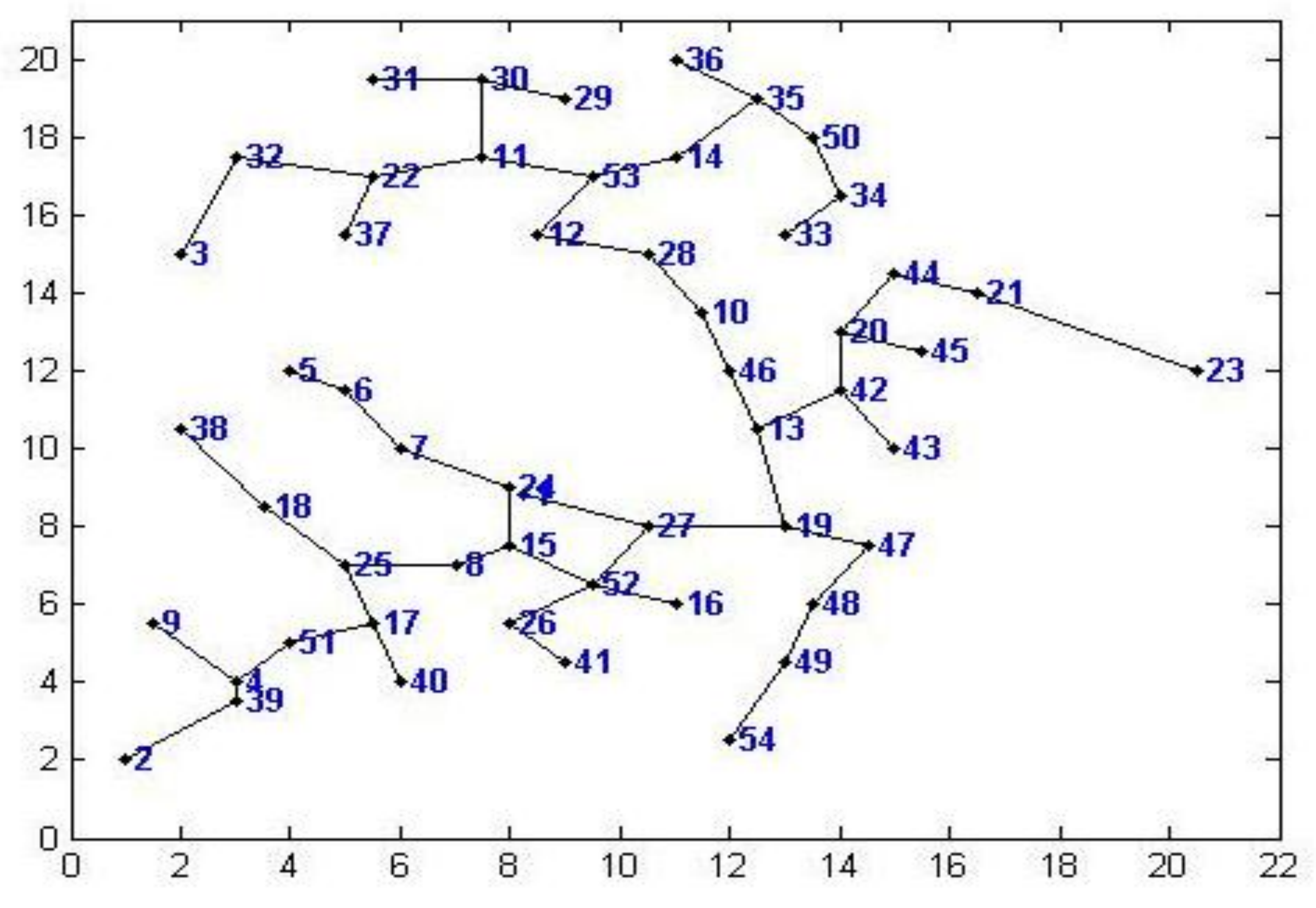

Figure 4.8 Optimal Feeders Routing using Existing Method (Single Feeder Case) [20]

Table 4.19 53-Load Point Radial Distribution System Feeder Routing for Single Feeder Case using Existing Method [20]

