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Reconfiguration and Enhancement of Multi Feeder Radial Distribution System of Pulchowk Distribution Network Lalitpur, Nepal

by

Govinda Prasad Pandey

A THESIS

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Head

Department of Mechanical Engineering

Pulchowk Campus, Institute of Engineering

Lalitpur, Nepal

TRIBHUWAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF MECHANICAL ENGINEERING

The undersigned certify that they have read, and recommended to the institute of engineering for the acceptance, a thesis entitled "**Reconfiguration and Enhancement of Multi Feeder Radial Distribution System Of Pulchowk Distribution Network Lalitpur, Nepal"** submitted by Govinda Prasad Pandey in partial fulfillment of the requirements for the degree of master of science in Renewable Energy Engineering.

____

Supervisor, Assoc. Prof. Dr. Ajay Kumar Jha
Department of Mechanical Engineering
Institute of Engineering, Pulchowk Campus

____

External Examiner, Asst. Prof. Dr. Shailendra Kumar Jha
Department of Electrical and Electronics Engineering
School of Engineering, Kathmandu University.

____

Committee Chairperson, Assoc. Prof. Dr. Nawraj Bhattarai
Head of Department,
Department of Mechanical Engineering

November 13, 2019

Date

ABSTRACT

In the current power system study, the topic related to distribution system; especially on distribution network re-configuration is a very important one. This concept helps to re-structure the distribution as well as transmission line in the existing power system. In this study, this concept is applied as a policy-making tool, that addressed the issues related to the poor voltage profile occurred in the existing distribution system. The voltage margin is improved through the configuration of tie-switches and sectionalizing switches, in between the existing radial feeders. A Genetic algorithm-based model has been developed to enhance the bus's voltage by optimal operation and allocation of the sectionalizing switches and tie switches. The proposed algorithm evaluates the base condition of loss and bus voltage, and then generate populations of switching points from the available feeders for the tie-switches and sectionalizing switches on the existing base configuration. It works with the main objective to minimize the active power loss and voltage drop, under a constraint of existing feeder limit and possible location of the switches' limit. An IEEE-33 bus system has been tested at first and then compared with the real case study of Pulchowk distribution network area for the model and result verification.

In the Pulchowk distribution network of 9 different radial feeders having 142 bus systems in total, it was observed that, most of the lines are facing the problems relating voltage drop and power loss. In this study, an optimal configuration has been identified from all of the possible configurations, by conducting the forward/ backward sweep algorithm based load flow analysis study. From the different cases of the possible networks, the best case is considered to be optimal with respect to the percentage of reduction of power loss and voltage drop from base case. From this study, the power losses and the lowest voltage profile for the Pulchowk feeder are calculated to be 1073.08 kW and 0.7694 pu at bus number 98. After the re-configuration, the power loss and voltage drop are found to be reduced by 44.29%and 3.85% from the base case scenario. Hence, it is concluded that, the optimal configurations of the distribution system can be identified by using some computational techniques that helps to reduce the system loss and voltage drop significantly.

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LIST OF ABBREVIATIONS

SESW	Sectionalizing Switch
GA	Genetic Algorithm
DCS	Distribution and Consumer Services
NEA	Nepal Electricity Authority
RDS	Radial Distribution System
RDF	Radial distribution feeder
Pu	Per unit system
IEEE	Institute of Electrical and Electronic Engineers
MATLAB	MATrix LABoratory
AC(or ac)	Alternate Current
DC(or dc)	Direct Current
ANN	Artificial Neural Network
LP	Linear Programming
NLP	Non Linear Programming
PSO	Particle Swarm Optimization
OPF	Optimal Power Flow
DPP	Discounted Payback period
NPV	Net present Value

CHAPTER ONE: INTRODUCTION

1.1. Background

Electrical distribution network reconfiguration and re-settlement is a complex combinational work that contains the optimization process; aimed at finding a radial operating structure and minimizes the system power loss while satisfying operating constraints. Feeder reconfiguration entails altering the topological structure of distribution feeders by changing the open/close status of the switches under both normal and abnormal operating conditions. It was estimated that from 5% to 13% of the total power system generation is wasted in the form of I^2R losses at the distribution level (Al-Abri, 2012). Recent advances in distribution automation technology have made it possible to reduce these losses by applying loss minimization techniques on a real-time basis.

In power Distribution system, research area is widening and one is Distribution Network Re-configuration in the distribution system. It restructures the power system and also helps in distribution system planning. This dissertation addresses the issue of voltage margin improvement by arranging of the tie-switches & sectionalizing switches (SESW) between different radial feeders and, therefore, this dissertation presents the model to enhance the candidate bus voltage of distribution system by optimal tie & sectionalizing switches allocation and operation. The technical analysis is performed for the existing Distribution Network of the radial distribution system (RDS) by only switching from different points of sectionalizing switches that can be allocated to minimize the power loss and voltage drop with making optimal configuration of base Network of Distribution.

This study will focus on the enhancement of existing structure of Pulchowk Distribution System by reconfiguration of the distribution system. Pulchowk Distribution System is located in Lalitpur district which has a different interconnect feeder but operated radially. This study will be conducted as a research and development project. This will be focused on the efficient and quality distribution system for the area. Optimization will be the focus in terms of power loss reduction and the voltage level of the system by reconfiguration of existing structure. The distribution losses of the system are high. Though the losses are inevitable a good engineering design of Distribution system can minimize these losses, so as to make the system as efficient as possible. Technically, power losses could also reduce the voltage profile of a system, especially in the heavily loaded system. The configuration of a distribution network can be changed by opening/closing the sectionalizing switches and tie switches at the network. In this study, data collection, design re-structure, simulation, and analysis will be performed. The Distribution Feeder System Reconfiguration is described as the procedure of changing the topology of the radial distribution system through a few sectionalizing and tie switches such that the maximum efficiency is accomplished.

Here we focused on Genetic Algorithm (GA). "Genetic Algorithm" (GA) is a search algorithm based on the mechanics of natural selection and natural genetics. It bines the adaptive nature of the natural genetics or the evolution procedures of organs with functional optimizations. By simulating the survival of the fittest among string structures, the optimal string (solution) is searched by randomized information exchange. In every generation, a new set of artificial strings is created using bits and pieces of the fittest of the old ones. It efficiently exploits historical information to speculate on a new search pint with expected improve performance.

Therefore, this study will be focused to optimize the system by reconfiguration of Distribution system so that the technical losses will be minimized and all affected area will be electrified in an efficient and reliable manner. It will provide the load flow analysis of the distribution system for variable load demand and find out the optimized state and configuration of the system. The advantages of the proposed technique will be a reduction in real power loss, enhanced system reliability, and power quality improvement.

During power distribution, power could be lost in the form of heat caused by current flow (I^2R). The total power loss of a system could be quite high for large-scale distribution systems. As per (Arash Lotfipour, 2016), power losses on transmission and sub-transmission lines made up to 30% of the total power losses, while losses in a distribution network system accounted for 70% of the total losses in power system network. According to (Pulchowk, 2019), Pulchowk Distribution System has eight feeders which are connected from three different substation. A power system is composed of a generation, transmission and distribution system, where the distribution system is that part of the power system that links electric utilities to consumers. The purpose of a power system is to provide electricity to its consumers in a reliable and economical way. However, the power industry has made remarkable modifications towards de-regulation to improve economic as well as the efficiency of the system. From the stand point of utility, power losses have a significant effect on the distribution system's efficiency. Therefore, active power loss minimization is an important factor to enhance the efficiency of the distribution systems. There are many and various methods to reduce the power loss of the distribution system. Some of the techniques are given here in (Sulaima, 2014).

1. Capacitor placement.
2. DG allocation.
3. Distribution system reconfiguration.

Distribution system reconfiguration (DSR) is a process which optimizes the operation of power distribution systems with different goals (such as active power loss minimization & voltage profile improvement). The DSR is performed by changing the status of sectionalizing (normally closed) and tie (normally open) switches in such a way that the reliability of the system is maintained, all the loads are energized and other constraints are satisfied.

1.2. Problem statement

In Nepal, the loss in the distribution system is significant. Although, there has been certain effort being taken by the government entity NEA still the problem is prevalent. The network reconfiguration problem in a distribution system to find a best configuration of radial network that gives minimum power loss while the imposed operating constraints are satisfied, which are voltage profile of the system, current capacity of the feeder, and radial structure of the distribution system. These factors add complexity in the switching operation of distribution system. The proposed study is intended to address the issue pertinent to the distribution losses.

The demand for power and energy has been consistently increasing by an average annual rate of 8% for the last few decades. The electrical power losses associated in Nepalese distribution system is 11.28% (NEA, 2019) The distribution system of the Pulchowk area is a densely populated region (about 24000 consumers) consist of different tariff group of consumers mainly some of them are domestic, non-domestic, commercial, non-commercial, industrial, irrigation, water supply, temple & street light.

