Radial Distribution System Reconfiguration for Loss Minimization using Exhaustive Search Techniques

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

Master of Engineering

in

Power Systems

Submitted By

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CERTIFICATE

I herby certify that the thesis work entitled **"Radial Distribution System Reconfiguration for Loss Minimization using Exhaustive Search Techniques"** in the partial fulfillment of the requirement for the degree of **Master of Engineering** in **Power System**, submitted in Electrical and Instrumentation Department, Thapar University, Patiala is an authentic work carried out under the guidance of **Dr. Smarajit Ghosh**, Professor, EIED, Thapar University.

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

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This is certifying that the above statement made by the student is correct and true to the best of my knowledge and belief.

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The paucity of words does not compromise to thank my parents, whose blessings have brought me this far in life.

(UTKARSH SINGH)

DEDICATED TO MY PARENTS,
TEACHERS AND FRIENDS

ABSTRACT

Reconfiguration is an indispensable method for loss reduction in power distribution systems and is also used to restore loads in out-of-service areas in case of a fault. This thesis focuses on reconfiguration of a radial distribution networks to optimize the power distribution process in the feeders and for voltage profile improvement. Feeder reconfiguration is done to minimize losses for the existing and new topology of the feeder system and for the purpose of maintenance in the distribution system.

In this thesis work, an IEEE 33 bus radial distribution system has been chosen as the test system. Reconfiguration of this system is done by changing the status of normally closed sectionalizing switches and normally open tie-switches. In general, the aim is to feed power in all nodes connected to the feeder while maintaining voltages within nominal range at all customer load points with minimum loss. None of the buses should be isolated during the process of reconfiguration. Initially, power loss for original configuration is obtained and same is checked for the reconfigured network and a comparative study has been done of the feeder system on the basis of power loss and other constraints including voltage deviation, capacity limit and power balance. The topological complexity of real distribution networks requires searching through many possible configurations.

This thesis presents three different methods for reconfiguration. A comparison has been done for power loss reduction and voltage profile improvement in these three cases. Also, the applicability of BIBC has been discussed for weakly meshed radial distribution networks.

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P_{loss}	Total real power loss of the system
N_s	Number of switching states
V_k	Voltage of buses at k_{th} iteration
P_{ij}	Real power flowing between i_{th} and j_{th} bus
Q_{ij}	Reactive power flowing between i_{th} and j_{th} bus
V_{ss}	Voltage at main substation
V_i	Voltage at i_{th} bus
V_j	Voltage at j_{th} bus
$y_{ss,j}$	Line admittance between the main substation bus and bus j
$PD_{ss,j}$	Real power load at bus j
[B]	Bus current matrix
[BIBC]	Branch input branch current matrix
[ΔV]	Change in values of bus voltage
[BCBV]	Branch current branch voltage
[DLF]	Distribution system load flow matrix
RDS	Radial distribution system
DG	Distributed generation
A	Component of DLF matrix in mesh load flow; square matrix
M^T	Component of DLF matrix in mesh load flow; column vector
M	Component of DLF matrix in mesh load flow; row vector
N	Component of DLF matrix in mesh load flow; square matrix
GSLF	Gauss siedel load flow
Y	Line admittance matrix

CHAPTER ONE

INTRODUCTION

Power system is a complicated inter-connection of different electricity carrying equipments. Some important components of this complex interlinking are: generating stations, transmission lines, substations, feeders and distribution system. Each component of this entire system can be technically monitored, examined and operated to obtain the maximum benefit out of it. To make a power system operate efficiently and in a reliable manner, we require efficient techniques and methodologies.

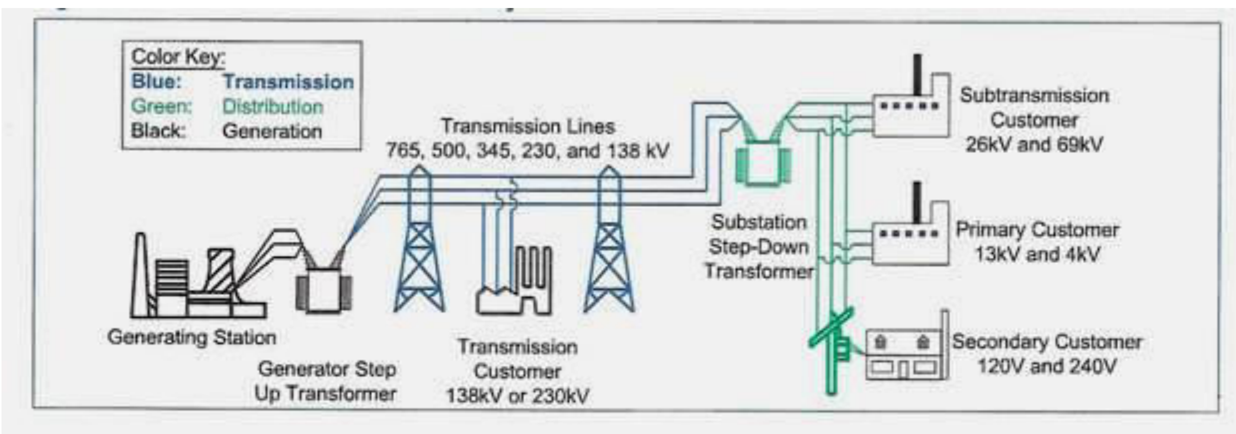

Figure 1.1 Basic structure of a Power System [1]

Power systems include three rudimentary subsystems. [2]

- Generation subsystem
- Transmission subsystem
- Distribution subsystem

The part which adjoins the EHV and HV transmission systems with the distribution system is known as transmission subsystem. These subsystems can be individualized depending on their operating voltage levels:

- Generation (Level: 11kV-30 kV)
- EHV Transmission (Level: 500kV-765kV)
- HV Transmission (Level: 230kV-345kV)
- Sub-transmission (Level: 69kV-169kV)
- Distribution (Level: 120V-35kV)

1.1 Overview of Distribution System

In this case our task is to elucidate the distribution system. Of the total expenditure in the power systems, the generation and distribution segments account for 40% each and the remaining 20% is given in transmission. Further sub categorization of distribution system results in three sub systems:

- Distribution substation
- Primary distribution system
- Secondary distribution system

1.1.1 Distribution substations

The distribution substation is provided power at any required transmission or sub-transmission voltage level by the transmission or sub transmission lines, which is forwarded to multiple distribution feeders originating in the substation. This comprises of the primary distribution system. Several feeders originate radially from the substation in order to supply the load. Functions of the distribution substation can be given as follows:

1. Transformation of voltage: Several transformers are located within the substation for stepping down voltage level as acceptable to the primary distribution voltage level. The configuration of these transformers would either be three phase or three single phase transformers connected as three phase banks. The primary distribution voltage standards are 4.16kV, 7.2kV, 12.47kV, 13.2kV, 14.4kV, 23.9kV, and 34.5kV.

2. Protection and switching: Various types of switchgear are located at the substation and can have the following components:

   Switches: These are those devices which connect/ disconnect different parts of a network and can also carry or obstruct normal load currents.

   Circuit breakers: These devices work in a similar fashion to switches, in addition to which they can interrupt short-circuit current. These devices are often paired with relays which can sense short-circuit condition using potential transformers and current transformers.

   Reclosures: These devices have the ability to- reclose after opening, open again, and reclose again, repeating this cycle a predetermined number of times until they lockout. These are somewhat similar to circuit breakers.

   Fuses: These devices have the capability of carrying a fixed load current without any hindrance and also obstruct a pre-defined fault current.

All of the above, but switches are protection devices. Switches are often used on the high voltage side of the transformer, whereas the protection devices are used on the low voltage side. In case of substations supplying large amount of currents, the protection devices can be on both sides. Special substation designs to achieve high reliability may utilize multiple circuit breakers. As shown in Figure 2, multiple circuit breakers may be employed in specially designed substations to achieve high reliability. As shown in Figure 3, the cost effective designs may employ protection only in series with the feeders. In the mentioned figures, circuit breakers and switches are normally closed unless there is a “N.O.” indicated beside it. Figure 1 indicates that all feeders can remain supplied for a transformer or a sub-transmission outage. The low voltage scheme of Figure 1.2 is called “breaker and a half”, given that it requires 3 breakers to protect 2 feeders.

3. Regulation of voltage: The feeder will cause a voltage drop IZ volts per unit length, owing to the current I flowing from source to load along the feeder length and a finite impedance Z per unit length. Thus, loads connected over the length of the bus will see varying voltage levels with the farthest load seeing the lowest voltage of all.

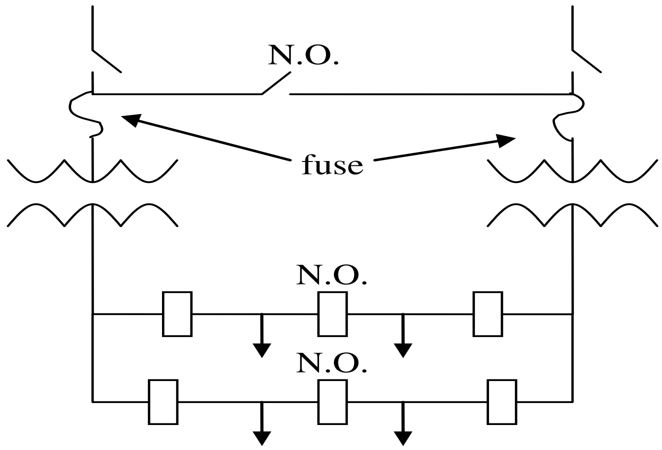

Figure 1.2 High reliability design

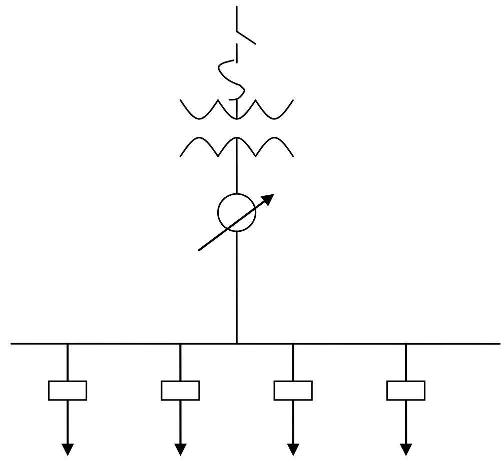

Figure 1.3 Low reliability design

This is illustrated by the solid line in Figure 1.3. It is notable, that the voltage at the substation end of the feeder is 1.02 p.u. However, the voltage at feeder far-end is about 0.97 p.u. If the load were to increase, the far-end voltage would drop to an even lower value. As a result, voltage regulation along the feeder is a must, as the load varies. Different ways to achieve this include substation bus voltage regulators or substation feeders, line voltage regulators, load tap-changing transformers, and switched or fixed shunt capacitors.

4. Metering: Several substations have some sort of metering device that record, minimum existing current and current peaks and falls that have occurred in the last time period (say, 1 hour). Digital recording which is capable of recording a large amount of substation operational information is also heavily employed.

1.1.2 Primary Distribution

The primary distribution system includes feeders coming out from the substation and supplying power to several secondary distribution systems. Such feeders are generally three-phase circuits. Feeders are usually radial from substation to loads (i.e., unidirectional power flow).

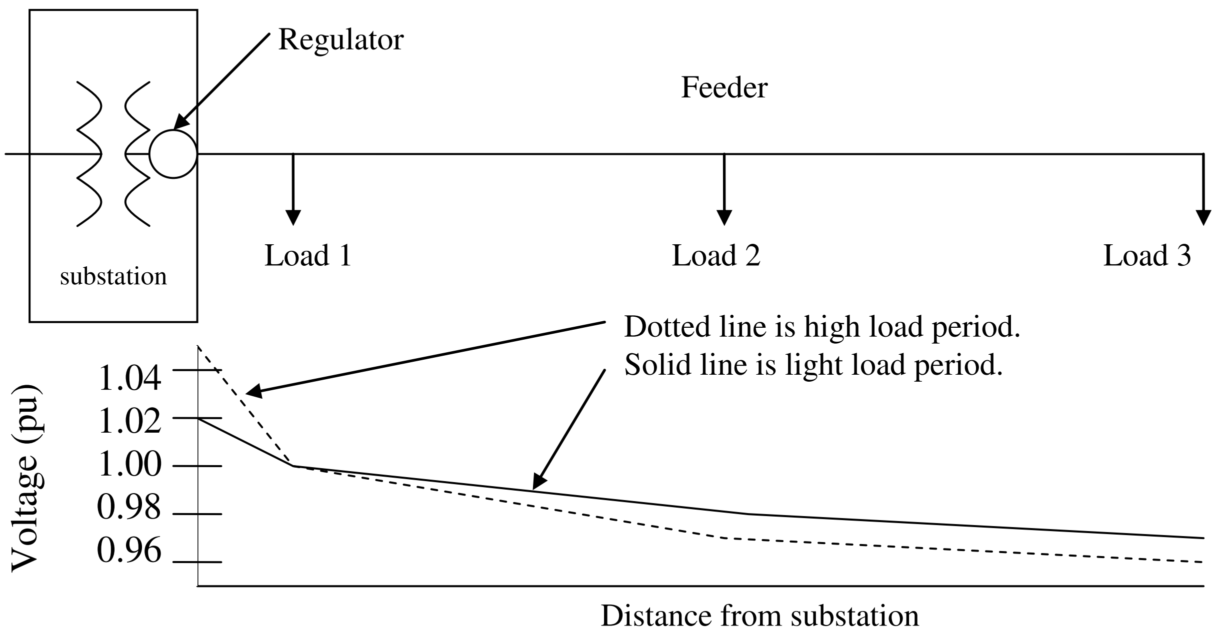

Figure 1.4 Illustration of feeder load variation

In densely populated cities, particularly commercial and business districts where reliability is indispensable, feeders may be meshed in topology. The prices to pay for such a reliable system are as follows:

- The cost incurred is huge because in case of a fault the system requires at least two protective devices operating simultaneously. Further, in order to guarantee the reliability, multiple switching devices should operate along the feeder.
- The fault currents tend to be lower, closer to normal load currents, and hence there is less margin between breaker trip current and normal load current.
- Voltage control is very difficult since there are two control points.