Branch No.	Sending-End Node	Receiving-End Node	Length of Each Branch (Km.)
1	1	27	0.700000
2	27	52	1.802776
3	52	16	1.581139
4	52	15	1.802776
5	15	8	1.118034
6	15	24	1.500000
7	52	26	1.802776
8	26	41	1.414214
9	8	25	2.000000
10	25	17	1.581139
11	17	40	1.581139
12	17	51	1.581139
13	51	4	1.414214
14	4	39	0.500000
15	25	18	2.121320
16	4	9	2.121320
17	24	7	2.236068
18	7	6	1.802776
19	6	5	1.118034
20	27	19	2.500000
21	19	47	1.581139
22	47	48	1.802776
23	48	49	1.581139
24	49	53	2.236068
25	39	2	2.500000

26	18	38	2.500000
27	19	13	2.539510
28	13	46	1.581139
29	46	10	1.581139
30	13	42	1.802776
31	42	20	1.500000
32	20	45	1.581139
33	10	28	1.802776
34	42	43	1.802776
35	20	44	1.802776
36	44	21	1.581139
37	28	12	2.061553
38	12	53	1.802776
39	53	14	1.581139
40	53	11	2.061553
41	11	30	2.000000
42	30	29	1.581139
43	30	31	2.000000
44	11	22	2.061553
45	22	37	1.581139
46	14	35	2.121320
47	35	50	1.414214
48	50	34	1.581139
49	34	33	1.414214
50	35	36	1.802776
51	22	32	2.539510
52	32	3	2.692582
53	21	23	4.472136

Table-4.20 Voltage (p.u.) of Each Node in 53-Load Point Radial Distribution System for Single Feeder Case using Existing Algorithm [20]

Node No.	Voltage at Each Node (p.u.)
1 (S/S)	1.000000
2	0.977245
3	0.952495
4	0.977610
5	0.980758
6	0.980949
7	0.981643
8	0.982791
9	0.977428
10	0.967682
11	0.954081
12	0.959640
13	0.975075
14	0.954922
15	0.984395
16	0.988929
17	0.979159
18	0.979784
19	0.984275
20	0.972319
21	0.971290
22	0.953178
23	0.970520
24	0.982985
25	0.980263
26	0.988300

27	0.994744
28	0.963763
29	0.952884
30	0.953022
31	0.952581
32	0.952731
33	0.952311
34	0.952559
35	0.953688
36	0.953530
37	0.952901
38	0.979358
39	0.977459
40	0.979024
41	0.988181
42	0.973289
43	0.972980
44	0.971699
45	0.972183
46	0.971207
47	0.983446
48	0.982888
49	0.982533
50	0.953113
51	0.978278
52	0.989063
53	0.956191
53	0.982152

Table 4.21 Sensitivity Index at Each Node in 53-Load Point Radial Distribution System for Single Feeder Case using Existing Algorithm Method [20]

Node No.	Sensitivity Index of Each Node
2	0.912041
3	0.823094
4	0.915448
5	0.925224
6	0.927105
7	0.931835
8	0.938303
9	0.912724
10	0.889389
11	0.835543
12	0.862103
13	0.936915
14	0.834727
15	0.955478
16	0.956447
17	0.923032
18	0.922921
19	0.978612
20	0.896165
21	0.891011
22	0.827965
23	0.887189
24	0.937082
25	0.930337
26	0.954605
27	0.999532

28	0.875732
29	0.824441
30	0.827057
31	0.823389
32	0.824684
33	0.822458
34	0.824274
35	0.830872
36	0.826680
37	0.824498
38	0.919951
39	0.913000
40	0.918700
41	0.953554
42	0.902819
43	0.896220
44	0.893220
45	0.893290
46	0.902698
47	0.937276
48	0.934828
49	0.932962
50	0.826954
51	0.918700
52	0.978760
53	0.847517
53	0.930495

4.2.5 Two Feeder Case using Existing Algorithm

In two feeder case, there is two feeders is emerging from the candidate substation found by the algorithm proposed by Ranjan and Das [20]. Figure 4.7 shows the 53-load point radial distribution network with a single feeder configuration with a substation placed on a point no. 1 whose coordinates are (10.50, 8.70).

Table 4.22 shows the feeder routing of the system using the proposed algorithm. In Table 4.23 voltage magnitude of each load point (p.u.) is represented whereas the Table 4.24 demonstrates the severity index at each node point in order to find out the stability of the system.