The power loss associated with the distribution system of Pulchowk area is high about 8 to 9 percentage; (Pulchowk, 2019). The system configuration is also responsible to maintain power loss. Thus, distribution losses in the system are very high. Though the losses are inevitable but a good engineering design of the distribution system can minimize these losses, so as to make the system as efficient as possible. Pulchowk Distribution Feeders have different interconnected sectionalizes, however, there is no significant amount of study being done which address the technical analysis during operation in a proper efficient way. If these sectionalizes are reconfigured in an optimized way, the distribution losses can be minimized.

In the proposed research, the reduction of distribution losses of Pulchowk Distribution Feeder have been considered by optimum reconfiguration of tie & sectionalizing switches (SESW).

1.3. Research Gap

Some of the researches focused only on the network reconfiguration of IEEE Networks but the network reconfiguring has not been conducted previously in real data of Distribution system of Nepal with more than one feeder supplying at a time to the specific area but run radially. The main challenge of altering the tie & SESW switches positions minimizing the objective function i.e. minimum power loss and improved voltage profile.

Nowadays reconfigurations is more efficient and popular in power system research for a modular power station that can be used as a power supply system to meet the electricity demand. Research area widens for re-configurations of the existing structure in the distribution system. Further research, the study and investigations of distributions re-configurations impacts on existing distribution network operation. The distribution system of Nepalese Power System is the radial type and impacts of re-configurations of existing structure in the radial distribution system can be studied. In Nepal, the re-configurations is done and/or planned to be made the re-arrangement of existing distributions structure to meet the demand.

In Nepal, if the existing condition of the distribution system is reconfigured then, the technical losses can be minimized to an acceptable value (Hong-Chan, 2000). Prevailing configurations had been designed based on the short term load forecasting data which may not be accurate thus causing more power losses at distributions side and no any improvement of the voltage at the farthest end of the radial distribution system. There is a research gap for optimal re-configurations by re-arranging of the existing structure of certain area of electrification with multi feeder feeding distribution line with sectionalizes and tie switching operation in the optimized module and planning for re-configurations to improve the voltage profile of the system and minimized the distributions technical power loss.

1.4. Scope of work

This study will be advantageous for the planning of power system distribution with multi-feeder distributed reconfiguration and also restructures a distribution system. The planning is obstructed with many factors and most common factors are proper arrangement of Sectionalizing Switches (SESW) and tie switches and its allocation in radial distribution system. Using the reconfiguration is most economical and reasonable than other restricting method like DG allocation and upgrading of system conductor (Hong-Chan, 2000). The optimization problem of Re-arrangement of tie-switches & SESW and its right allocation of SESW & tie-switches can be done using this study. The enhance structure in distributions of power and its re-root of feeder with existing one can be done using this study.

1.5. Objectives

1.5.1. Main objective

The main objective of this study is to reconfigure the multi feeders Pulchowk distribution network and enhance distribution model develop with the objective of loss minimization of system via optimal allocation of switching sequences.

1.5.2. Specific objectives

1. To conduct the Load flow analysis of base case distribution system.
2. To analyze the impact of re-configuration to the voltage profile and system losses.
3. To determine enhanced model of Pulchowk DCS network with the optimal location for the switching, and the sequences.

1.6. Limitations

This dissertation discusses on the reconfiguration by tie switches and SESW allocation and arrangement in the distribution system but limited to technical discussion on voltage profile improvement and power loss minimization. It does not consider thermal limit, current handling capacity, network sensitivity effect of impedance matching and harmonic resonance. It only provides information about tie switches and sectionalizing switches (SESW) arrangement in the network to achieve optimal configuration network with limited switching limit, not a upgrading of conductor size and capacity or any other distribution network configuration. It only specifies the switching root of operating the radial distribution feeder (RDF) to minimize the power losses and voltage drop in radial feeder.

CHAPTER TWO: LITERATURE REVIEW

A more efficient network configuration can be obtained to reduce loss by using algorithm. Through the ranking index for each boundary set in each closed loop, the on/ off switch statues can be determined. Meshed networks were considered instead of the radial topology by closing all the tie switches. By considering only the smallest ranking index in the boundary sets, the proposed algorithm can reduce the number of feasible states drastically. Tests in number of practical networks show that the desired switching operations can be reached in a very efficient manner by using this algorithm. (Sulaima, 2014)

The medium voltage distribution network of the Dutch DSO Alliander is operated using a radial topology. By optimizing this topology, it is possible to reduce the energy losses caused by the cable impedances. Various solutions algorithms have been compared for this distribution network reconfiguration problem, while taking into account network capacity and voltage levels. A Genetic algorithm combined with a Greedy demising starting condition yields the best results. Applying the algorithm on real life distribution networks shows with 226 buses and 406 buses yield a reduction in power losses of 15% and 27% respectively (werner, 2016).

The research title on “Distribution System reconfiguration for loss minimization using Binary Coding Particle Swarm Optimization”. This research proposes an improved approach based on to study distribution network reconfiguration based on binary coding particle swarm optimization. The objective is to minimize the system power loss. Based on distribution feeder operations feeder reconfiguration is done as ‘1’ & ‘0’ arrangement combination of switches. Shift operators and shift operator sets are used for analysis and programming purpose. This makes simple algorithm and easier programming. This research proposed method is tested on a 33-bus distribution network and this research conclude that this is improved method to study distribution network reconfiguration using binary coding PSO in IEEE 33 bus test system. The approach gives optimum or near to optimum result depending upon the parameter selection, no. of iterations, and termination parameters. The approach reconfigures the status of switches to obtain the optimal result. (Tandukar, 2014)

The research main purpose of network reconfiguration is to minimize power loss without violating operating constrain. In this thesis Harmony Search Algorithm is used as a network reconfiguration optimization tool. This meta-heuristic technique is simple in implementation and easy handling. There are two case cases considered which provide easy to understand the results. In first case network reconfiguration is obtained without constrain only satisfying objective function and in second case, reconfiguration obtained with constrain. Obviously reconfiguration minimize the power loss and improves the voltage profile as well as release the feeder overload. The research was based on IEEE 33 bus system analysis and the result of the research had active power loss reduced by 26.04% after reconfiguration without considering the limitation. (Mahato, 2018).

According to Yadaiah,(2016), the problem of network reconfiguration is reformulated with an objective to improve the power quality of the distribution system. Along with the traditional objective of loss minimization, power quality related objectives such as minimization of harmonic distortion of the voltage waveform, minimization of voltage unbalances at the nodes and maximization of sag voltages are identified as the objectives of reconfiguration. Branch exchange technique has been used to establish each of the objectives. The problem has also been formulated as a multi-objective optimization problem. The multiple objectives are, however, incorporated into a single objective using weighting multipliers and branch exchange technique has been judicially applied to take care of all the objectives. It is found that network reconfiguration can be used as an effective tool to improve the power quality of distribution system. Besides, the distributed energy sources also have great impacts on distribution network, as their size and locations are found to have great importance on the power loss, voltage sag, voltage harmonic distortion and unbalance.

The electricity production is in the flow of distributed – centralized and – distributed again with the development of technology and its advancement. Initially, the electric utilities were established in open territories and provide service in isolated mode granted with de facto monopolies without connection with other generating sources. The centralization process of generating sources was made by adjoining on another and interconnected grid system were made with various of peak load sharing, backup power and serving more areas with economic prices of electricity. The different distributed generation resources were innovated with technological advancement in power industry which again restructured the power utility decentralized. The deregulation of electricity made market competitive and introduction of DG unit in distribution system is more pronounced.

2.1. Power Distribution Systems Configurations

An important characteristic of distribution systems is their configuration, or how their lines are connected and basically three common configurations of distribution systems: radial, loop and network (Humayd, 2011).