One way to obtain the reliability benefit of a looped configuration while avoiding some of the above difficulties is to operate a looped configuration in open-loop, i.e., employs a normally open switch mid-way in the loop. When the loop is faulted, the normally open switch can be closed while a switch just downstream of the fault can be opened, and all of the de-energized loop up to the downstream switch can be supplied. This is illustrated in Figure 1.5.

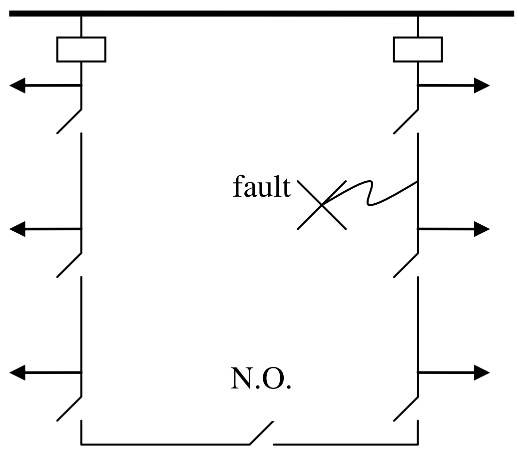

Figure 1.5 Normally open looped system

As indicated previously, the standard primary distribution voltage levels include 4.16kV, 7.2kV, 12.47kV, 13.2kV, 14.4kV, 23.9kV, and 34.5kV. However, equipment is specified in terms of voltage class. Equipment of one voltage class may be utilized in at any operating voltage assigned to that class. For example, an insulator of voltage class 15 kV may utilized in a 12.47kV, 13.2kV, and 13.8kV system. There are four major distribution-level voltage classes: 5kV, 15kV, 25kV, and 35kV. The 15kV voltage class is the most prevalent.

1.1.3 Secondary Distribution

Branching from the main feeder are laterals, also referred to in the industry as taps or branches. The laterals may be three-phase, two-phase (two phases of the three-phase feeder with a neutral), or single-phase (one phase from the single phase feeder and a neutral). The laterals are usually protected with fuses so that faulted laterals do not cause interruption at the feeder level.

Standard secondary voltage levels are

- 120/240 V single phase

- 120/208 V three phase
- 277/480 V three phase

1.2 Distribution System Types

Here the distribution type has been discussed on the basis of scheme of operation. All distribution of electrical energy is done by constant voltage system. In practice, the following three types of distribution circuits are generally used in distribution system.

1.2.1 Radial Distribution System

A schematic example of a radial distribution system is shown in Figure 1.6. In this system, primary feeders take power from the distribution substation to the load areas by way of sub feeders and lateral-branch circuits. This is the most common system used because it is the simplest and least expensive to build. It is widely used in sparsely populated areas. A radial system has only one power source for a group of customers Radial feeders are characterized by having only one path for the power to flow from the source (distribution substation) to each customer. If the distributor is connected to the supply system on one end only, that system is called radial distribution system. The radial system is employed when the power is generated at low voltage and the substation is located at the centre of the load. The consumers at the end of distributor would be subjected to serious voltage fluctuations when the load on distribution changes. The advantages of radial system are its simplicity, and low cost, the amount of switching equipment required is small and protective relaying is simple. The major disadvantage of radial system is its lack of security of supply. It is not the most reliable system, because a fault or short circuit in a main feeder may result in a power outage to all the users served by the system. Service on this type of system can be improved by installing automatic circuit breakers that will reclose the service at predetermined intervals. If the fault continues after a predetermined number of closures, the breaker will be locked out until the fault is cleared and service is restored.

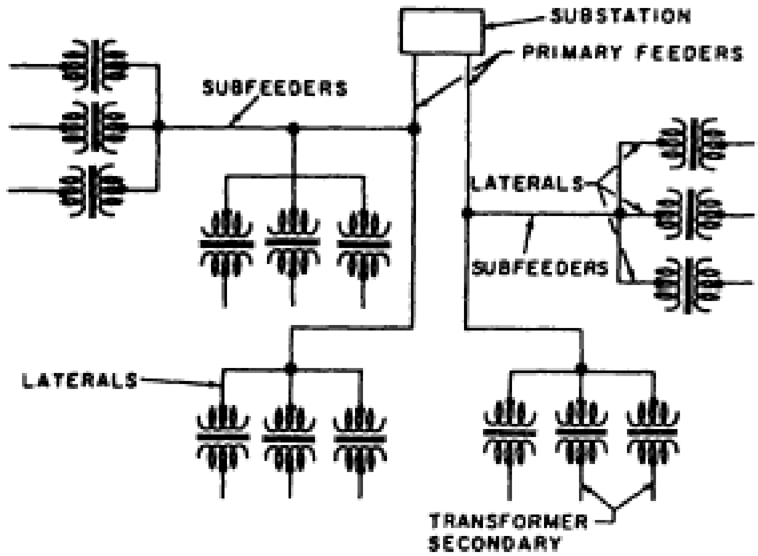

Figure 1.6 Radial distribution system

1.2.2 Ring main system

The loop (or ring) distribution system is one that starts at a distribution substation, runs through or around an area serving one or more distribution transformers or load centres, and returns to the same substation. The loop system shown in Figure 1.7 is more expensive to build than the radial type, but it is more reliable and may be justified in areas where continuity of service is required—at a medical centre. In the loop system, circuit breakers sectionalize the loop on both sides of each distribution transformer connected to the loop. A fault in the primary loop is cleared by the breakers in the loop nearest the fault, and power is supplied the other way around the loop without interruption to most of the connected loads. If a fault occurs in a section adjacent to the distribution substation, the entire load can be fed from one direction over one side of the loop until repairs are made. The ring main system has the following advantages:

a) There are very less voltage fluctuations at consumer’s terminals.

b) The system is very reliable as each distributor is fed with two feeders.

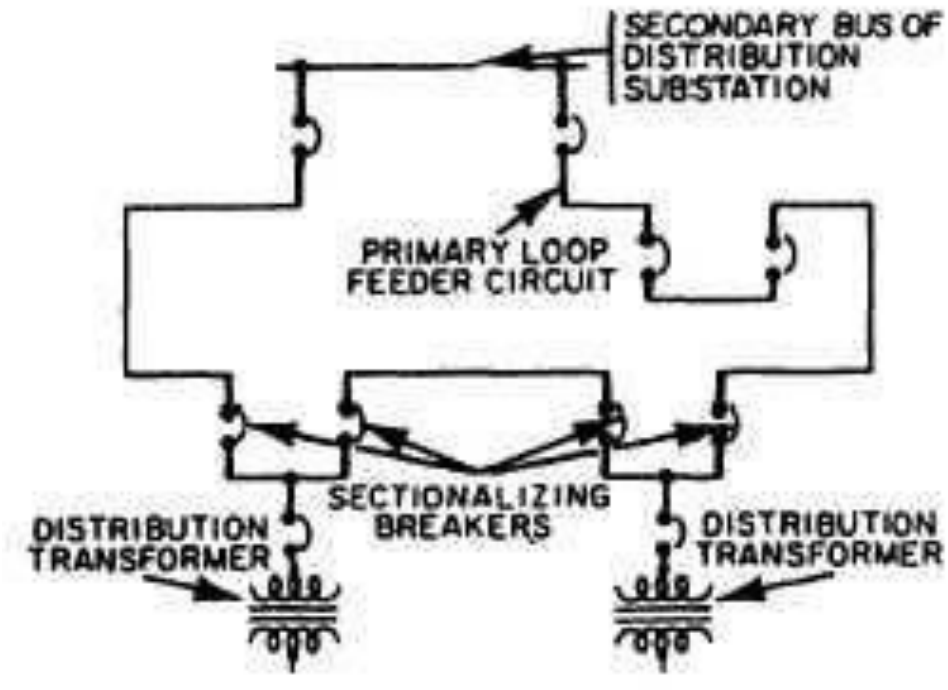

Figure 1.7 Ring main system

1.2.3 Interconnected system

The network system shown in Figure 1.8 is the most flexible type of primary feeder system. It provides the best service reliability to the distribution transformers or load centres, particularly when the system is supplied from two or more distribution substations. Power can flow from any substation to any distribution transformer or load centre in the network system. The network system is more flexible about load growth than the radial or loop system. Service can readily be extended to additional points of usage with relatively small amounts of new construction. The network system, however, requires large quantities of equipment and is, therefore, more expensive than the radial system. For this reason it is usually used only in congested, high load density municipal or downtown areas. When the feeder ring is energized by two or more than two generating stations or sub stations, it is called inter-connected system.

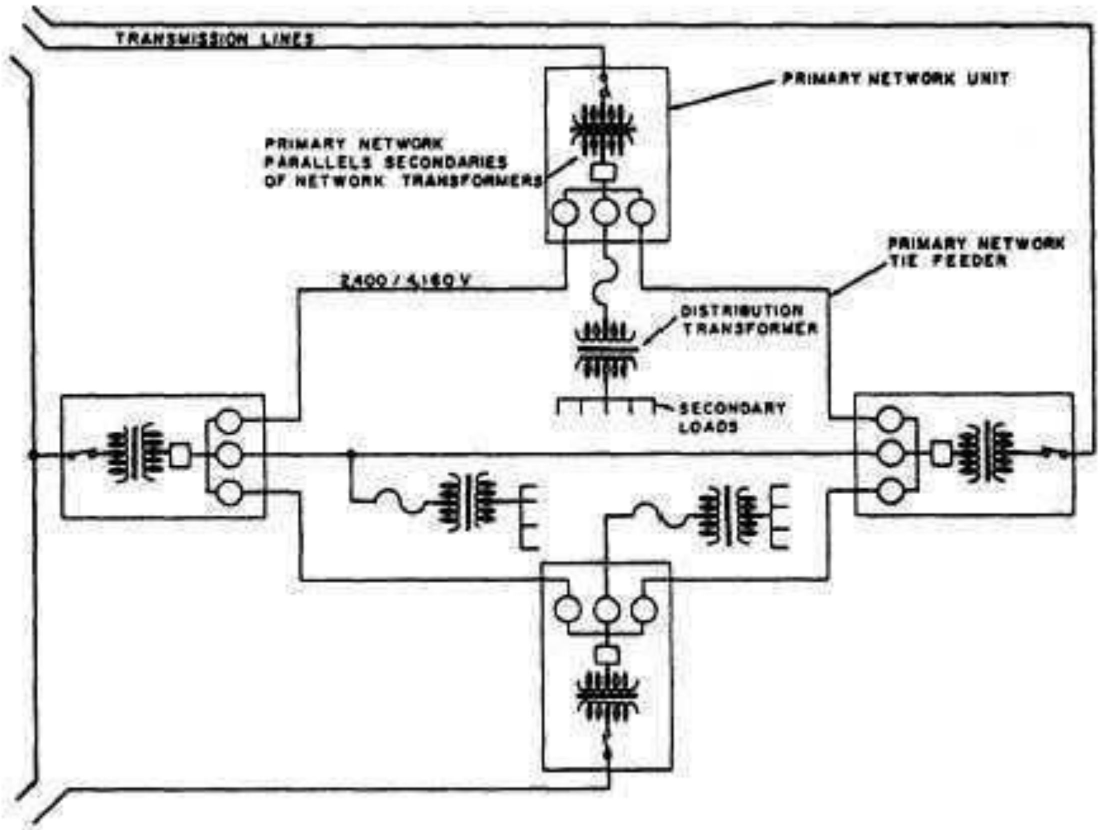

Figure 1.8 Interconnected system

1.3 Reconfiguration, Service Restoration, Islanding and Reliability Restoration in Radial Distribution System

There are some issues in radial feeder reconfiguration, which are to be addressed carefully for the optimized power distribution of the feeder system. These are Reconfiguration, Service Restoration, Islanding and Customer Reliability maintenance. These are explained below.

1.3.1 Distribution Feeder Reconfiguration

The objective of "Distribution Feeder Reconfiguration" can be a part of distribution automation. The configuration management is done at the time of service maintenance or service testing. The configuration of this radial distribution system can be changed by changing the status of switches. Here the normally close sectionalizing switches are opened and same numbers of normally open tie-switches are closed. This is called reconfiguration. In new topological structure, the tree shape of radial distribution is maintained. The procedure can be said as the part of “Distribution Management”. Here, reconfiguration is done to obtain minimum loss path for the load feeding.

1.3.2 Service Restoration in Distribution System

Service restoration is a process of restoring power flow immediately after any kind of disturbance in the power system. This disturbance may be due to the fault in the distribution system and in this case, some portions of the distribution system may run out of power. To establish the connection, some tie-switches have to be closed maintaining the radial structure. Here already some sectionalizing switches are off-line. Service restoration happens in the same procedure like feeder reconfiguration. For a complex distribution feeder system, it is quite cumbersome to restore ample amount of power from a distant control centre. There are varieties of loads in distribution system such as industrial, commercial and residential loads. If there is less power available at the feeding point, the control centre restores the service depending upon the priority of the customers.

1.3.3 Islanding

Power system islanding is closely related to the micro-grid islanding. It means isolation of one or more than one node at the time of power distribution due to faulty power controlling operation. As power flow is totally dependent on the status of the existing switches in the tree structure, bad controlling or an invalid sectionalizing and tie-switches combination can lead to islanding of the whole or a single region. Islanding hampers the reliability of the power system. This islanding should be eliminated quickly after any outage.