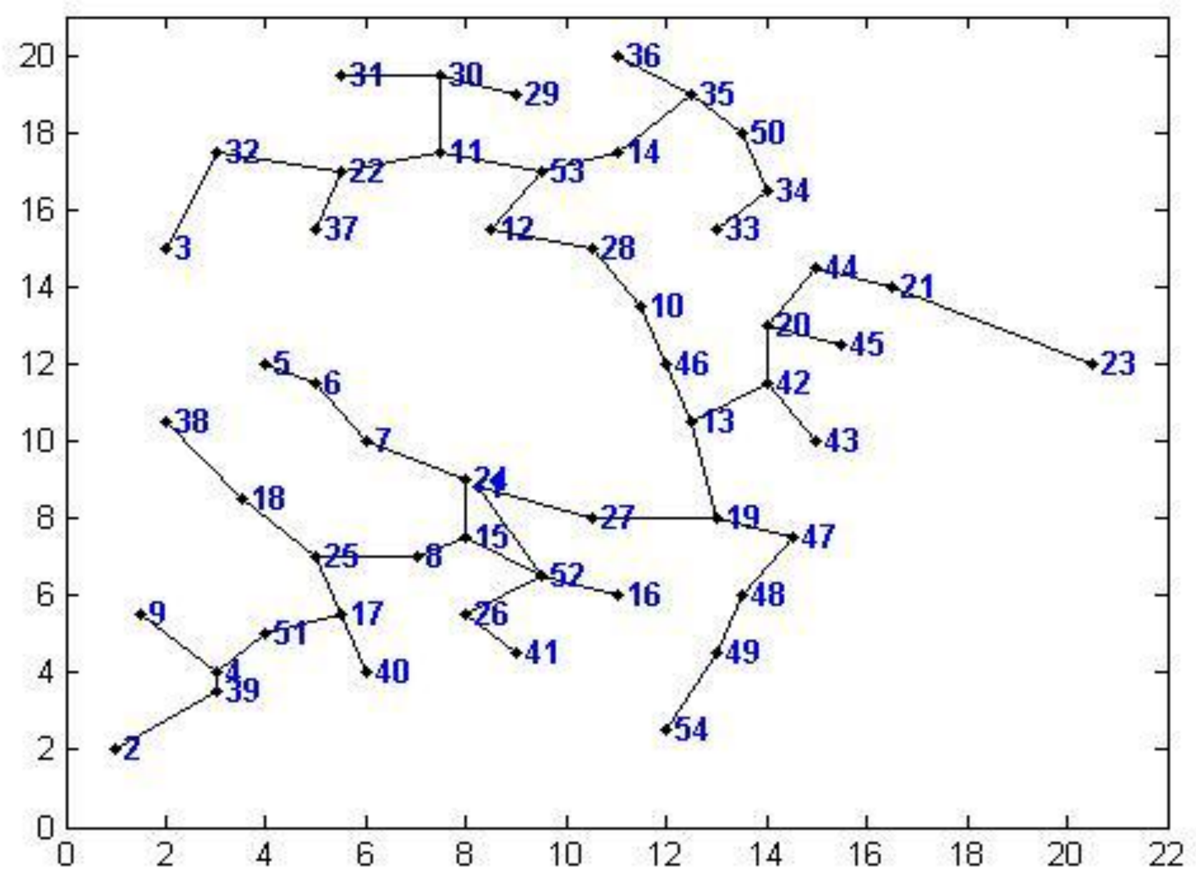

Figure 4.9 Optimal Feeder Routing (Two Feeder Case) using Existing Method [20]

Table 4.22 53-Load Point Radial Distribution System Feeder Routing for Double Feeder Case using Existing Method [20]

Branch No.	Sending-End Node	Receiving-End Node	Length of Each Branch (Km.)
1	1	27	0.700000
2	1	52	2.416609
3	52	16	1.581139
4	52	15	1.802776
5	15	8	1.118034
6	15	24	1.500000
7	52	26	1.802776
8	26	41	1.414214
9	8	25	2.000000
10	25	17	1.581139
11	17	40	1.581139
12	17	51	1.581139
13	51	4	1.414214
14	4	39	0.500000
15	25	18	2.121320
16	4	9	2.121320
17	24	7	2.236068
18	7	6	1.802776
19	6	5	1.118034
20	27	19	2.500000
21	19	47	1.581139
22	47	48	1.802776
23	48	49	1.581139
24	49	53	2.236068
25	39	2	2.500000