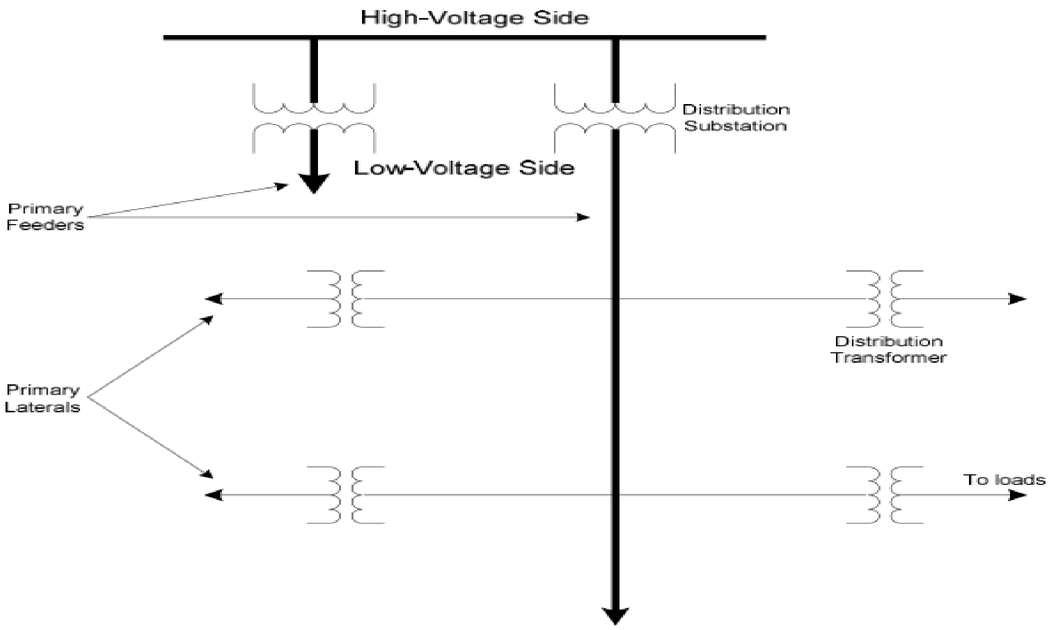

Figure 2.1: Radial Distribution System

2.1.1. Radial Distribution System

The radial distribution system configuration is shown in Figure 2.1 (Humayd, 2011). The characteristics (Gönen, 1986) of this distribution configuration are:

- power flows in one direction,
- lowest capital cost,
- lowest reliability,

A distribution system in which there is only one path between costumer and substation is called radial feeder system. The advantages and disadvantages of RDS are:

Advantages

- Low cost: this is least expensive type of distribution,
- Simplicity of analysis: It is easiest to analyze and operate the system.,

Disadvantages

- Less reliable: Any equipment failure will interrupt service to all consumers downstream from it,

A cleaver design and planning of radial distribution system can achieve a fair degree of reliability even without much addition of cost.

In some cases, feeder systems are constructed as a network and operates radially, In Y-connected radial systems, the neutral conductor is connected through all open switch points forming a network connecting feeder and substations.

2.1.2. Network Distribution System

The networked configuration distribution system shown in fig.2 and has following characteristics (Gönen, 1986):

- more interconnected between two points,
- more than one path and some lines form loops within the system,
- more reliable,
- highest cost,

The distribution network involves multiple paths between all points in the network. Power flow between any two points is usually split among several paths, and if a failure occurs it instantly and automatically re-routes itself. Rarely does a distribution network involve primary voltage level network design, in which all or most of the switches between feeders are closed so that the feeder system is connected between substations.

The major advantages are that it provides very high level of reliability. The loss of any source will not interrupt the flow of power to any customers. The multiple failure of sources can occur with little or no interruption. Among their disadvantages, feeder network systems costs considerably higher and much more complicated analysis and operating procedures.

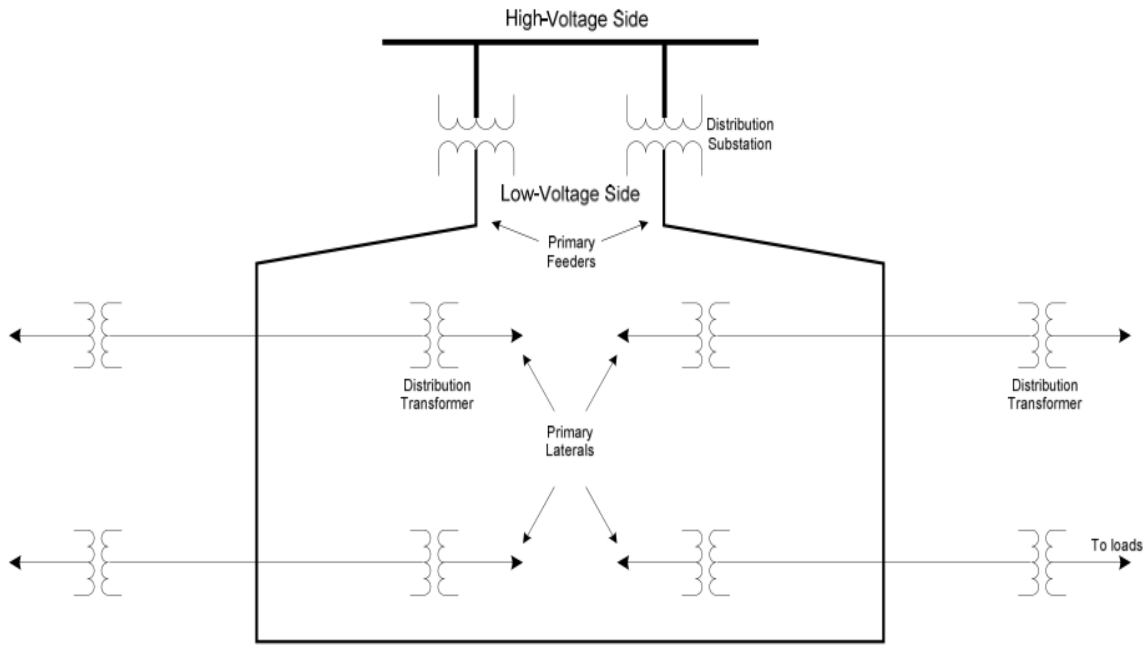

Figure 2.2 : Distribution System - Network configuration (Humayd, 2011)

2.1.3. Loop Distribution System

The loop configured distribution system shown in fig.3 and has following characteristics (Gönen, 1986):

- fall in between the two (radial and network) in terms of cost and reliability,
- two radial systems separated by a normally open switch,
- two paths from substation to the load,

Distribution systems can be operated as loop systems in which the two paths consist in between the consumers and substation. There is being a “null point” somewhere on the loop where no power passes. This layout is basically dynamic radial system with open point (null point) shifting as loads change. A loop must be able to meet all power and voltage drop requirements when fed from only one end, not both.

Advantages

- High reliability than radial system,

Disadvantages

- In terms of complexity, a loop feeder system is only slightly more complicated than a radial system,

- Major disadvantages are capacity and cost of the loop system,

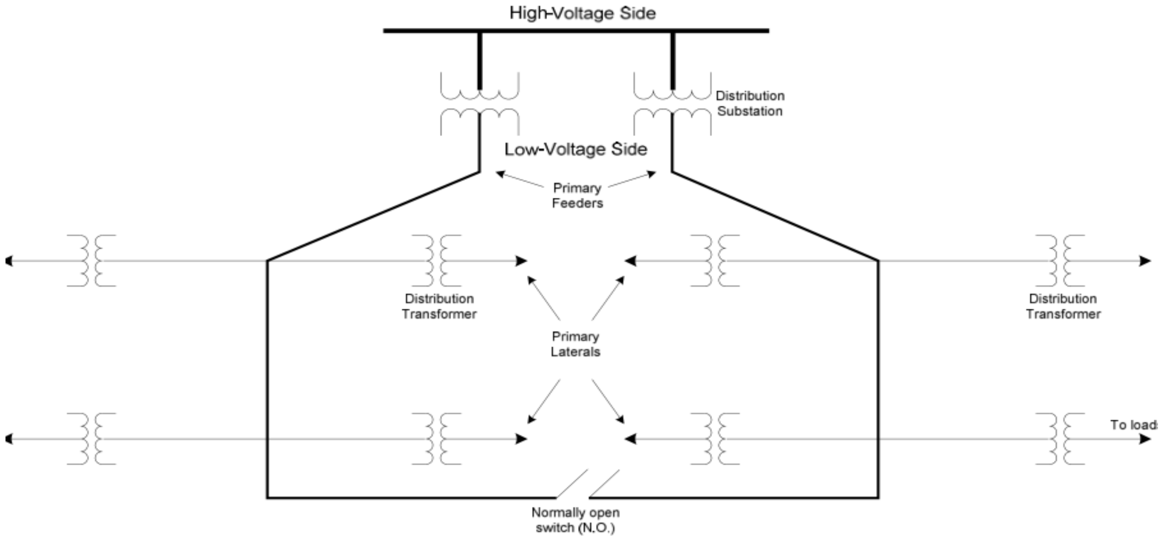

Figure 2.3 : Distribution System - Loop Configuration (Humayd, 2011)

2.2. Power System Losses

Electricity supply losses in power system consist of technical losses and non-technical losses. The non-technical losses are caused by actions external to the power systems such as inaccurate meter reading, non-payment of electricity bills, inaccurate estimation of no metered supplies, inefficiency in business and technology management systems. The technical losses occur in numerous small components in the distribution systems from the step-up transformers through all different stages until the consumer end (C. Daniel, 2005). Most losses are experienced during peak demand when all the resources are operating at maximum to match up with the power needed by the end user. As the load increases, the copper losses become more significant. The active power lost in the distribution system is mostly due to copper losses since these losses are a function of the square of current flowing through the line as shown in Equation 2.1.

$$P_{loss} = I^2R \qquad \text{Equation 2.1}$$

From the Equation 2.1, it is also noted that anything that changes resistance will affect the amount of power lost in the lines. The amount of real power and reactive power loading at the end of the line determines the magnitude of current in the line. The current flow will increase with more demand for power transmitted through the lines. Another determining factor for current flow is the operating voltage of the line. The apparent power in a radial system is given by Equation 2.2 from which high voltage will result in low current for the same apparent power.

$$\boldsymbol{S} = \boldsymbol{V}\,\boldsymbol{I} \qquad \text{Equation 2.2}$$

Unbalanced loading of the phases can also result in higher line losses. If one of the phases was heavily loaded than the others, the losses would be larger as compared to a balanced load case. The resistance of the line cannot be neglected since it plays a vital role in the line losses. Generally, a long line has higher resistance and larger losses compared to a short line with the same flow of current. Similarly, a small conductor will experience high losses as a result of high resistance than a large conductor.