1.3.4 Customer Feeding and Reliability Restoration

Customers of electricity are of three types such as industrial, commercial and residential. On the priority basis the electrical system is chosen to supply at the time of outage to these customers. In industrial hub, outage of electricity for one hour may cause serious loss of raw assists. In general, if a load point in feeder section is heavily loaded then there will be chance of voltage dipping. As stated earlier, reconfiguring the structure, the heavily loaded portion of the feeder can be transferred to lightly loaded feeder portion. By doing this, some nodes in the feeder system may lead towards the verge of voltage collapsing situation. Overloading can reduce the capacity of feeder line and life span of distribution transformers connected to the system. Apart from this, if configuration is changed by altering more number of switches in the system, the power system can suffer from the ill effect of the switching surge.

1.4 Optimization, feasibility and constraints

In near future our power generating units will run out of fuel and stop. Here we need the concept of sustainable development. To introduce the new strategy to live life we have to obey three terms *Optimization*, *Feasibility* and *Constraints* in any kind of process.

1.4.1 Optimization

Mathematicians have a craze to put every incident by mathematical terms. By that aspect the optimization means a way of selecting the best one from a set of alternative values. If we go by the book, again it means a set of techniques to design a system with respect to specific parameters. Here the parameters are nothing but the constraints, which guide any result to its desired value. Again these constraints can be the main problem to find the best result in some cases. Engineers are in work for the solo reason to earn high output conveying low input. If the constraints are water or coal or anything, the engineers are trained to minimize the loss of energy or loss of money. Here optimization means to utilize the resources wishfully. To do so deregulation in power system, decentralized generation using distribution generation are introduced in the whole system previously. Even in power stations, scheduling of units is done to meet the off peak and high peak demands. In case of the transmission system renewable sources are shunted in the lines to bear the load of the centralized generation and to minimize the loss. Here it is done for sustainable use of resources.

1.4.2 Feasibility

Feasibility is the term which is closely related to the real life use of any system. For any optimized system to find its strength and weakness is called feasibility. Any new technology or strategy in power system comes after some cost conveying. Installation of new unit in power station involves cost and time in the whole process. If new installed system does not come with fruitful result, it cannot be feasible at all. So an optimized system may not be feasible all the time. In general any research work is done to achieve both optimality and feasibility in the technology. Here in the project work considering some constraints it is tried to reach at the optimal results with proper explaining some criteria of feasibility.

1.4.3 Constraints

In our life the main constraint is shortage of time. With this philosophy in mind we can face each and every problem in our life. In case of power generation, the constraints are coal or water availability, number of running units, liquid assets to preserve raw material, number of technicians available. In case of the power transmission and distribution the practical constraints are conductor capability to bear heating, transformer overload, loading conditions. So any process can not yield suitable result without considering all the constraints of the system. Any research work has been executed fulfilling one or more that one constraint in the process. The thesis work is performed meeting the possible constraints in the system for reconfiguration.

1.5 Literature Survey

Merlin and Back [3] presented one of the first works to reduce losses in a distribution network. It showed an integer-mixed non-linear optimization model which was solved through the discrete branch and bound method. Due to the combinatorial nature of the problem, it required checking a great number of configurations for a real-sized system.

Civanlar *et al.* [4] presented a scheme that utilizes feeder reconfiguration as a planning and/or real-time control tool to restructure the primary feeder for loss reduction. The mathematical foundation of the scheme was presented. The solution was illustrated on simple examples.

Lin and Chin [5] provided a new approach to solve the distribution feeder reconfiguration by which a more efficient network configuration could be obtained to reduce loss. Three switching indices were defined in this paper. Branch voltage-drops and line constants were used with all the electrical constraints. Meshed networks were considered instead of the radial topology by closing all the tie switches. By considering only the largest switching index in each loop, this algorithm reduced the number of feasible states drastically. The switching index was also used for service restoration.

Baran and Wu [6] employed branch exchange for searching over different radial configurations. Two different power flow approximation methods with varying degree of accuracy were developed and tested. The methods were used to calculate the new power flow in the system after a branch exchange. This method could be used for even those systems, which were not well compensated. A load balance index had been used for load balancing.

Shirmohammadi and Hong [7] described a heuristic method for the reconfiguration of distribution networks in order to reduce their resistive line losses under normal operating conditions. The proposed approach was characterized by convergence to the optimum or a near-optimum solution and the independence of the final solution from the initial status of the network switches. The proposed technique was computationally robust and efficient and, hence, suitable for both planning and operations studies.

Goswami and Basu [8] reported a power-flow-minimum heuristic algorithm based on the concept of optimum flow pattern, which was determined by solving the KVL and KCL equations of the network. The optimum flow pattern of a single loop formed by closing a normally open switch was found, and the flow pattern was established in the radial network by opening a closed switch. This process was repeated until the minimum loss configuration was obtained.

Peponis and Papadopoulus [9] provided an efficient method for load balancing problem, using switch exchange operations. An overall algorithm for the reduction of the size of the network model without decreasing computations accuracy of all methods was also given. The adequate computer programs were applied on a real, large-scale 20 kV Greek network, under normal operating conditions and after the occurrence of an outage.

Taleski and Rajicic [10] proposed reconfiguration based on known techniques and algorithms for radial network analysis-oriented element ordering, power summation method for power flow, statistical representation of load variations and energy summation method for the computation of energy losses. These methods, combined with the heuristic rules developed to lead the iterative process, make the energy loss minimization method effective, robust and fast.

Song *et al.* [11] derived a fuzzy controlled EP (FCEP) based approach for reconfiguration. The mutation fuzzy controller adaptively adjusted the mutation rate during the simulated evolutionary process. The status of each switch in distribution systems was naturally represented by a binary control parameter 0 or 1. The length of string was much shorter than those proposed by others. A chain-table and combined depth-first and breadth-first search strategy was employed to further speed up the optimization process. The equality and inequality constraints were imbedded into the fitness function by penalty factors which guarantee the optimal solutions searched by the FCEP were feasible.

Jeon and Kim [12] showed that simulated annealing; tabu search and a hybrid algorithm of the two methods with some adaptations had been applied and compared. Numerical examples demonstrated the validity and effectiveness of the proposed methodology using KEPCO's distribution systems.

Huang [13] developed an enhanced genetic algorithm (EGA)-based fuzzy multi-objective approach to solve a network reconfiguration problem. Maximizing the fuzzy function satisfied multiple objectives of minimizing power loss, voltage violation, current constraints and switching number, while subject to a radial network structure in which all loads must be energized.

Fan *et al.* [14] indicated that the single-loop optimization approach actually originates from the same technical principle as the simplex method. This paper also presented a simple and effective scheme to efficiently determine the switch exchanges within a loop for minimum line losses, and proposed a heuristic scheme to develop the optimal switch plan with minimum switch operations in order to accomplish the transition from the initial configuration to the optimal configuration.

Gohokar *et al.* [15] described the formulation of the reconfiguration problem using network topology approach. Algorithm developed could be used in general to radial system with any number of bifurcations. A modified iterative load flow method was also discussed. Simple and efficient technique was described to detect the loops formed during reconfiguration process. Formulation of single loop optimization problem was implemented to obtain network reconfiguration under normal operation.

Su and Lee [16] proposed an improved mixed-integer hybrid differential evolution (MIHDE) based method to reduce power loss and enhance the voltage profile. This research recognized beneficial load transfers to minimize power loss and ensure prescribed voltage limits. The proposed method determined the proper system topology that reduced the power loss according to a load pattern.

Venkatesh and Ranjan [17] reconfigured an RDS under the umbrella of SCADA to achieve the best voltage profile and minimal kW losses amongst several objectives. That problem required the determination of the best combination of feeders from each loop to be switched out such that the resulting RDS gave the optimal performance in the chosen circumstance. The problem had a discontinuous solution space and certain problem variables assume discrete values of zero or one. Fuzzy adaptation of EP was necessitated while considering optimization of multiple objectives.

Hsiao [18] elucidated a multi-objective evolution programming method for distribution feeder reconfiguration in a practical system. The multiple objectives were minimizing power losses, ensuring voltage quality, service reliability assurance, and minimizing switching operations. Generally, the attributes of the above four objectives were not the same and operators' judgment must be involved in trading off between these objectives. Accordingly, this investigation presented an interactive fuzzy algorithm for obtaining a compromise solution. Furthermore, the solution algorithm was implemented in C++ with man-machine interactive procedures and tested on a Tai-Power 102-bus system with very promising results.

Su *et al.* [19] introduced ant colony search algorithm (ACSA) to solve the optimal network reconfiguration problem for power loss reduction. The ACSA applied the state transition rule, local pheromone-updating rule, and global pheromone-updating rule to facilitate the computation. Numerical results showed that the proposed method was better than genetic algorithm and simulated annealing.

Prasad *et al.* [20] developed a method based on a fuzzy mutated genetic algorithm, which overcame the combinatorial nature of the reconfiguration problem and dealt with non continuous multi-objective optimization. The attractive features of the algorithm were: preservation of radial property without islanding any load point and an efficient convergence.

Das [21] presented an algorithm for network reconfiguration based on the heuristic rules and fuzzy multi-objective approach. Multiple objectives were considered for load balancing among the feeders and also to minimize the real power loss, deviation of nodes voltage, and branch current constraint violation, while subject to a radial network structure in which all loads must be energized.

Sahoo and Prasad [22] demonstrated a fuzzy genetic approach for reconfiguration so as to maximize the voltage stability of network for a specific set of loads. In one approach a function was chosen as the average of a voltage stability index of all the buses, while in the second approach, the complete RDS was reduced to a two bus equivalent system and the optimizing function was the voltage stability index of this reduced two bus system. This method, tested on 69 bus and 33- bus RDSs, shows promising results for the both approaches. It was also observed that the network losses were reduced when the voltage stability was enhanced by the network reconfiguration.

Ahuja *et al.* [23] introduced a hybrid algorithm based on artificial immune systems and ant colony optimization for distribution system reconfiguration, which was formulated as a multi-objective optimization problem. The search space was explored by means of the hyper mutation operator that perturbs existing antibodies to produce new ones. A table of pheromones was used to reinforce better edges during hyper mutation. An added innovation was the use of the pheromones to obtain quick solutions to restore the distribution system under contingency situations.

Dolatdar *et al.* [24] proposed a new approach based on a simple optimum loss calculation by determining optimal trees of the given network. From graph theory a distribution network could be represented with a graph that consists of a set of nodes and branches. In fact this problem could be viewed as a problem of determining an optimal tree of the graph which simultaneously ensured radial structure of each candidate topology. This algorithm reduce the number of load flow runs and also reduced the switching combinations to a fewer number and gave the optimum solution. To demonstrate the validity of these methods computer simulations with PSAT and MATLAB programs were carried out on 33-bus test system.

Kumar and Jayabarathi [25] developed a bacterial foraging optimization algorithm (BFOA) for distribution network reconfiguration. According to the characteristics of distribution network, some modifications were done to retain the radial structure and reduce the searching requirement. Test results of a 33- bus sample network had shown that the proposed feeder reconfiguration method could effectively ensure the loss minimization, and the BFOA technique was efficient in searching for the optimal solution.

Shariatkhah *et al.* [26] presented a method to determine annual feeder reconfiguration scheme considering switching costs and time-varying variables such as load profiles. In the first stage of the proposed method, to obtain effective configurations, optimal configuration for each day of year was determined independently using harmony search algorithm (HSA) and graph theory. After determination of effective configurations for the network, in the second stage, year was divided into multi equal periods and considering loss cost, interruption cost and also switching cost from a configuration to another configuration, dynamic programming algorithm (DPA) was used to find the optimum annual reconfiguration scheme.

Ahuja and Pahwa [27] presented an algorithm based on hybridization of pheromones derived from ant colony optimization with crossover operator and was applied to minimize real losses in distribution systems using reconfiguration. The algorithm maintained a population of candidate solutions and a table of pheromones to reinforce better edges during search process. Exploration for better solutions was performed by means of crossover operator directed by the information stored in the pheromone table. The hybrid approach had been successfully implemented on three test networks.

Oliveira *et al.* [28] explained a bio-inspired meta-heuristic Artificial Immune System to minimize energy losses. The proposed approach could handle this combinatorial mixed integer problem of nonlinear programming. Radiality and connectivity constraints were considered as well as different load levels for planning the system operation. For this purpose, improvements to an algorithm in the literature were proposed to better accommodate the features of the problem and to improve the search process.

Teimourzadeh and Zareh [29] introduced binary group search optimization algorithm (BGSO) with fundamental modifications in order to be fit for reconfiguration and all binary form problems. All formulation of conventional GSO had been modified for accessing a novel powerful binary searching algorithm. Additionally, the forward‑backward sweep, load flow was used in this paper, due to its accuracy.

Imran and Kowsalya [30] proposed Meta-heuristics Fireworks Algorithm (FWA) to optimize the radial distribution network while satisfying the operating constraints. The radial nature of the system was secured by generating proper parent node‑child node path of the network during power flow. It was tested on a standard IEEE 33- and 119-bus system. The simulated results were compared with other methods and performance of proposed method was found better than the other methods in terms of quality of solutions.

Barbosa *et al.* [31] presented Interval Multi-objective Evolutionary Algorithm for Distribution Feeder Reconfiguration (IMOEA-DFR). It used interval analysis to perform configuration assessment by considering the uncertainties in the power demanded by customers. Simulations performed in three cases on a 70-busbar system demonstrated the effectiveness of the IMOEA-DFR, which obtained robust configurations that were capable to keep such system working under significant load variations. Moreover, the approach achieved stable configurations that remained feasible over long periods of time not requiring additional reconfigurations. The results reinforced the need to include load uncertainties when analyzing DFR under realistic conditions.