26	18	38	2.500000
27	19	13	2.539510
28	13	46	1.581139
29	46	10	1.581139
30	13	42	1.802776
31	42	20	1.500000
32	20	45	1.581139
33	10	28	1.802776
34	42	43	1.802776
35	20	44	1.802776
36	44	21	1.581139
37	28	12	2.061553
38	12	53	1.802776
39	53	14	1.581139
40	53	11	2.061553
41	11	30	2.000000
42	30	29	1.581139
43	30	31	2.000000
44	11	22	2.061553
45	22	37	1.581139
46	14	35	2.121320
47	35	50	1.414214
48	50	34	1.581139
49	34	33	1.414214
50	35	36	1.802776
51	22	32	2.539510
52	32	3	2.692582
53	21	23	4.472136

Table 4.23 Voltage (p.u.) of Each Node in 53-Load Point Radial Distribution System for Two Feeder Case using Existing Algorithm [20]

Node No.	Voltage at Each Node (p.u.)
1 (S/S)	1.000000
2	0.980630
3	0.954803
4	0.980993
5	0.984131
6	0.984321
7	0.985013
8	0.986158
9	0.980812
10	0.969956
11	0.956385
12	0.961932
13	0.977332
14	0.957225
15	0.987757
16	0.992276
17	0.982538
18	0.983161
19	0.986512
20	0.974582
21	0.973556
22	0.955484
23	0.972787
24	0.986351
25	0.983637
26	0.991649

27	0.996957
28	0.966046
29	0.955191
30	0.955329
31	0.954889
32	0.955038
33	0.954619
34	0.954867
35	0.955994
36	0.955836
37	0.955208
38	0.982735
39	0.980843
40	0.982403
41	0.991530
42	0.975551
43	0.975242
44	0.973963
45	0.974447
46	0.973473
47	0.985685
48	0.985128
49	0.984773
50	0.955420
51	0.981659
52	0.992409
53	0.958491
53	0.984393

Table 4.24 Sensitivity Index at Each Node in 53-Load Point Radial Distribution System for Two Feeder Case using Existing Method [20]

Node No.	Sensitivity Index at Each Node
2	0.924742
3	0.831102
4	0.928173
5	0.938019
6	0.939913
7	0.944676
8	0.951189
9	0.925430
10	0.897719
11	0.843612
12	0.870303
13	0.945467
14	0.842793
15	0.968483
16	0.969460
17	0.935811
18	0.935699
19	0.987352
20	0.904527
21	0.899348
22	0.835996
23	0.895509
24	0.949960
25	0.943167
26	0.967604
27	0.999532

28	0.883998
29	0.832455
30	0.835084
31	0.831398
32	0.832699
33	0.830462
34	0.832287
35	0.838918
36	0.834705
37	0.832512
38	0.932709
39	0.925708
40	0.931449
41	0.966546
42	0.911213
43	0.904583
44	0.901568
45	0.901638
46	0.911092
47	0.945830
48	0.943371
49	0.941495
50	0.834980
51	0.931449
52	0.999482
53	0.855645
53	0.939018

4.2.6 Three Feeder Case using Existing Algorithm

In three feeder case, there is three feeders is emerging from the candidate substation found by the algorithm proposed by Ranjan and Das [20]. Figure 4.8 shows the 53-load point radial distribution network with a single feeder configuration with a substation placed on a point no. 1 whose coordinates are (10.50, 8.70).

Table 4.25 shows the feeder routing of the system using the proposed algorithm. In Table 4.26 voltage magnitude of each load point (p.u.) is represented whereas the Table 4.27 demonstrates the severity index at each node point in order to find out the stability of the system.