2.3. Distribution Feeder Reconfiguration

Network reconfiguration is a common practice that performed by the utility to change the topology of the distribution system. The Distribution feeder Reconfiguration is the part of distribution automation. The reconfiguration is done at the time of service maintenance or service testing and that can also be done for balancing the load variation. The configuration of the radial distribution system can be changed by changing the status of sectionalizing switches and tie-switches.

Here the normally close sectionalizing switches are opened and same numbers of normally open tie-switches are closed. This is called reconfiguration. The tree shape of radial distribution is maintained in the new topological structure. This procedure can be said as the part of “Distribution Management”. Here, reconfiguration is done to obtain minimum loss path for the load feeding.

2.4. 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 center restores the service depending upon the priority of the customers.

2.5. 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.

2.6. Customer Feeding and Reliability Restoration

Customers of electricity are of mainly three types such as industrial, commercial and residential. On the priority basic the electrical system is chosen to supply at the time of outage to those 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, reconfiguration 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.

2.7. Effect of reconfiguration on Voltage Profile and Loss of the System

The reconfiguration process is done by closing and opening the switches that exist in each branch. However, searching process for optimal combination of opened/closed switches is a complicated task that needs to be done properly. As an alternative of loss reduction, the network reconfiguration also offers other advantages that can be leveraged by the distribution system. The listed several advantages of network reconfiguration in the distribution system, as listed here in:

i. Improve reliability of the distribution network.
ii. Restrain the distribution line from being overloaded.

iii. Improve the voltage profile at all network buses.
iv. Reduces the line loss due to overload distribution line.
v. Help to restore supply to the demands when fault occurred.

2.8. Power Flow Analysis in Distribution System

The power-flow analysis of a distribution feeder is similar to that of an interconnected transmission system (Kersting, 2013). The distribution networks because of the some of the following special features fall in the category of ill-condition (Rupa at al, 2014).

- Radial or weakly meshed networks,
- High R/X ratios,
- Multi- phase, unbalanced operation,
- Unbalanced distributed load and/or distributed generation,

Due to the above factors the Newton Raphson (N-R), Gauss Siedel (G-S) and other transmission system algorithms are failed with distribution network. Because a distribution feeder is radial, iterative techniques commonly used in transmission network power flow studies (Kersting, 2013). Instead, an iterative technique specifically designed for a radial system is used. The sweeping algorithm is iterative technique and has the advantages of less computation effort and calculation time compared to the N – R and G – S methods (Teng, 2014).

2.8.1. Backward / Forward Sweep Algorithm

The unique path from any given bus back to the source in RDS is the key feature exploited by the backward / forward sweep algorithm (Zimmerman, 1995). The sweep algorithm consists of two basic steps, backward sweep and forward sweep, which are repeated until convergence is achieved. The backward sweep is primarily a current or power flow summation with possible voltage updates. The forward sweep is primarily a voltage drop calculation with possible current or power flow updates (Zimmerman, 1995).

Table 2.1: Backward / Forward Sweep Method (Zimmerman, 1995)

Backward / Forward Sweep Algorithm	
Initialize all bus voltages	
1	Backward Sweep: Sum currents or power flows (and possibly update voltages)
2	Forward Sweep: Calculate voltage drops (and possibly update current/power
Repeat steps 1 and 2 until convergence is achieved	

In distribution system, the sweeping process includes different methods and are power summation method, current summation method, and admittance summation method (Teng, 2014).

2.8.2. Power Summation Method

The sweep algorithm using power summation method (al, 2014) is described in detail. The single line diagram of radial distribution network is shown in Figure 2.4.Considering the active power (P_k) and reactive power (Q_k) that flows through branch from node 'k' to node 'k+1'.

Initially, a flat voltage profile is assumed at all nodes i.e., 1.0 pu.

Backward Sweep

The power flows through each branch is calculated in backward direction from last node and is given as Equation 2.3

$$P_k = P'_{k+1} + r_k \frac{\left(P'^2_{k+1} + Q'^2_{k+1}\right)}{V^2_{k+1}}$$

Equation 2.3

where,

$$P'_{k+1} = P_{k+1} + P_{Lk+1}$$

$$Q'_{k+1} = Q_{k+1} + Q_{Lk+1}$$

P_{k+1} and Q_{k+1} are the effective real and reactive power flows from node 'k+1' and P_{Lk+1} and Q_{Lk+1} are loads that are connected at node 'k+1'.

Forward Sweep

The voltage magnitude and angle at each node are updated in forward direction using equation Equation 2.4.

$$V_{k+1}=V_k-Z_kI_k \quad \text{Equation 2.4}$$

where,

I_k is the current flows through branch and Z_k is the impedance of branch connected from node 'k' to node 'k+1'.

The backward and forward sweep equations are calculated iteratively until it converges.

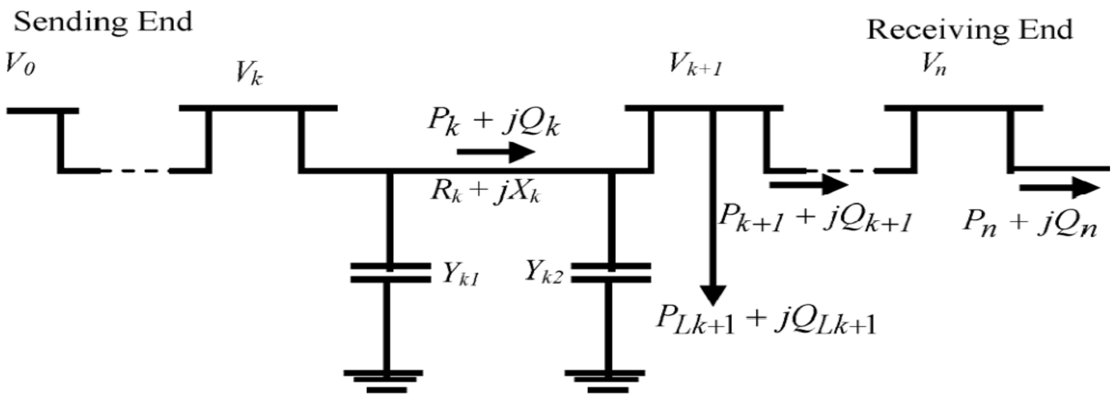

Figure 2.4 : Single line diagram of radial distribution network

Given the voltage of the root bus and an initial voltage guess of other buses, the algorithm takes three steps for each iteration (Teng, 2014):

Step 1: Nodal current calculation:

The current injection at each node '*i*' is calculated using Equation 2.5.

$$I_i^{(k)} = \left(\frac{S_i}{V_i^{(k)}}\right)^* - y_iV_i^{k-1} \quad \text{Equation 2.5}$$

Where,

i = 1, 2, 3, ……., n.

S_i is the power at node i. V_i is the voltage at node I and y_i is the shunt admittance at node i.

Step 2: Backward sweep:

Starting from the last ordered branch, current flow J_l in branch l is calculated using Equation 2.6.

$$J_l^{(k)} = -I_{lr} + \sum J_{lr} \qquad \text{Equation 2.6}$$

Where,

$l = b, b\text{-}1, \ldots\ldots, 1.$

I_{lr} is the current injection of node lr calculated from step 1, $\sum J_r$ is the currents in branches emanating from node lr.

Step 3: Forward Sweep:

Starting from the root bus, the node voltages are updated using Equation 2.7

$$V_{lr}^{(k)} = V_{ls}^{(k)} - Z_l J_l^{(k)} \qquad \text{Equation 2.7}$$

Where,

$l = 1, 2, \ldots\ldots., b.$

ls and lr denote the sending and receiving end of branch l, Z_l is the series impedance of branch l.

2.9. Methods of Network Reconfiguration with Optimization Techniques

There are two types of switches used in network reconfiguration which are sectionalizing switches (normally closed) and tie switches (normally open). Those switches are used for protection and configuration management. The network topology of the distribution system is changed by altering the switch status (open/closed). Figure 2.5 shows an example of a distribution network which makes a comprehensible explanation of the operation of switches. The dashed lines 3, 8 and 12 show branches of the network which are normally open tie-switches and the other continuous lines represent branches which are normally closed sectionalizing switches.