Nayak [32] solved a feeder reconfiguration problem in the presence of distributed generators to minimize the system power loss while satisfying operating constraints using Hyper Cube-Ant Colony Optimization (HC-ACO) algorithm. Loss Sensitivity analysis was used to identify optimal location for installation of DG units. Simulations were conducted on 33 – bus radial distribution system at four different cases to verify the efficacy of the proposed method with other recent published approaches reported in the literature. The results were fast and effective.

1.6 Scope of the Research

Literature survey shows that a number of methods had been proposed for reconfiguration of radial distribution networks. Most of the cases used different optimization techniques to minimize losses. There is a scope of making the reconfiguration process fast and feasible. The losses could be further reduced and voltage profile could be improved drastically.

1.7 Objectives of Thesis Work

- Implementation of three different methods for reconfiguration based on exhaustive search.
- Loss minimization in radial distribution network through reconfiguration.
- Comparison of voltage profiles and power loss reduction in these methods.

1.8 Organization of Thesis Work

Chapter 1 shows the introduction of distribution system, literature survey on reconfiguration, objectives, scope and organization of the research.

Chapter 2 presents various methods available for load flow and optimization.

Chapter 3 gives the detailed problem formulation and simulated results.

Chapter 4 concludes the thesis work by giving the positive and negative aspects of the work and the scope of future work.

References section enlists previous papers published by researchers in reconfiguration of radial distribution networks surveyed by the author.

Appendix-A shows the parameters for 33- bus distribution system.

CHAPTER TWO
LOAD FLOW AND OPTIMIZATION TECHNIQUES

2.1 Load flow methods

Several methods are available for load flow evaluation in radial distribution networks. Some of them have been discussed as under:

i) Gauss–Seidel method

This is the earliest devised method. It gives very slow rates of convergence as compared to other iterative methods, but involves very small amount of memory and does not necessarily involve, solving of matrices.

ii) Newton–Raphson method

Several methods are based on this technique. The convergence clip is appreciably swift, only it might rarely falter rightful to innate difficulties of fractality in the basins of attraction of the fundamental iterative plot.

iii) Fast-decoupled-load-flow method

During operations of a power system, it is integral for the workers to have a high level of contingency information. It is a must for the workers to know what power-flow changes can occur due to generator outages. This conditional information could also be used to foresee future power outages in the power network. In this case fast decoupled load flow method is generally used to recoup the requisite info conveniently.

iv) Backward/ Forward sweep method

Kirchhoff's Current Law and Kirchhoff's Voltage Law are used during the backward flow to calculate the bus voltages from last node towards first node of each line or a transformer branch. Then, the linear proportional principle is used to find the ratios of the real and imaginary parts of the specified voltage to the calculated voltages at the substation bus. During the forward sweep, the voltages at buses starting from first node towards the last node are updated by the real and imaginary parts of the calculated bus voltage multiplying with the corresponding ratio. The entire process stops after the mismatch of the calculated and the specified voltages at the substation and when the convergence rate is less than tolerance limit.

v) BIBC/BCBV method

In this method two developed matrices bus injection to bus current (BIBC) and branch current to bus voltage (BCBV), and a simple matrix multiplication (DLF) are used to the obtain load flow solutions. The solution converges very early on; therefore execution time is very small.

2.2 Optimization Techniques

Several techniques have been proposed to solve the reconfiguration problem.

i) Heuristic Methods

Many papers used this technique to solve the reconfiguration problem for different objective functions. The solution process leads to the optimum or near optimum in lesser computation time.

ii) Fuzzy Logic

It uses the logic rules and does not require load flow solution. This method can solve a multi-objective optimization problem. The global optimal solution can be obtained very quickly. There is a difficulty in maintaining the radiality.

iii) Genetic Algorithm

It is a search technique based on the mechanism of natural selection and natural genetics. It can be used to solve the multi-objective optimization problem. This method depends solely on efficient coding and decoding of the chromosome and the structure of the fitness function. It converges smoothly to global optimum with lesser computational time and the radiality is also maintained.

iv) Artificial Neural Network method

This approach is different where the aspects are load transfer and the corresponding load flow solution during the search process is not required. It needs a very large number of neurons and leads to divergent solution in a large system.

v) Expert System

The search space is shrunk using heuristic rules to reduce the computational time. Only a feasible solution can be obtained for knowledge based method.

vi) Tabu Search

It enhances the solution accuracy to get the global optimal with less computation effort. It is an efficient and robust method and can be implemented in parallel.

vii) Simulated Annealing

This method can avoid local optima but requires excessive computational time.

viii) Evolutionary Programming

This method uses a fixed mutation rate that leads the convergence to local optima.

ix) Ant Colony Method

It is a recent method for solving hard combinatorial optimization problems. It is based on the behavior of real ants. It uses the heuristic information of the problem and the pheromone trails to build the solution and guides the search.

CHAPTER THREE
PROBLEM FORMULATION AND RESULTS

3.1 Problem Formulation

Radial distribution system reconfiguration is done by opening/closing two types of switches, tie switches and sectionalizing switches. A feeder may be served from another feeder by closing a tie switch linking the two while a particular sectionalizing switch must be opened to maintain radial structures. In case of loss reduction, the problem here to be addressed is to identify tie and sectionalizing switches that should be closed and opened, respectively, to achieve a maximum reduction in losses. Theoretically, it is a straightforward matter to determine whether or not, the new system obtained through a feeder reconfiguration would incur lower losses. The reduction in losses can easily be computed from the results of two load flow studies of the system configurations before and after the feeder reconfiguration.

3.1.1 Objective function:

The objective of the optimal feeder reconfiguration problem to minimize the total power loss can be expressed as:

$$\textbf{Minimize } P_L = \sum_{i=1}^{(N_{br}+N_{ts})} x_i {I_i}^2 R_i \qquad \textbf{(3.1)}$$

where, P_L = total power loss

N_{br} = number of branches

N_{ts}= number of tie switches

I_i = current flow in i^{th} branch

R_i = Resistance of i^{th} branch.

x_i = 0 or 1 to represent the status of i^{th} branch/tie switch

3.1.2 Constraints:

The objective function in (3.1) is subjected to the following constraints.

(a) Bus voltage limits:

It is well known that a small change in nodal voltage affects the flow of reactive power whereas active power practically does not change. Further, the operating voltage at each node must be in safety range as given below.

$$V_{i_{min}} \leq V_i \leq V_{i_{max}} \qquad \mathrm{i} \in \{1, 2, 3, \dots\dots, N_b\} \tag{3.2}$$

where, $V_{i_{min}}, V_{i_{max}}$ = minimum and maximum voltage limits of i[th] node respectively.

V_i = voltage at i[th] node.

N_b = number of buses.

(b) Feeder capacity limits:

Power flow in each branch must be less than or equal to its maximum capacity as given below.

$$|I_i| \leq I_{i_{max}} \qquad \mathrm{i} \in \{1, 2, 3, \dots\dots, (N_{br} + N_{ts})\} \tag{3.3}$$

where, $I_{i_{max}}$ = maximum current capacity of i[th] branch.

I_i = current in i[th] branch

(c) Radial configuration:

The system has to remain radially operated after reconfiguration. In other words, no loop is allowed in the reconfigured network. Following condition must be fulfilled in order to have the radial configuration of the distribution network.

$$\sum_{i=1}^{(N_{br}+N_{ts})} x_i = \mathrm{N_b} - 1 \tag{3.4}$$

where, x_i = 0 or 1 to represent the status of i[th] branch/tie switch.

N_b = number of buses.

(d) Bus isolation:

All nodes/buses have to be served after reconfiguration. The node must not be isolated without output supply from any feeder. It means only one switch should be opened in a loop.

(e) Power flow equations:

Total active power generation must be equal to the sum of total active power losses and total active load. Similarly, total reactive power generation must be equal to the sum of total reactive power losses and total reactive load as given by following equations.

$$\sum \mathbf{P}_{\mathbf{i}_{\mathbf{Gen}}} = \mathbf{P}_{\mathbf{L}} + \sum \mathbf{P}_{\mathbf{i}_{\mathbf{Load}}} \quad \textbf{(3.5)}$$

$$\sum \mathbf{Q}_{\mathbf{i}_{\mathbf{Gen}}} = \mathbf{Q}_{\mathbf{L}} + \sum \mathbf{Q}_{\mathbf{i}_{\mathbf{Load}}} \quad \textbf{(3.6)}$$

where,

$\sum P_{i_{Gen}}$ = Total active power generation.

$\sum Q_{i_{Gen}}$ = Total reactive power generation.

P_L = Total active power loss.

Q_L = Total reactive power loss.

$\sum P_{i_{Load}}$ = Total active load.

$\sum Q_{i_{Load}}$ = Total reactive load.

3.1.3 Statement of the problem:

The statement of the DSR problem can be given as:

Minimize $\quad \boldsymbol{P_L = \sum_{i=1}^{(N_{br}+N_{ts})} x_i I_i^{\,2} R_i}$

Subject to:

(i) $\boldsymbol{V_{i_{min}} \leq V_i \leq V_{i_{max}}}$, $\quad$ $\mathbf{i} \in \{\mathbf{1, 2, 3, \ldots \ldots}, \boldsymbol{N_b}\}$

(ii) $\boldsymbol{|I_i| \leq I_{i_{max}}}$, $\quad$ $\mathbf{i} \in \{\mathbf{1, 2, 3, \ldots \ldots}, (\boldsymbol{N_{br} + N_{ts}})\}$

(iii) $\boldsymbol{\sum_{i=1}^{(N_{br}+N_{ts})} x_i = \mathrm{N_b} - 1}$

(iv) $\sum \mathbf{P}_{\mathbf{i}_{\mathbf{Gen}}} = \mathbf{P}_{\mathbf{L}} + \sum \mathbf{P}_{\mathbf{i}_{\mathbf{Load}}}$ **&** $\sum \mathbf{Q}_{\mathbf{i}_{\mathbf{Gen}}} = \mathbf{Q}_{\mathbf{L}} + \sum \mathbf{Q}_{\mathbf{i}_{\mathbf{Load}}}$

3.2 Load Flow

The load flow has been explained separately. Two different load flow methods have been illustrated: BIBC normal and meshed load flow. It was observed during the reconfiguration process that BIBC is very fast and needs very little number of iterations.

3.2.1 BIBC load flow method

The BIBC load flow method depends on branch currents. Three matrices are formed in order to calculate the bus voltages. The entire method has been summarized as under [35]:

- Computation of voltage at buses : If V_k is the voltage of buses at k_{th} iteration, then V_{k+1} is the voltage at buses at $(k+1)_{th}$ iteration is given by :

$$\mathbf{V_{k+1} = V_k - \Delta V_k} \tag{3.7}$$

  where ΔV_k is the change in bus voltages after two successive iterations.

- Real and reactive power flow: If P_{ij} and Q_{ij} be the real and reactive power flowing between i_{th} and j_{th} bus, V_i and V_j are bus voltages of i_{th} and j_{th} bus, y_{ij} is the admittance between i_{th} and j_{th} bus then:

$$\mathbf{P_{ij} = Real\ [V_i\{ (V_{i-} V_j)\ y_{ij}\}^*]} \tag{3.8}$$

$$\mathbf{Q_{ij} = Imag\ [V_i\{ (V_{i-} V_j)\ y_{ij}\}^*]} \tag{3.9}$$

- Real power loss: If V_{ss} and V_j refers to the voltages at main substation and bus j, respectively, $y_{ss,j}$ refers to the line admittance between the main substation bus and bus j, $PD_{ss,j}$ refers to the real power load at bus j and N the number of buses in the radial distribution system (RDS), then real power loss can be given by:

$$\mathbf{P_{Loss} = Real\ \{V_{ss} \sum_{j\in ss}[(Vss - Vj)yss,j] * - \sum_{j=1}^{N} PDj\}} \tag{3.10}$$

- Now the current injection at the kth iteration of the solution is:

$$\mathbf{Ii_k = Ii_k(Vi_k) + j\ Ii_k(Vi_k) = \left(\frac{Pi+jQi}{Vik}\right)^*} \tag{3.11}$$

  where Vi_k and Ii_k are the respective bus voltage and equivalent circuit injection of bus I at k_{th} iteration