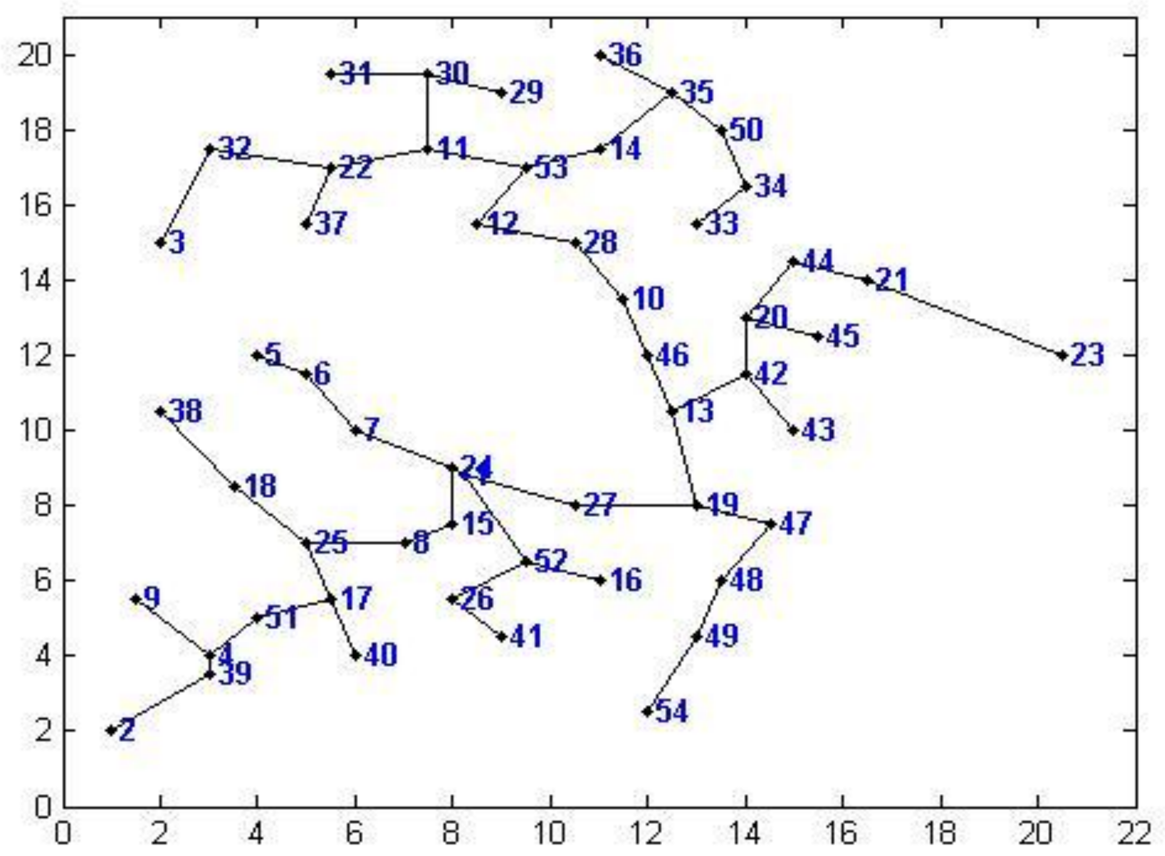

Figure 4.10 Optimal Feeder Configurations (Three Feeder Case) [20]

Table 4.25 53-Load Point Radial Distribution System Feeder Routing for Three Feeder Case using Existing Method [20]

Branch No.	Sending-End Node	Receiving-End Node	Length of Each Branch (Km.)
1	1	27	0.700000
2	1	52	2.416609
3	1	24	2.517936
4	24	15	1.500000
5	15	8	1.118034
6	52	16	1.581139
7	52	26	1.802776
8	26	41	1.414214
9	8	25	2.000000
10	25	17	1.581139
11	17	40	1.581139
12	17	51	1.581139
13	51	4	1.414214
14	4	39	0.500000
15	25	18	2.121320
16	4	9	2.121320
17	24	7	2.236068
18	7	6	1.802776
19	6	5	1.118034
20	27	19	2.500000
21	19	47	1.581139
22	47	48	1.802776
23	48	49	1.581139
24	49	53	2.236068
25	39	2	2.500000

26	18	38	2.500000
27	19	13	2.539510
28	13	46	1.581139
29	46	10	1.581139
30	13	42	1.802776
31	42	20	1.500000
32	20	45	1.581139
33	10	28	1.802776
34	42	43	1.802776
35	20	44	1.802776
36	44	21	1.581139
37	28	12	2.061553
38	12	53	1.802776
39	53	14	1.581139
40	53	11	2.061553
41	11	30	2.000000
42	30	29	1.581139
43	30	31	2.000000
44	11	22	2.061553
45	22	37	1.581139
46	14	35	2.121320
47	35	50	1.414214
48	50	34	1.581139
49	34	33	1.414214
50	35	36	1.802776
51	22	32	2.539510
52	32	3	2.692582
53	21	23	4.472136