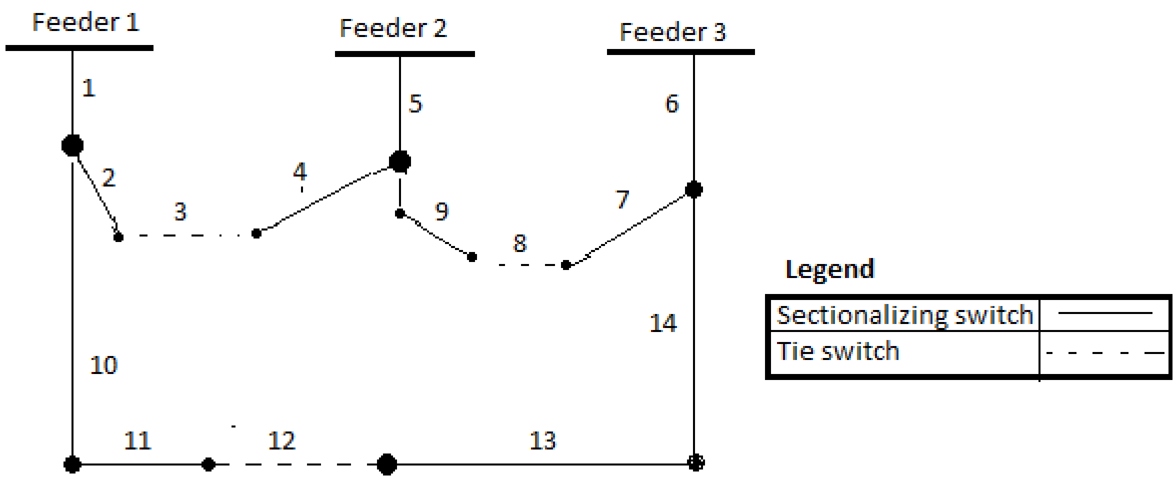

Figure 2.5 : Single line diagram for feeder connections system

During feeder reconfiguration, a tie-switch may be closed to transfer loads to different feeders and a sectionalizing switch will be open to maintain the radial structure of the system. Different methods have been developed for the reconfiguration of the distribution network with some of the studies including single- and multi-objective functions with

2.10. Optimization Techniques

Over the years, in order to solve the problem, many traditional and mathematical methods are studied. These methods include (Luo, Cui, & Yang, 2011) branch exchange algorithm (BEA), optimal flow pattern (OPF) algorithm, mathematical optimization theory algorithm and artificial intelligent (AI) algorithm. Among them, artificial intelligent algorithm is widely used in distribution network reconfiguration in recently years, such as artificial neural network (ANN), genetic algorithm (GA), simulated annealing algorithm (SA), ant colony Optimization (ACO) and particle swarm optimization (PSO). The different approaches for optimization of distributed generation in distribution systems are presented in this section.

2.10.1. Analytical Method

This method is classical method previously used for optimization of DG unit. If only a given demand-generation snapshot scenario is taken into account, a specific technical aspect (or objective function) can be formulated analytically in such a way that it is possible to find the most beneficial DG unit capacity (Keane, 2012). This type of analysis, focusing particularly on real power losses, was used in (Acharya, Mahat, &

Mithulananthan, 2006). However, while power losses can be studied in passive networks considering peak load scenarios as is traditionally done distribution networks with DG plants require the assessment of energy losses. The incorporation of operational solutions such as coordinated voltage control or generation curtailment cannot be done either. Consequently, although analytical approaches are straightforward alternatives to assess DG unit siting and sizing, care must be taken as the results are only indicative and scenario limited (Keane, 2012). The limitation of this process is that single DG unit can only be evaluated at a time.

2.10.2. Exhaustive Method

A single technical issue, such as voltage rise or power losses, can also be approached by exhaustively exploring the entire (or most of the) search space corresponding to the locations and sizes of DG plants that could be connected to a distribution network (Keane, 2012). However, the actual benefit brought by exhaustive analyses is that it is possible to cater for a number of technical issues and constraints. Indeed, with this more direct approach the objective function can be the combination of parameters or indices that represent different technical and non-technical aspects, although it will be very time consuming (Keane, 2012).

2.10.3. Linear Programming (LP) Method

Linear programming (LP) has also been employed to address the capacity allocation and energy optimization issues. Fundamentally, the use of linear programming entails a linearization of the power flow or the linearization of the results from an ac power flow. It has been demonstrated through simulation that the resulting approximation inevitably introduces an error, but not a significant one in the context of discrete turbine sizes (Keane, 2012). A linear programming formulation of optimal power flow (OPF) is employed to assess the control of multiple DG plants. The objective employed is to minimize the annual active generation curtailment cost. Ac power flow is employed to calculate linearized sensitivity factors. The sensitivities are employed to characterize a range of constraints, such as voltage, thermal and short circuit limits. The method is formulated as a linear program and solved with the objective of maximizing the capacity of DG, subject to typical network constraints and taking account of N-1 configurations (Mahmoud, Yorino, & Ahmed, 2016) (Dent, 2010) An advantage of

LP is that it offers significant potential for development of operational methods and is a robust optimization method (Keane, 2012).

2.10.4. AC Optimal Power Flow (OPF) Method

The ac OPF (Dent, 2010) is used to widely acknowledge by the electric industry for powerful optimization tool. The ac OPF is a nonlinear programming (NLP) problem, for which many solution methods exist including some which are highly specialized to OPF problems. The ac OPF formulation can be adapted to have different objectives and constraints according to the study being carried out (Keane, 2012). A number of solution methods can be adopted to solve the ac OPF problem: from special linear programming formulations to branch and bound techniques. Commercial solvers specialized for NLP problems include CONOPT, that uses a generalized reduced gradient, and, KNITRO, that uses interior points. Although no practical method exists which can guarantee to find the global optimum of a non-convex NLP, local optima can be found in most cases (Keane, 2012).

2.10.5. Metaheuristics Method

A metaheuristic method is defined as an iterative generation process which guides a subordinate heuristic by combining intelligently different concepts for exploring and exploiting the search space. Learning strategies are used to structure information in order to efficiently find near-optimal solutions (Keane, 2012). There are numerous metaheuristic algorithms: ant colony optimization (ACO), artificial bee colony optimization (ABC), tabu search (TS), particle swarm optimization (PSO), simulated annealing (SA) including genetic algorithms (GA). All these algorithms have been used to solve the problem of optimal allocation of DG (Keane, 2012) (Dent, 2010) and the PSO method is described in detail.

Artificial ants in ACO algorithm can be seen as probabilistic construction of heuristics that generate solutions iteratively by taking into account of accumulated past search experience: pheromone trails and heuristic information on the instance under solution (Lessing, Dumitrescu, & Stutzle, 2004)

ACO and ABC are based on the dynamic of the social insect population. The interactions are executed via multitude of various chemical and/or physical signals (e.g., bee dancing during the food procurement, ants’ pheromone secretion, and performance of specific acts, which signal the other insects to start the same actions). The final product of different actions and interactions represents the behavior of social insect colony. ABC algorithms has been used for determining the optimal DG-unit's size, power factor, and location in order to minimize the total system real power loss (Abu-mouti, 2011).

TS is a metaheuristic that guides a heuristic method to expand its search beyond local optimality, with the systematic prohibition of some solutions to prevent cycling and to avoid the risk of being trapped in local minima. New solutions are searched in the set of the points reachable with a suitable sequence of local perturbations (neighborhood). One of the most important features of TS is that a new configuration may be accepted even if the value of the objective function is greater than that of the current solution. To prevent cycling, some moves are marked "tabu" for a number of iterations; the length of the tabu list, the tabu-tenure, fixed or variable, guides the optimization (Keane, 2012).

The SA is an algorithm that combines combinatorial search with a very simple metaheuristic that follows the cooling process of materials. Following an appropriate cooling schedule, the SA has the potential to avoid local minima and converges to the global minimum in a reasonable computing time. The parameters to tune are the annealing temperature, the number of iterations at constant temperature and the cooling strategy. SA annealing has been used for multi-objective optimization to minimize energy losses, polluting emissions and contingencies (Keane, 2012).

Genetic Algorithm (GA) is the process of evolution. The most promising individuals have greater chances of transmitting their genes to offspring. By so doing, the population, generation by generation, improves and, if the premature convergence is avoided, for instance, with a random mutation, the algorithm converges. The reason of the success is that GA is intrinsically suited to solve location problems. The coding of a solution can be very simple, a binary vector with as many positions as the number of bus candidate to SESW and tie switches connection. The classical GA operators (selection, crossover and mutation) can be used simply and effectively with few or no changes. As in many metaheuristic algorithms, high values of penalty factors can be added to the fitness function of those individuals that do not comply with the constraints (Keane, 2012).