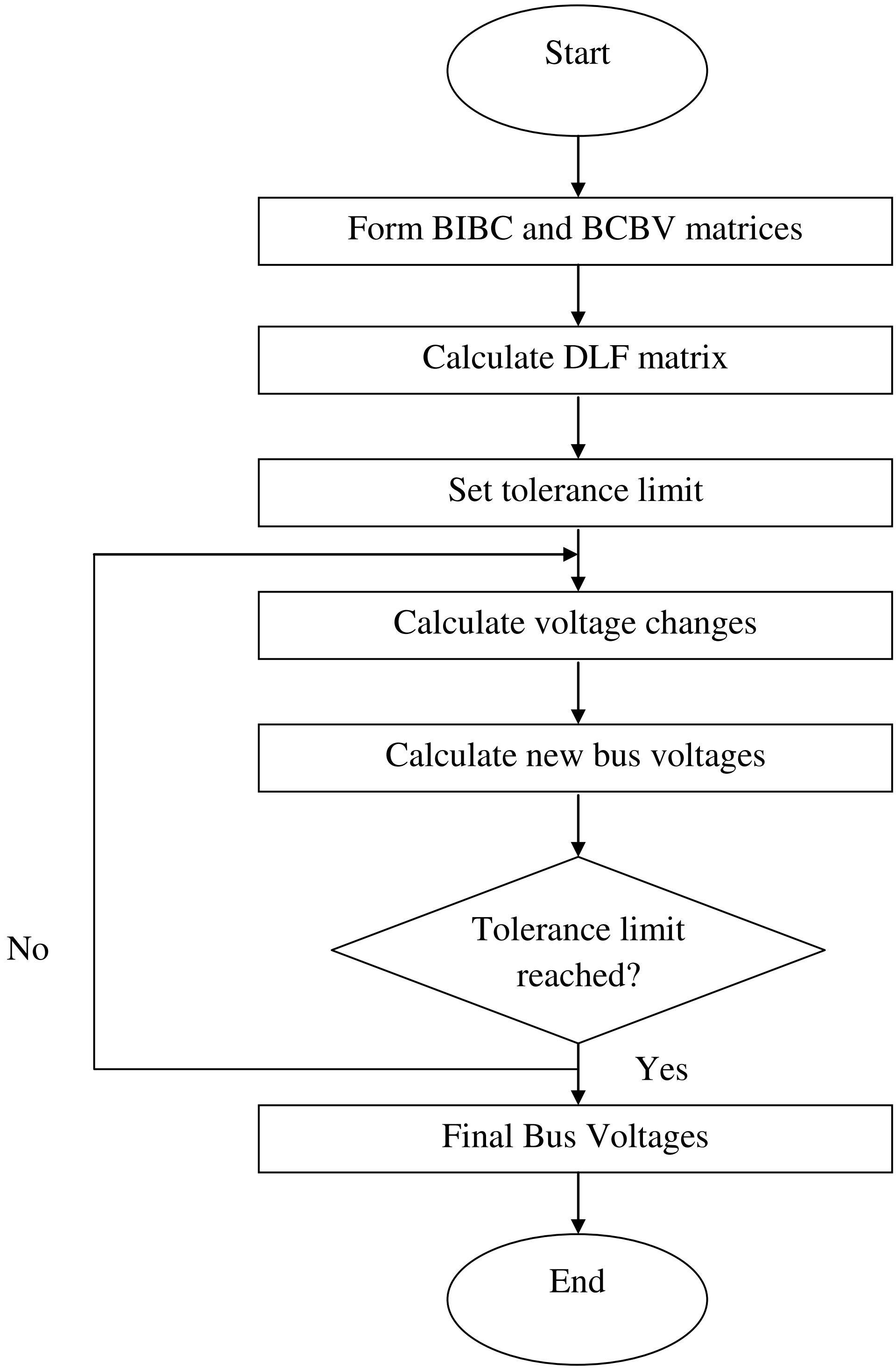

Figure 3.1 Flowchart for BIBC load flow

- Now various relations between bus current injections, branch current and change in bus voltage are given as:

$$[B] = [BIBC]\,[I] \quad (3.12)$$

$$[\Delta V] = [BCBV]\,[B] \quad (3.13)$$

$$[\Delta V] = [BCBV]\,[BIBC]\,[I] \quad (3.14)$$

$$[\Delta V] = [DLF]\,[I] \quad (3.15)$$

where BIBC is the branch induced branch current matrix, BCBV is the branch current branch voltage matrix and DLF is a multiplication matrix of BCBV and BIBC matrices and the solution for distribution load flow can be obtained by iterations of:

$$Ii_k = Ii_k(Vi_k) + j\,Ii_k(Vi_k) = \left(\frac{Pi+jQi}{Vik}\right)^* \quad (3.16)$$

$$[\Delta V_{k+1}] = [DLF]\,[I_k] \quad (3.17)$$

$$[V_{k+1}] = [V_0] + [\Delta V_{k+1}] \quad (3.18)$$

3.2.2 BIBC load flow for weakly meshed networks

Existence of loops in the system does not affect the bus current injections, but new branches will need to be added to the system. For this let us consider a case where a new branch B_k is being added between nodes I_k and I_{k-1} and is forming a loop. Taking this new branch current into account the new current injections at bus k and (k-1) will be [34]:

$$I_{k-1}' = I_{k-1} + B_k$$
$$I_k' = I_k - B_k \quad (3.19)$$

After modification it will be observed that the generalized BIBC matrix in this case can be obtained as given below:

$$\binom{B}{Bnew} = [BIBC]\binom{I}{Inew} \quad (3.20)$$

If a new branch B_k makes the system become meshed (the new branch is between bus i and j), copy the elements of the i-th bus column to the k-th column and minus the elements of the j-th bus column. Finally, fill a value to the position of the k-th row and the k-th column. The modified form for BCBV matrix can be expressed as:

$$\binom{\Delta V}{0} = [BCBV]\binom{B}{Bnew} \quad (3.21)$$

If a new branch makes the system become meshed, adds a new row to the original BCBV matrix by KVL. The general form of KVL for a loop can be expressed as:

$$\sum_{l=1}^{nl} Z_l B_l = 0 \quad \textbf{(3.22)}$$

where n_l is the number of branches in this loop, Z_l and is the line impedance corresponding to the branch current B_l. The voltage change matrix can be modified as shown below:

$$\begin{pmatrix} \Delta V \\ 0 \end{pmatrix} = [BCBV][BIBC]\begin{pmatrix} I \\ Bnew \end{pmatrix} \quad \textbf{(3.23)}$$

$$= \begin{bmatrix} A & M^T \\ M & N \end{bmatrix}\begin{pmatrix} I \\ Bnew \end{pmatrix} \quad \textbf{(3.24)}$$

Applying Kron's reduction to (3.24), the modified algorithm for weakly meshed networks can be expressed as:

$$\Delta V = [A - M^T N^{-1} M][I]$$

$$= [\mathrm{DLF}]\,[\mathrm{I}] \quad \textbf{(3.25)}$$

3.3 Reconfiguration

Reconfiguration is the process of opening sectionalizing switches and closing a tie switch corresponding to each sectionalizing switch. This should be done in such a way that the radiality of the system is maintained and none of the loads is isolated. In this thesis, three different methods are proposed with initial radial and meshed topologies. The initial meshed topology gives the minimum loss configuration for the system and as we reconfigure the network, we move towards the radial configuration with minimum losses.

Figure 3.3 shows a distribution system in which there are 33- buses, 32 sectionalizing switches and 5 tie-switches. Detailed parameters are given in the appendix. Three different methods for reconfiguration will now be discussed here. The voltage profiles and loss reduction in respective cases will also be compared subsequently.

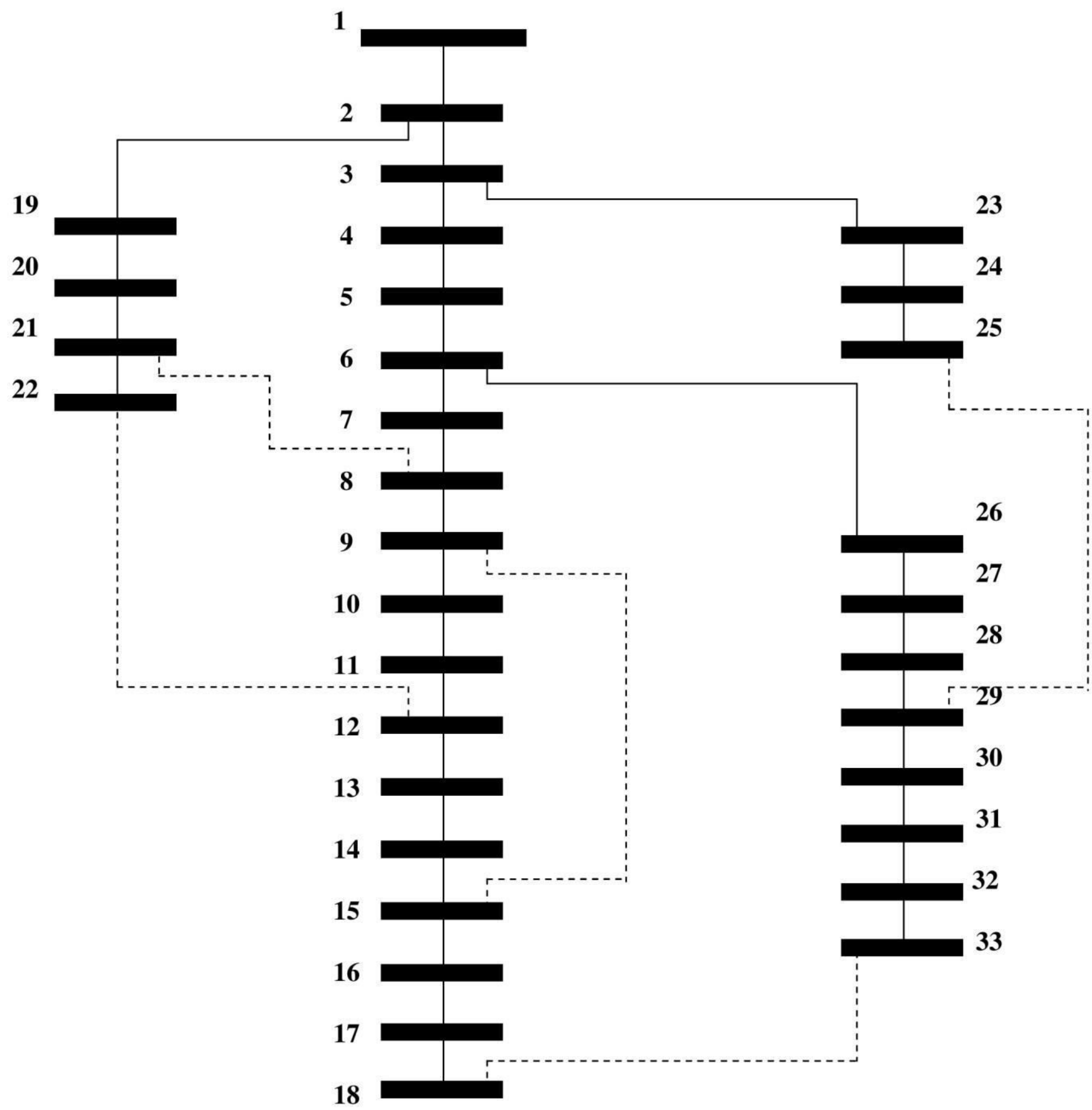

Figure 3.2 33- Bus Radial Distribution System

for small bus systems. Hence, gauss siedel load flow has been used in the entire reconfiguration process. The methods are as follows:

3.3.1 Method 1: Minimum branch current based reduction

This method requires the system to be completely meshed initially. Before that, we calculate active power loss for radial distribution system and keep it aside for calculation of percentage power loss reduction. The steps can be summarized here:

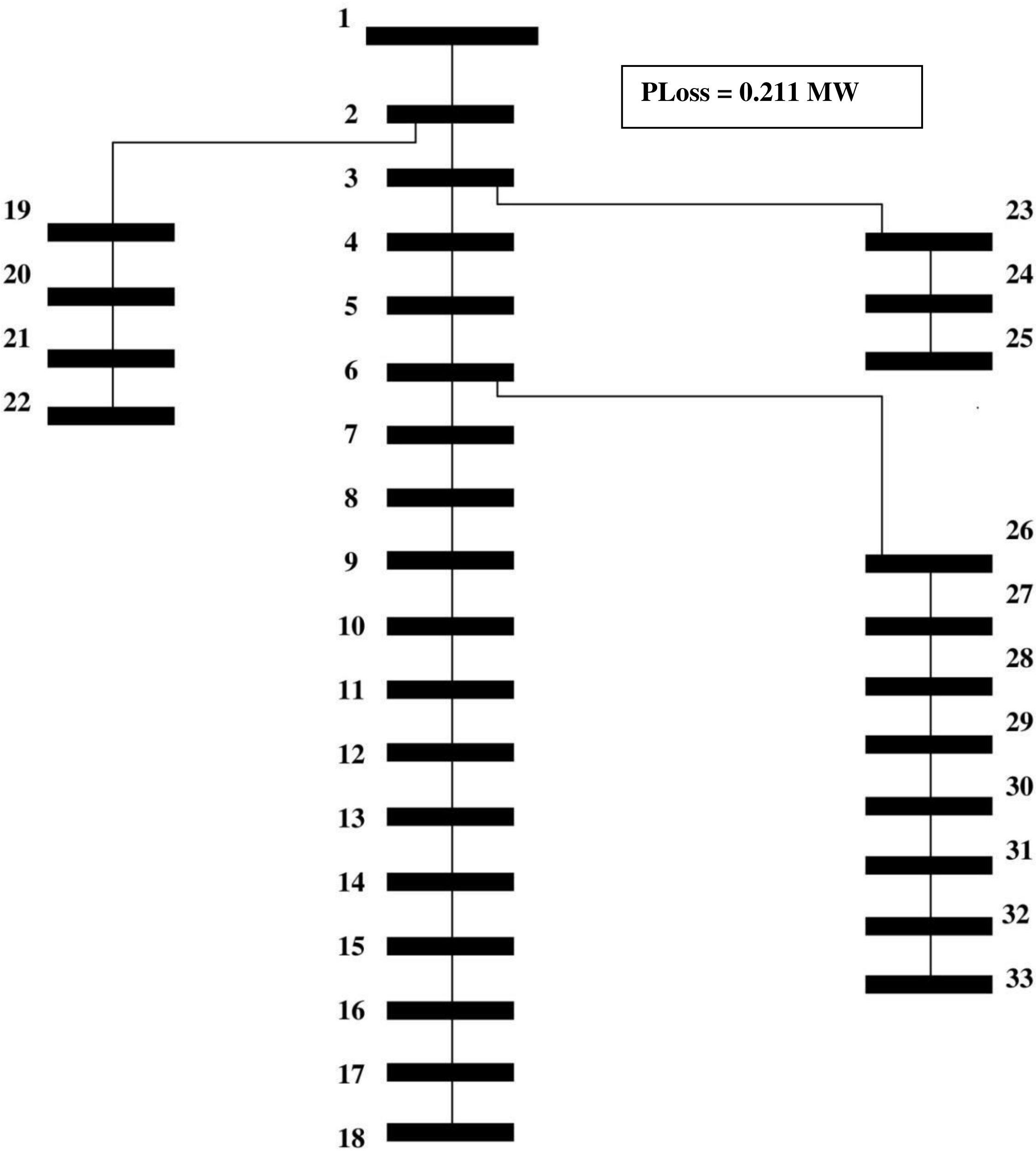

Figure 3.3 33- Bus RDS without tie lines

1) Calculate active power loss for radial distribution system. It comes out to be 0.211 MW.
2) Now consider fully meshed configuration. After load flow, power loss comes out to be 0.1159 MW. This is the least power loss the system can have. Our aim is to reach the most feasible radial state in terms of power loss by opening sectionalizing switches in each loop such that radiality is maintained and none of the loads is isolated.