Table 4.26 Voltage (p.u.) of Each Node in 53-Load Point Radial Distribution System for Three Feeder Case using Existing Algorithm [20]

Node No.	Voltage at Each Bus (p.u.)
1 (S/S)	1.000000
2	0.977245
3	0.952495
4	0.977610
5	0.980758
6	0.980949
7	0.981643
8	0.982791
9	0.977428
10	0.967682
11	0.954081
12	0.959640
13	0.975075
14	0.954922
15	0.984395
16	0.988929
17	0.979159
18	0.979784
19	0.984275
20	0.972319
21	0.971290
22	0.953178
23	0.970520
24	0.982985
25	0.980263
26	0.988300

27	0.994744
28	0.963763
29	0.952884
30	0.953022
31	0.952581
32	0.952731
33	0.952311
34	0.952559
35	0.953688
36	0.953530
37	0.952901
38	0.979358
39	0.977459
40	0.979024
41	0.988181
42	0.973289
43	0.972980
44	0.971699
45	0.972183
46	0.971207
47	0.983446
48	0.982888
49	0.982533
50	0.953113
51	0.978278
52	0.989063
53	0.956191
53	0.982152

Table 4.27 Sensitivity Index at Each Node in 53-Load Point Radial Distribution System for Three Feeder Case using Existing Method [20]

Node No.	Sensitivity Index at Each Node
2	0.912041
3	0.823094
4	0.915448
5	0.925224
6	0.927105
7	0.931835
8	0.938303
9	0.912724
10	0.889389
11	0.835543
12	0.862103
13	0.936915
14	0.834727
15	0.955478
16	0.956447
17	0.923032
18	0.922921
19	0.978612
20	0.896165
21	0.891011
22	0.827965
23	0.887189
24	0.937082
25	0.930337
26	0.954605
27	0.999532

28	0.875732
29	0.824441
30	0.827057
31	0.823389
32	0.824684
33	0.822458
34	0.824274
35	0.830872
36	0.826680
37	0.824498
38	0.919951
39	0.913000
40	0.918700
41	0.953554
42	0.902819
43	0.896220
44	0.893220
45	0.893290
46	0.902698
47	0.937276
48	0.934828
49	0.932962
50	0.826954
51	0.918700
52	0.978760
53	0.847517
53	0.930495

Table 4.28 shows the comparison between proposed method and existing method for one feeder, two feeder and three feeder case.

Table 4.28 Comparison of Cost, Minimum Voltage and Sensitivity Index between Proposed Method and Existing Method

Method	No. of Feeders	Node No.	Minimum Voltage (p.u.)	Sensitivity Index	Total Length (Km.)	Fixed Loss	Cost of Interruption (US$)	Cost of Loss (US$)	Total Cost (US$)
Proposed Method	1	33	0.952532	0.778986	96.8157	267211.46	37428.95	166.95	37595.91
	2	33	0.954747	0.830907	97.3818	268773.78	34937.89	150.34	35088.24
	3	33	0.954747	0.830907	98.0511	270621.18	33466.66	137.56	33604.22
Existing Method	1	33	0.952311	0.822458	96.8438	267289.12	37435.85	168.32	37604.17
	2	33	0.954619	0.830462	97.4577	268983.28	34941.87	151.20	35093.08
	3	33	0.954619	0.830462	98.1728	270957.12	33470.12	138.28	33608.40

CHAPTER-FIVE

CONCLUSIONS AND FUTURE SCOPE

5.1 CONCLUSION

A new method of optimal feeder routing and optimal substation placement is proposed in this thesis to plan a radial distribution network with economical satisfactory without losing the system electrical characteristics and stability. In this proposed planning methodology, the minimum voltage at the node, the sensitivity index of most sensitive node is improved and total length of the reconfiguration, real and reactive power losses in the system as well as overall system costs are reduced by sufficient amount. The facts have been demonstrated by using two examples of 23-load point network and 53-load point network.

5.2 FUTURE SCOPE OF THE WORK

As with any work of research, there is always more that can be done. Aside from further testing of the code and the algorithms as they stand, there are several extensions and modifications which can be explored.

These include:

- Ill condition unbalanced radial distribution system analysis,
- Remove limitations on formulation,
- Explore possibilities for improved contingency analysis,
- Implement for industry use.