PSO makes use of a velocity vector to update the current position of each particle in the swarm. The position of each particle is updated based on the social behavior that a population of individuals, the swarm in the case of PSO, adapts to its environment by returning to promising regions that were previously discovered (Keane, 2012). The particle swarm optimization concept consists of, at each time step, changing the velocity (accelerating) each particle toward its *pbest* and *gbest* locations (global version of PSO). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward *pbest* and *gbest* locations (Eberhart & Shi, 2001). The process for implementing the global version of PSO is as follows (Eberhart & Shi, 2001):

i. Initialize a population (array) of particles with random positions and velocities on d dimensions in the problem space.
ii. For each particle, evaluate the desired optimization fitness function in the variables.
iii. Compare particle's fitness evaluation with particle's *pbest*. If current value is better than *pbest*, then set *pbest* value equal to the current value, and the *pbest* location equal to the current location in d-dimensional space.
iv. Compare fitness evaluation with the population's overall previous best. If current value is better than *gbest*, then reset *gbest* to the current particle's array index and value.
v. Change the velocity and position of the particle according to Equation 2.8 and Equation 2.9 respectively.

$$v_{id} = w * v_{id} + c_1 * rand() * (p_{id} - x_{id}) + c_2 * rand() * \left(p_{gd} - x_{id}\right) \qquad \text{Equation 2.8}$$

$$x_{id} = (x_{id} + v_{id}) \qquad \text{Equation 2.9}$$

The acceleration constants c_1 and c_2 in Equation 2.8 represent the weighting of the stochastic acceleration terms that pull each particle towards *pbest* and *gbest* positions. Therefore, adjustment of these constants changes the amount of "tension" in the system. Low values allow particles to roam far from target regions before being tugged back, while high values result in abrupt movement toward, or past, target regions.

vi. Loop to step ii) until a criterion is met, usually a sufficiently good fitness or a maximum number of iterations (generations).

2.10.6. Genetic Algorithm

The genetic algorithm (GA) is an optimization and search technique based on the principles of genetics and natural selection. A GA allows a population composed of many individuals to evolve under specified selection rules to a state that maximizes the “fitness” (i.e., minimizes the cost function).

The characteristics of genetic algorithms make them particularly suited to ill-structured optimization problems. Based upon the mechanics of natural selection and natural genetics, the GA combines the evolutionary process with functional optimization. The coded discrete information of artificial strings used by the GA lends itself favorably to the binary status of switches in the distribution reconfiguration problem. An interesting feature of the GA is that it searches from a population of points and not from a particular search point, so that there is the possibility of obtaining an optimal solution very rapidly.

The features of GA algorithms are:

1. GAs work with a coding of the parameters set, not the parameters themselves. Therefore GAs can easily handle the integer or discrete variables.

2. GAs search with in a population of points, not a single point. Therefore GAs can provide a globally optimal solution.

3. GAs use only objective function information, not derivatives or other auxiliary knowledge. Therefore GAs can deal with non-smooth, non-continuous and non-differentiable functions which are actually exist in a practical optimization problem.

4. GAs use probabilistic transition rules, not deterministic rules. We use GAs because the features of GA are different from the other search techniques in several aspects, such as:

5. The algorithm is a multipath that searches many peaks in parallel and hence reducing the possibility of local minimum trapping.

6. GA works with a coding of parameters instead of the parameter will help the genetic operator to evolve the current state into next state with minimum computations.

Advantages of Genetic Algorithm Advantages:

• GAs can handle the integer or discrete variables well

• GAs can provide a globally optimum solution as it can avoid the trap of local optima

• GAs can deal with the non-smooth, non-continuous, non-convex and non-differentiable functions which actually exist in practical optimization problems.

• GAs have the potential to find solutions in many areas of search space simultaneously, there by multiple objectives can be achieved in single run.

• GAs are adaptable to change, ability to generate large number of solutions and rapid convergence.

• GAs can be easily coded to work on parallel computers.

Genetic Algorithms: Natural Selection

Genetic Algorithms (GA) are direct, parallel, stochastic method for global search and optimization, which imitates the evolution of the living beings, described by Charles Darwin. GA are part of the group of Evolutionary Algorithms (EA). The evolutionary algorithms use the three main principles of the natural evolution: reproduction, natural selection and diversity of the species, maintained by the differences of each generation with the previous.

Selection Process

In the nature, the selection of individuals is performed by survival of the fittest. The more one individual is adapted to the environment - the bigger are its chances to survive and create an offspring and thus transfer its genes to the next population.

In EA the selection of the best individuals is based on an evaluation of fitness function or fitness functions. Examples for such fitness function are the sum of the square error between the wanted system response and the real one; the distance of the poles of the closed loop system to the desired poles, etc. If the optimization problem is a minimization one, than individuals with small value of the fitness function will have bigger chances for recombination and respectively for generating offspring.

CHAPTER THREE: METHODOLOGY

3.1. Research Framework

This chapter shows the fundamental information and applications of the proposed sweep algorithm and Genetic algorithm (GA) in radial distribution network reconfiguration. The load flow analysis is performed on the multi-feeder Pulchowk DSC having 142 bus in total, existed in the radial type under different scenarios.

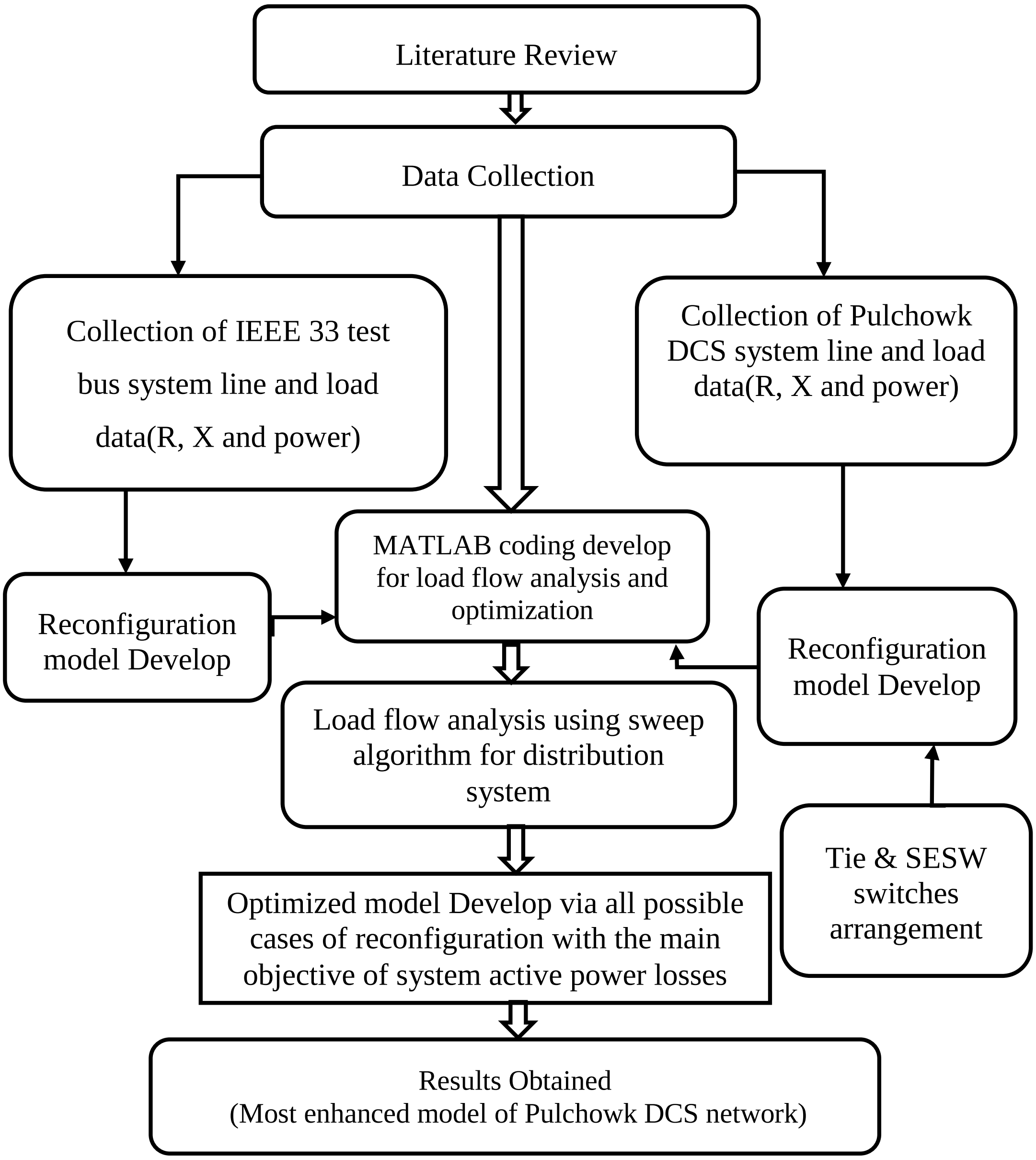

Figure 3.1: Research Framework flowchart

The successful planning for integration of switches in radial feeder reconfiguration of distribution system must be covered by all of the static and dynamic analysis on technical and economic aspects. Configuration should be optimized to obtain the minimum loss under a given constraint of technical, environmental and economic aspects. In this study, technical aspects such as; voltage stability, marginal improvement of voltage and network minimum loss are considered for optimal reconfiguration of existing network, and the environmental and economic aspects are considered to be out of limit in this study. This study use iterative techniques of sweeping process to conduct load flow analysis and optimization approach through GA. The details of proposed methodology are described herein

3.2. Data collection

Data collections regarding the reconfiguration of power distribution system network as: IEEE 33 test bus system and the existing structural data of distribution network of Pulchowk DCS Lalitpur; Nepal.