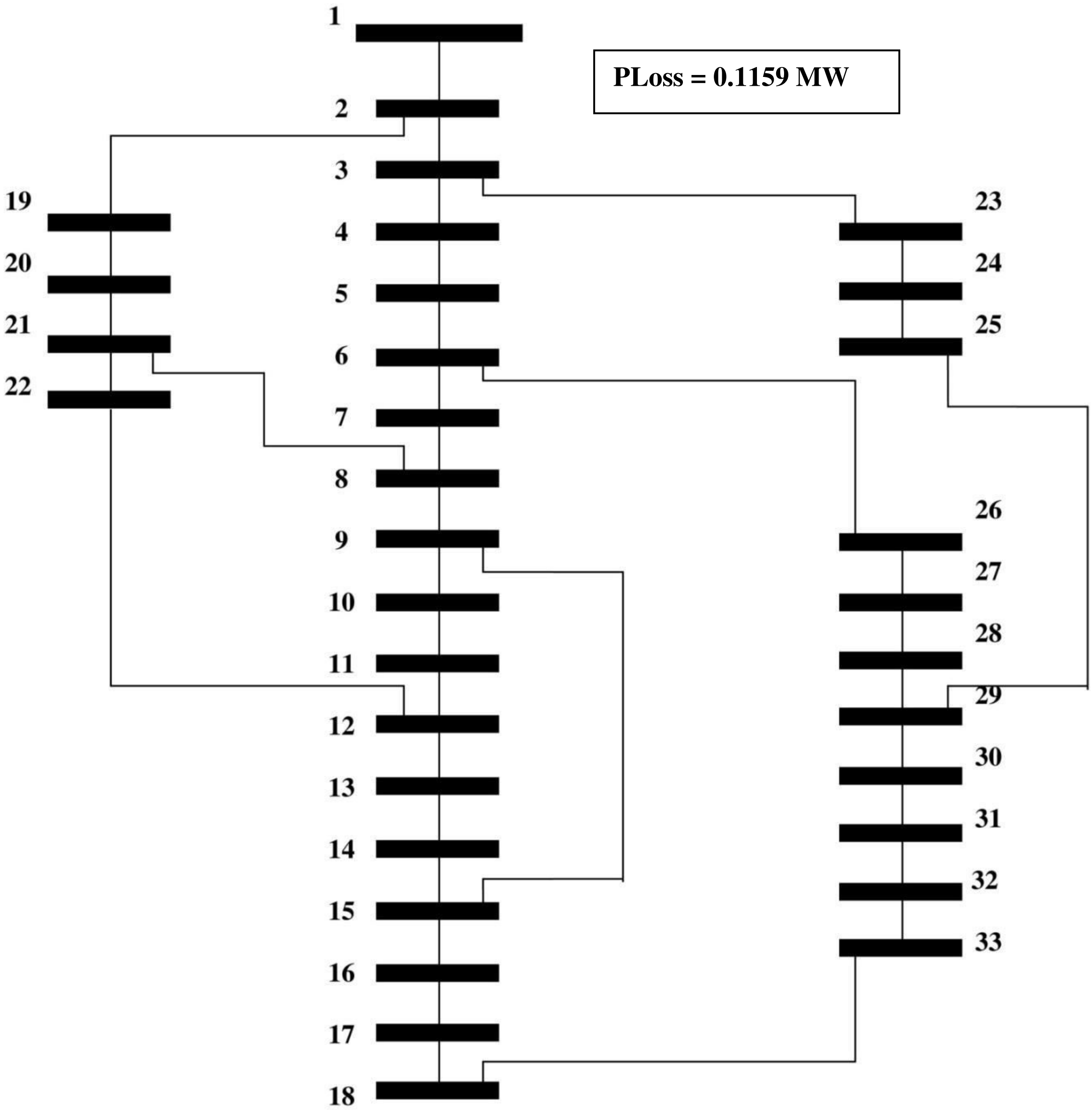

Figure 3.4 Fully Meshed 33- Bus RDS

3) After the power flow in base case, sort all the branch currents. The branch with the minimum current will be opened. In this way minimum current will be redistributed in the new configuration and increase in power loss will also be very small.
4) Repeat load flow and open the switch with next minimum branch current, such that it is lies in a different loop, no load is isolated and radial structure is maintained.
5) Since five loops have been created due to tie switches, hence five sectionalizing switches will be opened corresponding to each loop. Repeat step (4) till the network is radial and note down the final configuration power loss.

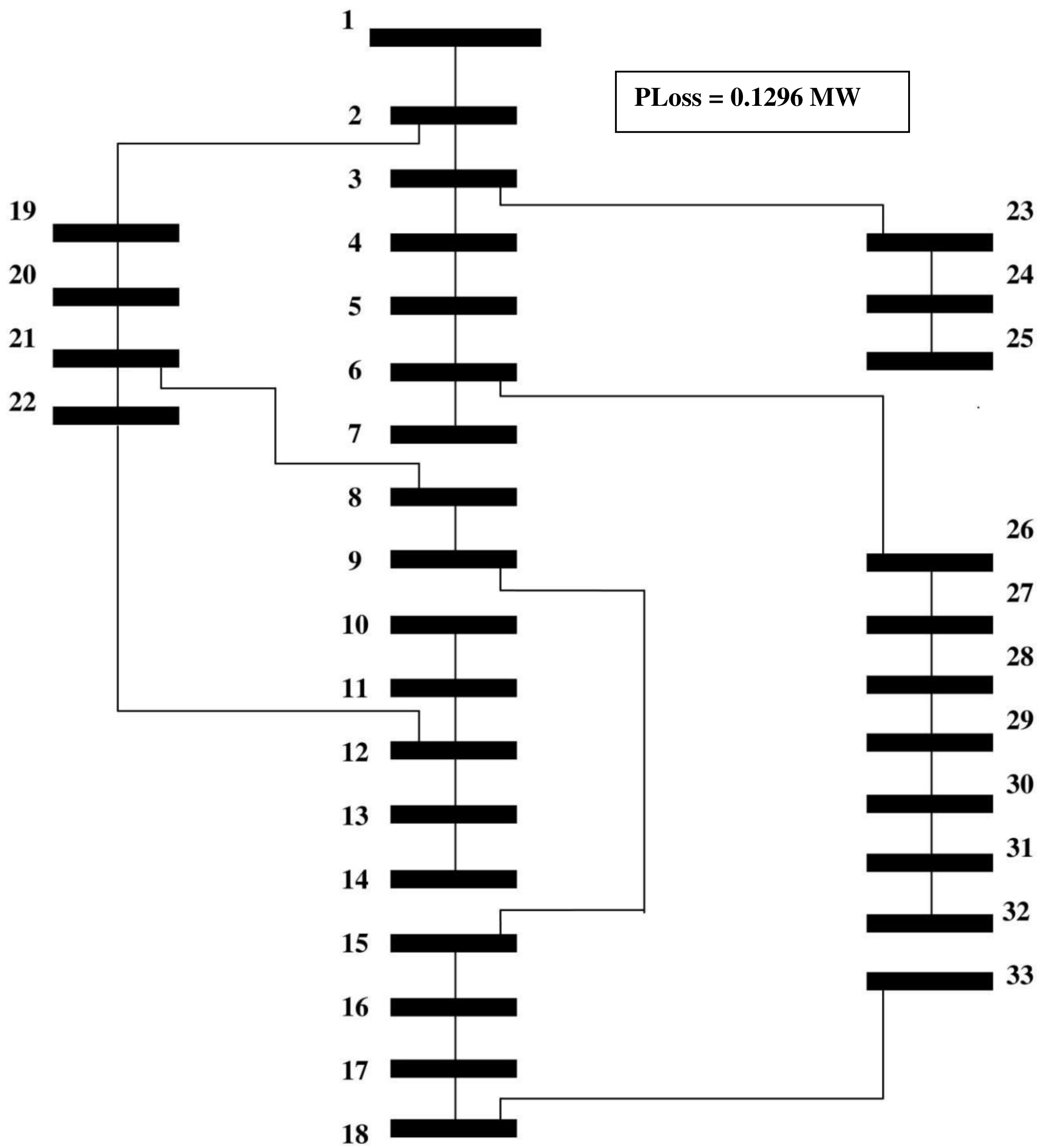

Figure 3.5 Final radial configuration using method 1

6) Final configuration power loss comes out to be 0.1296 MW. Calculate percentage power loss reduction according to following formula:

$$\textbf{\% loss reduction} = \frac{(power\ loss\ in\ radial\ state - reconfigured\ state)}{power\ loss\ in\ radial\ state} \textbf{ x 100}$$

3.3.2 Method 2: Minimum voltage difference based reduction

This method also requires the system to be completely meshed state in the beginning. The steps have been summarized as given below:

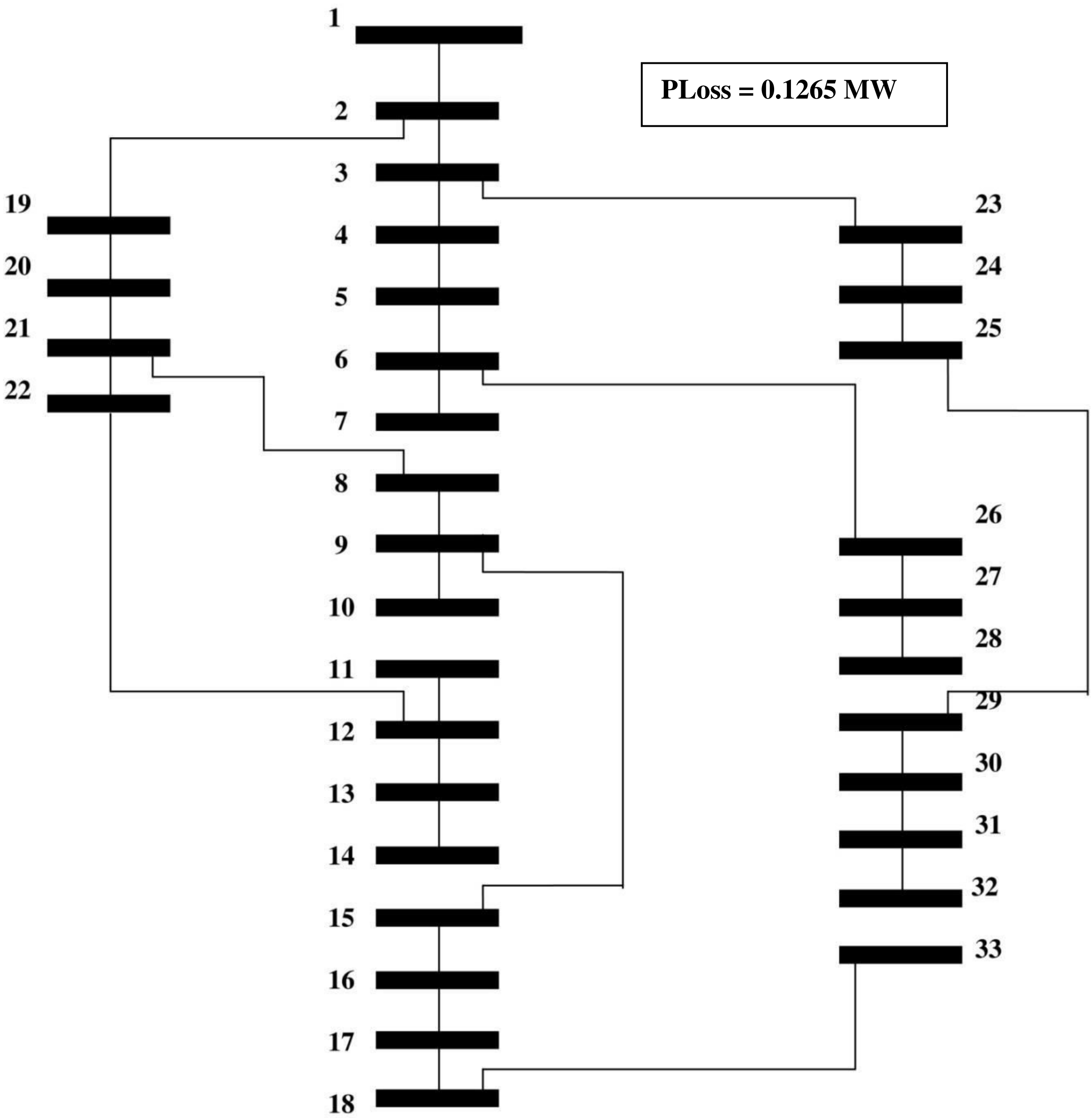

Figure 3.6 Final radial configuration using method 2

1) Calculate active power loss for radial distribution system. It comes out to be 0.211 MW.
2) Now consider fully meshed configuration. After load flow, power loss comes out to be 0.1159 MW. This is the least power loss the system can have. Our aim is to reach the most feasible radial state in terms of power loss by opening sectionalizing switches in each loop such that radiality is maintained and none of the loads is isolated.