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APPENDIX-A

Table A.1 Data for 23-Load Points [30]

Node No.	X-coordinate	Y-coordinates	Load (kVA)
1 (Substation)	8.525	6.055	0
2 (Back up station)	8.400	8.200	0
3	9.011	10.767	640
4	6.653	6.583	320
5	6.926	5.683	320
6	8.153	6.653	320
7	8.325	7.453	320
8	8.325	8.140	320
9	7.383	9.953	320
10	8.325	6.026	320
11	9.596	4.941	320
12	7.811	4.927	320
13	9.353	4.498	320
14	7.925	5.869	320
15	8.768	4.712	320
16	9.325	6.555	320
17	8.282	5.598	320
18	8.468	5.198	320
19	8.868	5.783	320
20	8.825	6.512	320
21	9.039	5.255	320
22	9.425	5.612	320
23	7.553	5.555	320
Conductor Impedance (per phase)		0.8306 + j 0.376	
Working Voltage (kV)		34.5	
Base (MVA)		10	

Table A.2 Cost and Complementary Load Data [30]

Power Factor	Load Factor (α)	Capital Recovery Rate (g)	Interest Rate	Branch Failure rate	Repair Duration (d), hrs.
0.9	0.6	0.1	0.1	0.2	3.0

Table A.3 Cost Data [30]

Cost of Branch 'k' (c_k) (US$/kWh)	Cost per unit of Energy Not Delivered (c_i) (US$/kWh)	The Cost of Energy Losses (c_l) (US$/kWh)
20	5	0.1

APPENDIX-B

Table B.1 Data for 53-Load Points [20]

Node No.	X coordinates	Y coordinates	Load (kVA)
1 (Substation)	10.45	8.47	-
2	1	2	25
3	2	15	25
4	3	4	25
5	4	12	50
6	5	11.50	63
7	6	10	63
8	7	7	50
9	1.50	5.50	25
10	11.50	13.50	16
11	7.50	17.50	16
12	8.50	15.50	25
13	12.50	10.50	50
14	11.00	6.00	25
15	8.00	7.50	63
16	11.00	6.00	25
17	5.50	5.50	16
18	3.50	8.50	16
19	13.00	8.00	16
20	14.00	13.00	63
21	16.50	14	25
22	5.50	17.00	25.00
23	20.50	12.00	50.00
24	8.00	9.00	100.00
25	5.00	7.00	100.00
26	8.00	5.50	100.00
27	10.50	8.00	50.00

28	10.50	15.00	50.00
29	9.00	19.00	25.00
30	7.50	19.50	63.00
31	5.50	19.50	63.00
32	3.00	17.50	25.00
33	13	15.50	50.00
34	14.00	16.50	50.00
35	12.50	19.00	25.00
36	11.00	20.00	25.00
37	5.00	15,50	50.00
38	2.00	10.50	50.00
39	3.00	3.50	63.00
40	6.00	4.00	25.00
41	9.00	4.50	25.00
42	14.00	11.50	50.00
43	15.00	10.00	50.00
44	15.00	14.50	25.00
45	15.50	12.50	25.00
46	12.00	12.00	63.00
47	14.50	7.50	63.00
48	13.50	6.00	25.00
49	13.00	4.50	16.00
50	13.50	18.00	16.00
51	4.00	5.00	25.00
52	9.50	6.50	16.00
53	9.50	17.00	25.00
53	12.00	2.50	50
Loss factor		0.1	
Base kV		11	
Base (kVA)		100	

Table B.2 Technical information of conductors

Conductor Type	Resistance ($\Omega/km.$)	Reactance ($\Omega/km.$)	Maximum current ($Amp.$)
Squirrel	1.376	0.3896	80
Weasel	0.9108	0.3797	100
Rabbit	0.5531	0.3673	120
Raccoon	0.3657	0.3579	150
Dog	0.2745	0.3112	220

Table B.3 Cost and Complementary Load Data

Power Factor	Load Factor (α)	Capital Recovery Rate (g)	Branch Failure rate	Repair Duration (d), hrs	Working Voltage (kV)
0.75	0.6	0.12	0.2	3.0	11

Table B.4 Cost Data

Cost of Branch 'k' (c_k) (US$/kWh)	Cost per unit of Energy Not Delivered (c_i) (US$/kWh)	The Cost of Energy Losses (c_l) (US$/kWh)
23	5.5	0.12