3.3. IEEE 33-Bus Test radial distribution network

The study used an IEEE 33-bus test RDS which comprises of 33 buses with 32 lines and some dotted tie switches has been modeled and simulated in MATLAB. The first bus in the system is taken as the substation which supplies power to all of the buses, connected with fixed loads as depicted in Figure 3.2. Being a radial network, configurations are carried out by manipulating the tie switches and sectionalizing switches in the feeder system. Distribution networks are usually built as interconnected networks, while in operation they are arranged into a radial tree-like structure.

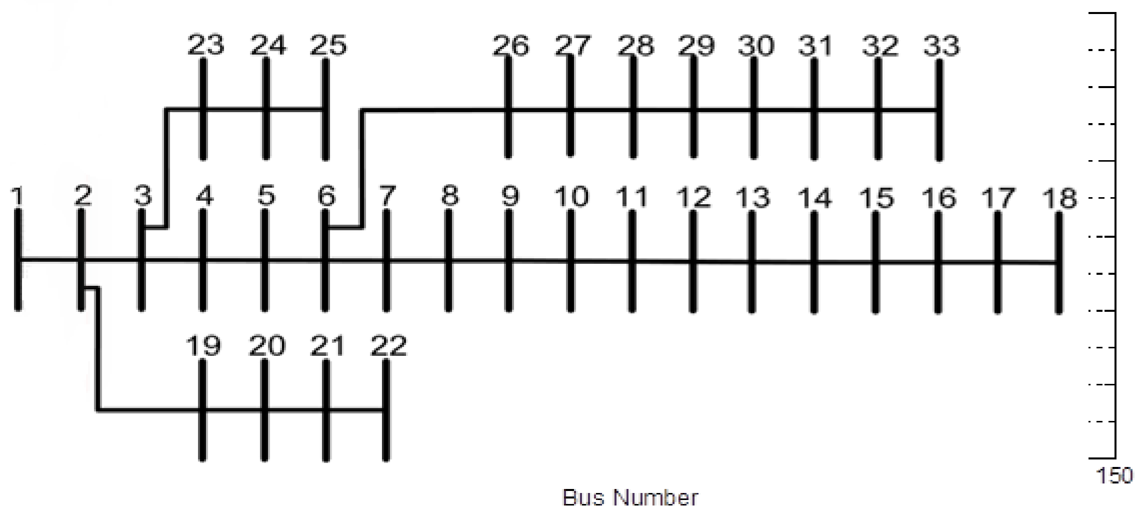

Figure 3.2: IEE 33 test Bus system of RDS.

The distribution systems are divided into subsystems of radial feeders, which contain a number of normally closed switches and normally open switches. Initially, the open line switches before reconfiguration are 33, 34, 35, 36 and 37. The total load of the system is considered to be 3715 kW and 2300 kVAR. In this system, the reference bus is taken as 1st one with 1 pu of bus voltage. The standard line data and load data of the network is tabulated in Appendix A.

3.4. Reconfiguration IEEE 33 test Bus network

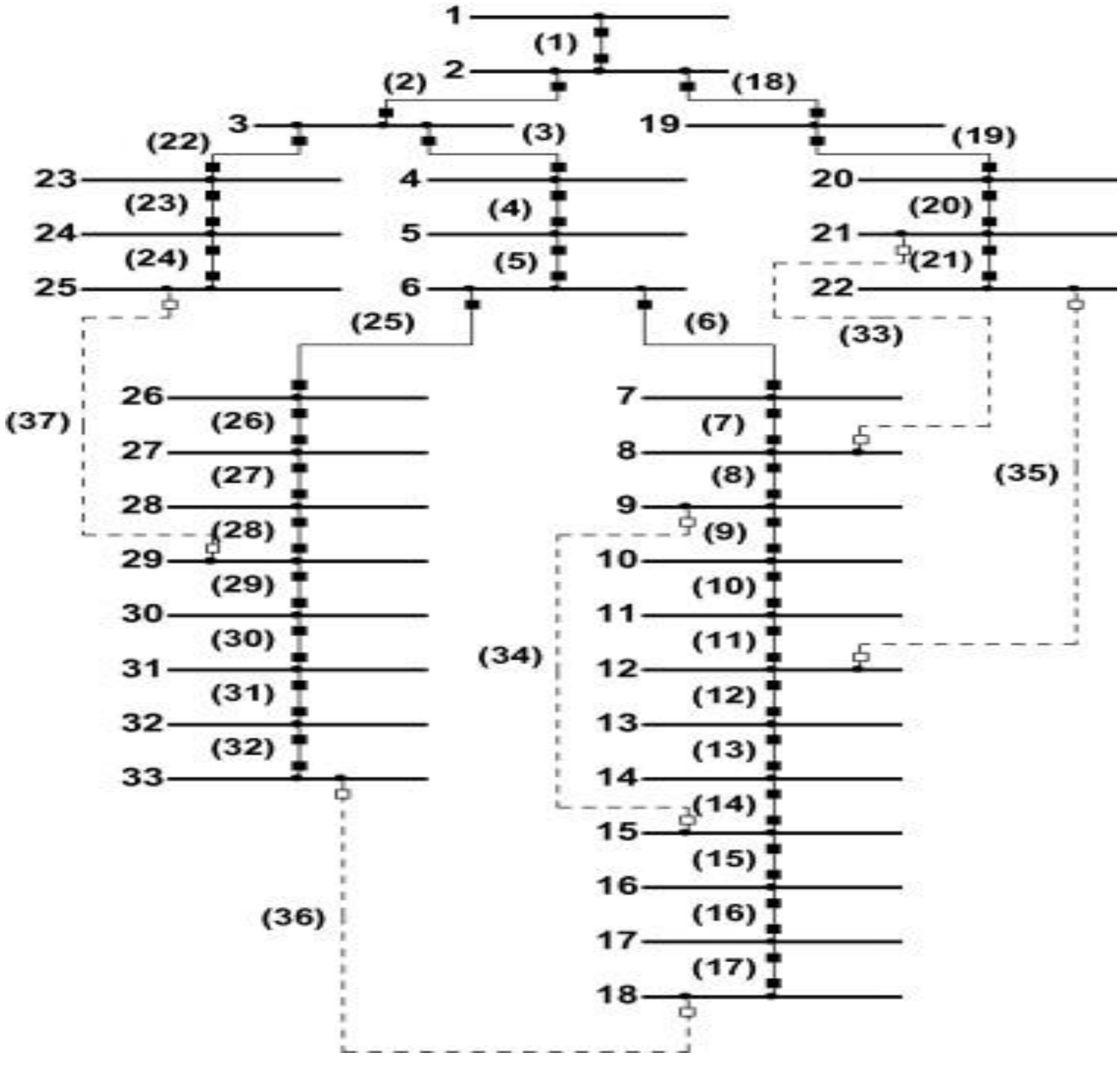

Figure 3.3: IEEE 33 Bus test system with different case of reconfigured

In the Figure 3.3, IEEE 33 Bus standard system is configured in different possible cases. The configuration has been done through tie-switches and sectionalizing switches. The tie-switches is used to connect bus between different radial line, as shown by dotted lines and the sectionalizing switches is used to connect the section part between two conjugative bus as shown in Figure 3.2. There are 32 possible sectionalizing switches in 33 bus system:

Base Case: No any Dotted line of above single line diagram of IEEE 33 bus system which result is explained in above section

Case 1: 34 dotted line connected the bus 9 to the bus 15 and bus 15 is disconnected form bus 14 and hence analysis power has been taken similarly to the base case and result is save to compared for optimization. And the similarly other cases are study.

Case 2: 37 dotted line connected the bus 9 to the bus 15 and bus 15 is disconnected form bus 14 and hence analysis power has been taken similarly to the base case and result is save to compared for optimization.

Table 3.1: IEEE 33 bus of different possible condition

Test case	**Tie-line connected**	**Test case**	**Tie-line connected**	**Test case**	**Tie-line connected**
base case	No any	6	34,33	11	34,37,33
1	34	7	34,35	12	34,37,35
2	37	8	37,33	13	37,33,35
3	33	9	37,35	14	33,35,34
4	35	10	33,35	15	34,37,33,35
5	34,37				

After 15 possible case of configuration the best case and its comparison with base case line loss data is calculated using sweep algorithm Equation 2.3 and the optimized module is found using Genetic Algorithm(GA).

3.5. Pulchowk DCS 142 bus multi feeder Radial Network Distribution System

In this study, the proposed case of Pulchowk DCS having 142 buses, 141 lines and 9 different feeder start from substation. The total line length of 11kv line of this area is about 65.17 kilo meter.