3) After the power flow in base case, sort voltage differences between all buses. The branch with the minimum voltage difference between its buses will be opened.
4) Repeat load flow and open the switch with next minimum voltage difference, such that it is lies in a different loop, no load is isolated and radial structure is maintained.
5) Since five loops have been created due to tie switches, hence five sectionalizing switches will be opened corresponding to each loop. Repeat step (4) till the network is radial and note down the final configuration power loss.
6) Final configuration comes out to be 0.1265 MW. Calculate percentage power loss reduction according to following formula:

$$\textbf{\% loss reduction} = \frac{(power\ loss\ in\ radial\ state - reconfigured\ state)}{power\ loss\ in\ radial\ state} \textbf{x 100}$$

3.3.3 Method 3: Voltage difference based closing/ opening method

In this method, the initial state of the system is radial. To maintain the radial structure if tie switch is closed to form a loop, a sectionalizing switch within that loop has to be opened. The tie switch with maximum voltage difference across it is closed while the opening sectionalizing switch should have minimum voltage drop across it. In this method it will be observed that the power loss increases as we move from the initial configuration to final configuration, contrary to the previous two methods. The steps have been summarized below:

1) Calculate power loss of initial 33- bus radial distribution system configuration. It comes out to be 0.211 MW.
2) Calculate voltage difference across all tie switches after base case load flow and sort them in descending order. This will be the sequence of closing switches.
3) Close the first tie switch (with maximum voltage difference across it) and run the load flow on this system. Now search for the sectionalizing switch inside the loop hence formed, with minimum voltage difference across it. Open that switch, it will give the new configuration. Note down the power loss.
4) Repeat step (3), till all the tie switches are closed and system is radial. Note down the power loss of final configuration.
5) Final configuration power loss comes out to be 0.1268 MW. Calculate percentage power loss reduction according to following formula:

$$\% \text{ loss reduction} = \frac{(power\ loss\ in\ radial\ state - reconfigured\ state)}{power\ loss\ in\ radial\ state} \text{x } 100$$

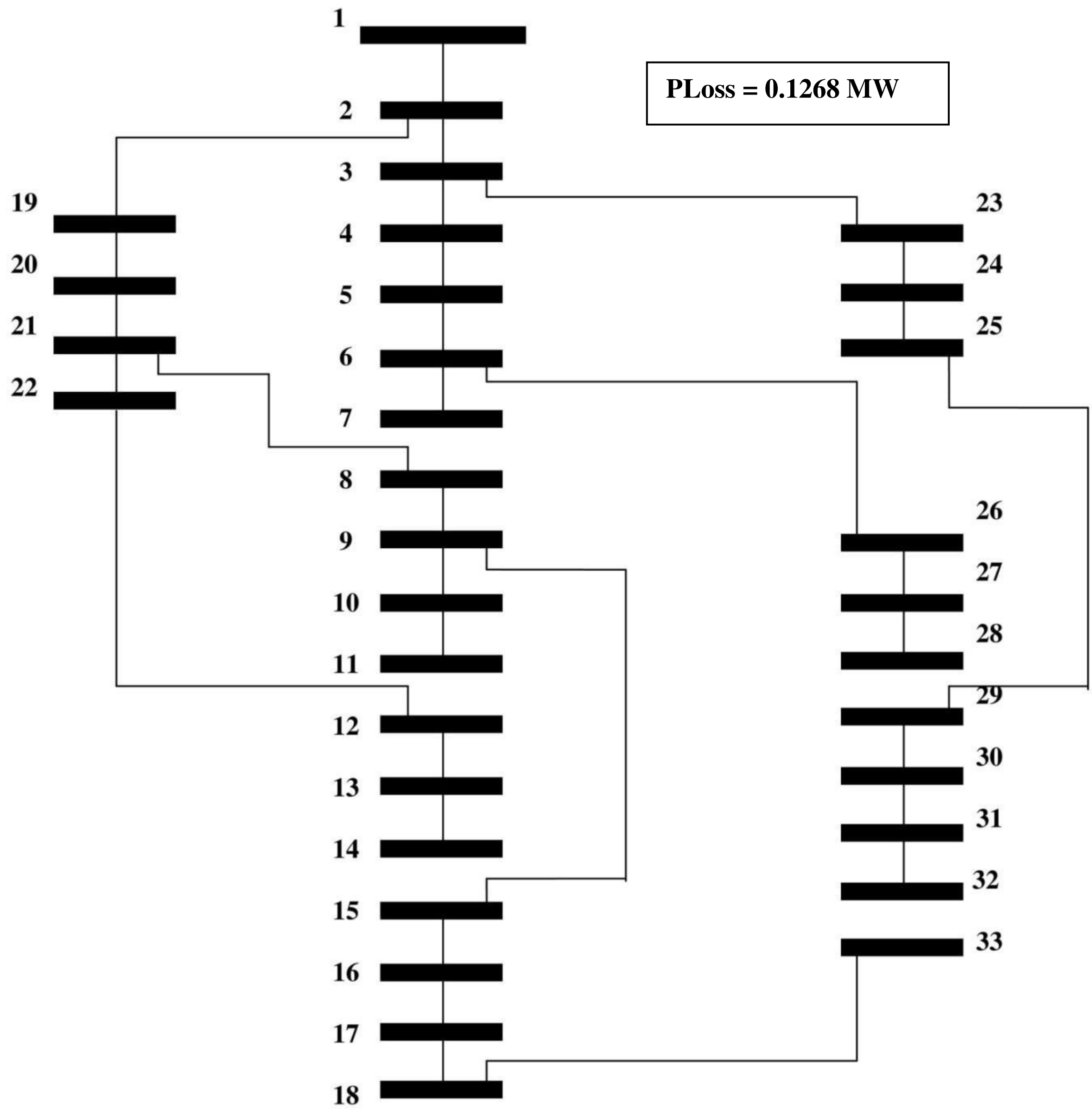

Figure 3.7 Final radial configuration using method 3

3.4 Results and Comparison

Final reconfigured states of the methods used have been shown above. Now the percentage power loss reduction in these methods and their respective voltage profiles will be compared. The best method will be the one which gives maximum power loss reduction and bus voltages between prescribed limits. The table given below shows the bus voltages of 33- bus radial distribution system and the bus voltages obtained in the final radial configurations of the methods used.

Table 3.1: Bus voltages of 33- bus RDS and reconfigured cases

Bus Number	Method 1	Method 2	Method 3	33- bus RDS
1	1	1	1	1
2	0.9971	0.9971	0.9971	0.9970
3	0.9870	0.9870	0.9870	0.9829
4	0.9852	0.9825	0.9852	0.9754
5	0.9837	0.9782	0.9837	0.9680
6	0.9805	0.9673	0.9805	0.9495
7	0.9799	0.9667	0.9799	0.9460
8	0.9702	0.9705	0.9698	0.9323
9	0.9664	0.9671	0.9655	0.9260
10	0.9659	0.9673	0.9646	0.9201
11	0.9682	0.9674	0.9645	0.9192
12	0.9684	0.9677	0.9691	0.9177
13	0.9658	0.9651	0.9666	0.9116
14	0.9650	0.9644	0.9658	0.9093
15	0.9647	0.9654	0.9638	0.9078
16	0.9629	0.9637	0.9621	0.9065
17	0.9600	0.9608	0.9592	0.9044
18	0.9590	0.9598	0.9582	0.9038
19	0.9951	0.9951	0.9951	0.9965
20	0.9784	0.9784	0.9783	0.9929
21	0.9737	0.9738	0.9737	0.9922
22	0.9707	0.9703	0.9711	0.9916
23	0.9796	0.9834	0.9796	0.9793
24	0.9648	0.9768	0.9648	0.9726

25	0.9535	0.9735	0.9535	0.9693
26	0.9803	0.9655	0.9803	0.9475
27	0.9800	0.9632	0.9800	0.9450
28	0.9795	0.9527	0.9795	0.9335
29	0.9423	0.9451	0.9423	0.9253
30	0.9391	0.9419	0.9391	0.9218
31	0.9356	0.9385	0.9356	0.9176
32	0.9350	0.9378	0.9350	0.9167
33	0.9585	0.9593	0.9576	0.9164

When we plot these bus voltages altogether, we get the voltage profiles for each case. The dotted magenta line depicts 33- bus radial distribution system bus voltages. The red, blue and

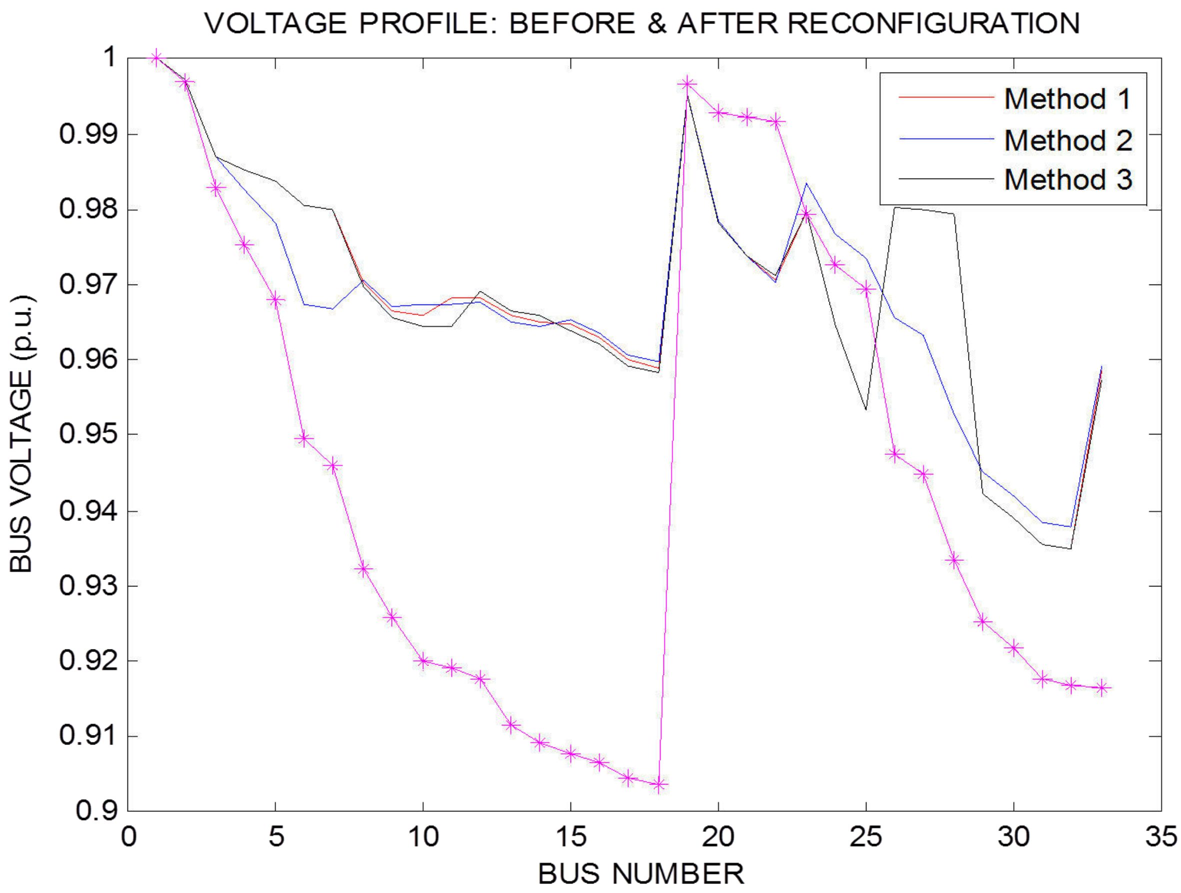

Figure 3.8 Voltage profiles before and after reconfiguration

black lines show bus voltages of final radial states of each method. On careful analysis of the graph it can be observed that: the voltage profiles have improved after reconfiguration in all the cases; the best voltage profile is obtained in method 2 (minimum voltage difference based reduction) because it has minimum number of voltage dips and the magnitude of bus voltages is better as compared to the other methods. Now we can move over to the analysis of power loss reduction in each case. The table given below shows initial and final active power loss (MW), switches opened (in sequence) and percentage loss reduction in each method of reconfiguration.

Table 3.2: Power loss reduction

S.NO.	METHOD	INITIAL ACTIVE POWER LOSS (MW)	SWITCHES OPENED	FINAL ACTIVE POWER LOSS (MW)	% LOSS REDUCTION
1	Minimum branch current based reduction	0.1159 (Fully meshed state)	14-15, 9-10, 32-33, 28-29, 7-8	0.1296	38.60 %
2	Minimum voltage difference based reduction	0.1159 (Fully meshed state)	10-11, 14-15, 32-33, 28-29, 7-8	0.1265	40.05 %
3	Voltage difference based closing-opening method	0.211 (Radial state)	7-8, 32-33, 28-29, 11-12, 14-15	0.1268	40.00 %

It can be observed that minimum voltage difference based reduction method gives the best voltage profile and power loss reduction. The voltage difference based closing- opening method gives the second best result followed by branch current based reduction method. From, the voltage profile graph it can be seen that second method gives best profile whereas the voltage profiles of the first and third method are almost very close. Hence, it can be concluded that the overall best method for reconfiguration in this case is the second method.

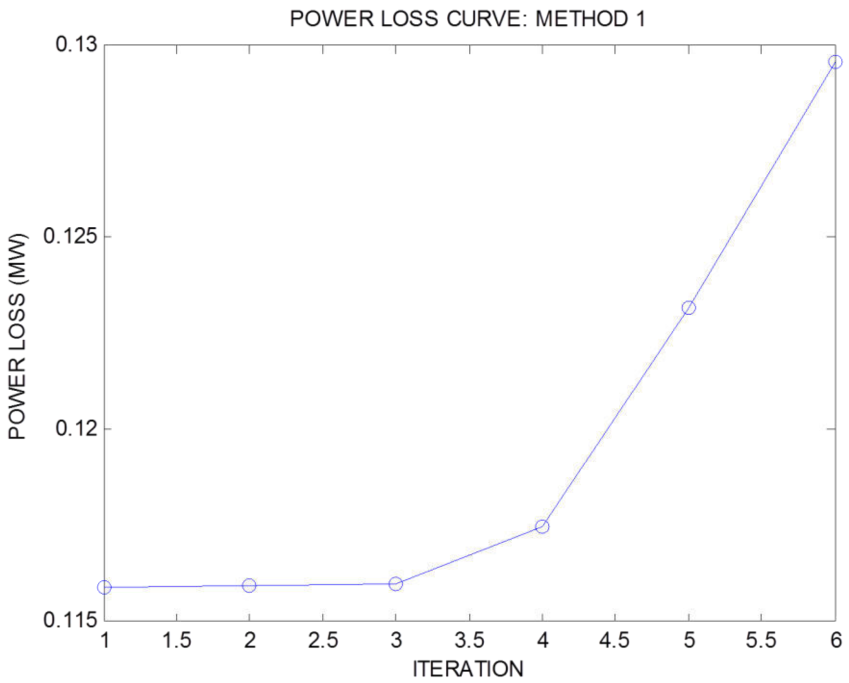

Figure 3.9 Power Loss Curve for Method 1

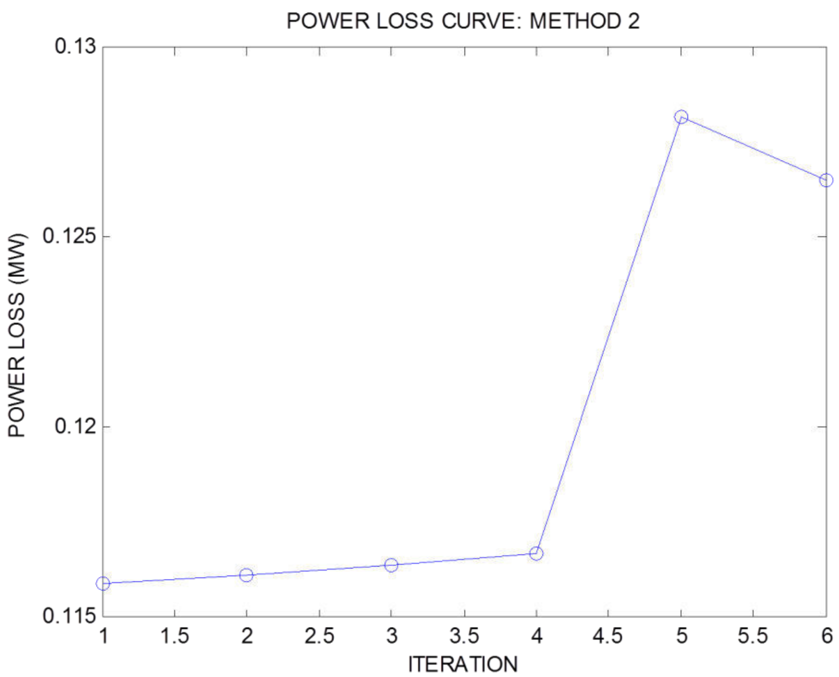

Figure 3.10 Power Loss Curve for Method 2

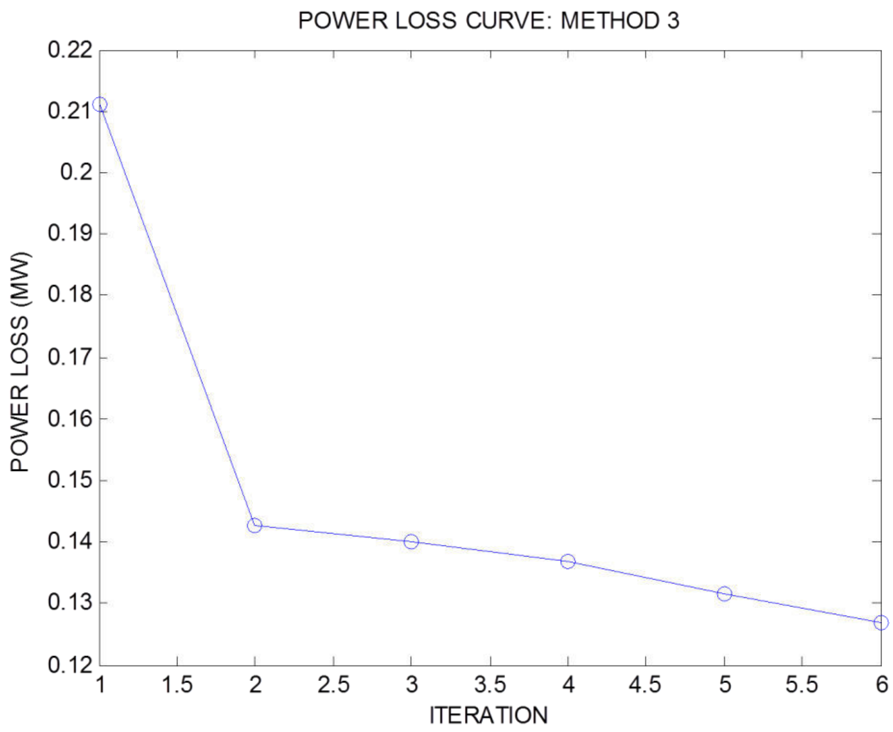

Figure 3.11 Power Loss Curve for Method 3

3.4.1 Further improvement of voltage profile

In the previous segment, the voltage difference based reduction method comes out to be the best method. But still, the table and graph shown above, clearly demonstrate that the voltages at buses 29, 30, 31, 32. From Figure 3.7 and using trial and error method it was concluded that

Table 3.3: Bus voltages after DG placement in method 2 reconfigured network

Bus Number	33- bus RDS	Reconfigured with DG
1	1	1
2	0.997	0.9977
3	0.9829	0.9896
4	0.9754	0.9878
5	0.968	0.9863
6	0.9495	0.9832
7	0.946	0.9825

8	0.9323	0.9765
9	0.926	0.9753
10	0.9201	0.9748
11	0.9192	0.9745
12	0.9177	0.9746
13	0.9116	0.972
14	0.9093	0.9713
15	0.9078	0.9736
16	0.9065	0.9738
17	0.9044	0.9743
18	0.9038	0.9752
19	0.9965	0.9961
20	0.9929	0.9834
21	0.9922	0.9799
22	0.9916	0.9769
23	0.9793	0.984
24	0.9726	0.973
25	0.9693	0.9653
26	0.9475	0.9829
27	0.945	0.9826
28	0.9335	0.9821
29	0.9253	0.9543
30	0.9218	0.9531
31	0.9176	0.9535
32	0.9167	0.9541
33	0.9164	0.9747

a 400 kW DG at bus 18 and 600 kW DG at bus 31 can be installed to bring drastic change in voltage profile and above 0.95 p.u. The improved voltage profile after adding DG to the reconfigured network has been shown in Figure 3.13 with 33- bus RDS voltage profile.

The final power loss after placing DGs came out to be 0.0828 MW. Since initial power loss is 0.211 MW, the power loss reduction comes out to be **60.76%.**

3.4.2 Comparison with previous works

In this section the results obtained, have been compared with earlier works on 33- bus radial distribution system to show the feasibility of the methods employed.

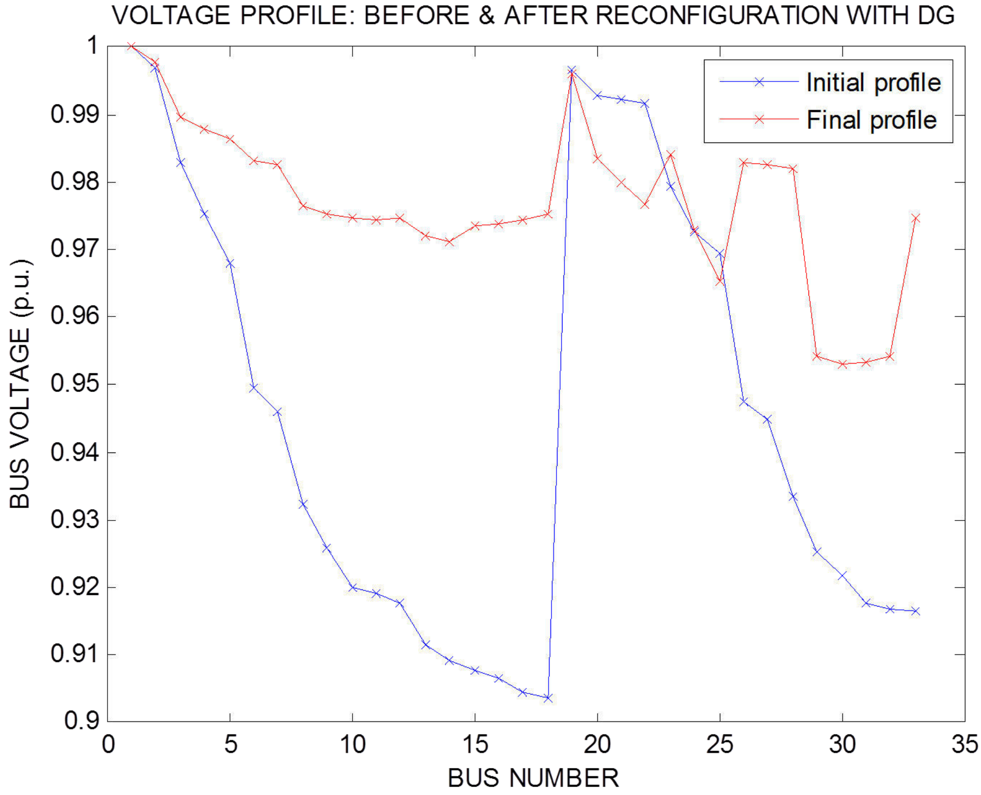

Figure 3.12 Voltage profile of reconfigured network with DG

Table 3.4: Comparison of results for 33-bus RDS reconfiguration

Reference Papers	**Open Switches**	**P_{Loss} (kW)**	**Loss Reduction (%)**
Merlin and Back [13]	7-8, 10-11, 14-15, 25-29, 32-33	140.3	30.74
Imran and Kowsalya [25]	7-8, 9-10, 14-15, 28-29, 32-33	139.98	30.93
Teimourzaeh and Zare [26]	6–7, 8-9, 13–14, 24–28, 31-32	139.5	31.15

Kumar and Jayabarathi [28]	7-8, 9-10, 13-14, 14-15, 32-33	135.78	33.02
Wu, Lee and Tsai [36]	7-8, 9-10, 14-15, 28-29, 32-33	137.0	35.77
Srinivasa and Narsimham [37]	7-8, 11-12, 14-15, 28-29, 32-33	130.7	38.74
Qiwan [38]	7-8, 9-10, 14-15, 25-29, 32-33	139.53	31.01
Mirhoseini et. al. [39]	7-8, 9-10, 14-15, 25-29, 32-33	139.51	31.11
Swarnkar, Gupta and Niazi [40]	7-8, 9-10, 14-15, 25-29, 32-33	139.55	31.15
Proposed Method 1	**7-8, 9-10, 14-15, 28-29, 32-33**	**129.6**	**38.60**
Proposed Method 2	**7-8, 10-11, 14-15, 28-29, 32-33**	**126.5**	**40.05**
Proposed Method 3	**7-8, 11-12, 14-15, 32-33, 28-29,**	**126.8**	**40.00**

CHAPTER FOUR
CONCLUSIONS AND FUTURE WORK

4.1 Conclusions

This thesis shows loss reduction by reconfiguration of a radial distribution network. A 33-bus system was used for the purpose. Following conclusions can be drawn from the work:

1) BIBC load flow method gives very fast convergence to the load flow problem and takes very small number of iterations as compared to any other method.
2) Method 1 and 2 are almost similar in approach, but method 2 gives better loss reduction, this is due to exhaustive search for minimum voltage drop in each loop. The disparity is evident from the power loss trend in method 2.
3) Whatever method is used for reconfiguration, better results will always be obtained when the system is completely meshed in the beginning.
4) Voltage profiles improved drastically after reconfiguration and even more after DG placement.
5) Considerable power loss reduction was obtained by all the stated methods.

4.2 Future Scope

Clearly there are some shortcomings in this work which have been discussed above. Considering these problems, this has a scope for improvement.

1) Keeping the basic idea same, various optimization techniques can be used to automate and check the efficiency of the process.
2) Obviously there is a scope for further power loss reduction. Also, a technique can be devised for making the voltage profile more linear.

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APPENDIX-A

PARAMETERS FOR 33-BUS DISTRIBUTION SYSTEM

Branch Number	Bus (From)	Bus (To)	R (ohm)	X (ohm)	P-load (kW)	Q-load (kVar)
1	1	2	0.0922	0.047	100	60
2	2	3	0.493	0.2511	90	40
3	3	4	0.366	0.1844	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.819	0.707	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.03	0.74	60	20
9	9	10	1.044	0.74	60	20
10	10	11	0.1966	0.065	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.7463	0.545	60	20
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	90	40
18	2	19	0.164	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50

23	23	24	0.898	0.7091	420	200
24	24	25	0.896	0.7011	420	200
25	6	26	0.203	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.059	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.963	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.341	0.5302	60	40
33	21	8	0	2		
34	9	15	0	2		
35	12	22	0	2		
36	18	33	0	2		
37	25	19	0	2		

Base kV= 12.66, Base MVA= 0.1

Tie switches = 21-8; 9-15; 12-22; 18-33; 25-19