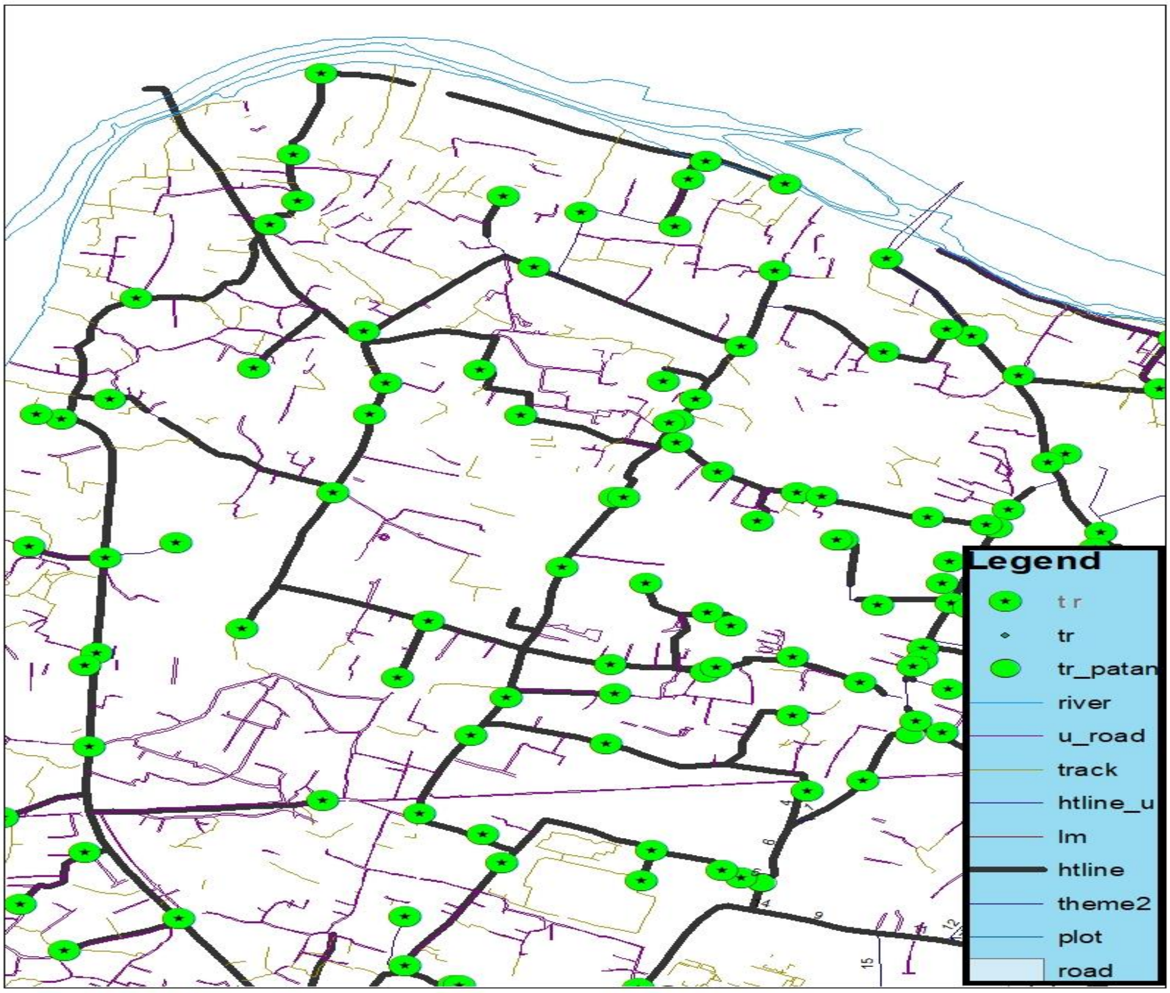

Figure 3.4 : Sectional part of GIS line and load center of Pulchowk DCS network.

The existing structures of the network consisting 9 feeder of line are radially operated. The interconnection may have possible by allocating tic-switches near about possible area of existing line.

3.6. Reconfiguration of 142 bus multi feeder system of Pulchowk DCS network

The methodology is applied to the Pulchowk distribution center of 9 different feeder of total 142 bus distribution to re-configure and to improve the voltage of system with minimized power loss and also to fine the enhance best possible configuration of this distribution system. The possible configuration is done

- Forecast possible tie-switches allocation to be closed.
- Forecast switches (SESW) to be opened.
- Find available tie-lines allocation to remove shadow (tie-line with only one end connected to one of the shadow nodes).
- Select first available tie-line.
- Prepare modified line date connecting selected tie-line.
- Load flow using backward / forward sweep method for the prepared module.

In this chapter, the base cases of the system is studied using forward / backward sweep load flow method and then reconfigured with different possible case of configuration with improved voltage profile and reduce power loss in each case. Then compared these possible cases and hence best module of distribution system has been found. The enhanced module is recommended to the most sensitive system which provides minimum power loss under voltage limits. The Possible reconfiguration set has been develop on the basis of topologically possible allocation of switching. The switching in different section with sectionalizing switches and tie switches set allocating that can able to restructure the existing distribution system for the research objective requirement.

Table 3.2 : Possible set of reconfiguration of 142 bus system of Pulchowk DCS Network

Case no.	Tie-switches connect between the buses9(from -to)	SESW Switches open between the bus section	Number of Tie-switches connected
Base case	No any branch interchanged	All closed	0
1	19-25	24-25	1
2	10-52	51-52	1
3	1-67	66-67	1
4	1-38	37-38	1
5	4-39	38-39	1
6	2-25,3-39,3-72,4-94,3-117,6-134	24-25,38-39,71-72,93-94,116-117,133-134	6
7	2-10,15-25,5-36,8-45	9-10,24-25,35-36,44-45	4
8	3-14,2-25,13-40,3-72,4-94,3-117,6-134	13-14,24-25,39-40,71-72,93-94,116-117,133-134	7
9	3-14,13-25,11-40,35-57,24-72,37-94,68-117,108-134	13-14,24-25,39-40,56-57,71-72,93-94,116-117,133-134	8
10	13-25,12-39,38-56,24-72,38-92,55-108,70-119,105-137	24-25,38-39,55-56,71-72,91-92,107-108,118-119,136-137	8
11	4-13,13-25,12-39,38-56,24-72,38-92,55-108,70-119, 105-137	12-13,24-25,38-39,55-56,71-72,91-92,107-108,118-119, 136-137	9
12	4-16,13-25,12-39,38-56,8-66,24-72,64-84,38-92,53-107, 67-119,110-131,105-137	15-16,24-25,38-39,55-56,65-66,71-72,83-84,91-92,106-107, 118-119,130-131,136-137	12
13	4-16,13-25,12-39,38-56,24-72,64-84,38-92,53-108, 67-119,110-131,105-137	15-16,24-25,38-39,55-56,71-72,83-84,91-92,107-108, 118-119,130-131,136-137	11

In this research, set the switching location in different possible location and then arrange those switches in optimal way with respect of power losses minimization and voltage profile of system improvement. The possible set of arrangement of switches for making new structure of distribution system has been developed as tabulated in Table 3.2.

In the Table 3.2, the possible set of reconfiguration with switching arrangement are shown. The arrangement of the set switching are selected on the basic of topological location of each bus with possible location and set the switching position between the separate feeders as topologically arrangement possible location. The tapping of the line is done between the different feeders through dog conductor.

3.7. General Procedure for Optimum Reconfiguration using Genetic Algorithm

First all of, the system inputs are taken and entered to the developed model in MATLAB, for the numerous operating cases, and then the optimum configurations have been evaluated using corresponding model. To complete the reconfiguration analysis following procedures have been adopted:

1. Start

2. Data Collection: load variation, distribution line parameters, and equality and inequality constraints (voltage limits, distribution line flow limits etc.) of the test system.
3. Perform Load flow using backward / forward sweep method.
4. Save all the results.
5. Initialize G.A. tools.
6. Forecast switches (s/ws) to be opened using G.A.
7. Initialize base configuration (for each cases).
8. Select first switch to be opened.
9. Analysis of the obtained results.
    a. Find all the nodes in shadow.
    b. Find available tie-lines to remove shadow (tie-line with only one end connected to one of the shadow nodes).
    c. Select first available tie-line.
    d. Prepare modified line date connecting selected tie-line.
    e. Load flow using backward / forward sweep method.
    f. Save the results as well as the modified tie-line data and parameters, with if the parameters is considerable than previously saved one.
    g. Is any other available tie-line left? If yes select next available tie-line and go to step (b) otherwise go to step h.
    h. Is any other forecasted switch left? If yes select next forecasted s/w and go to step (i) otherwise go to step 10.
10. Is the G.A. constrains justified? If yes go to step 11. Otherwise go to step 6.
11. Display result.
12. Stop

3.8. Detail Procedure with flow chart for system power loss calculation

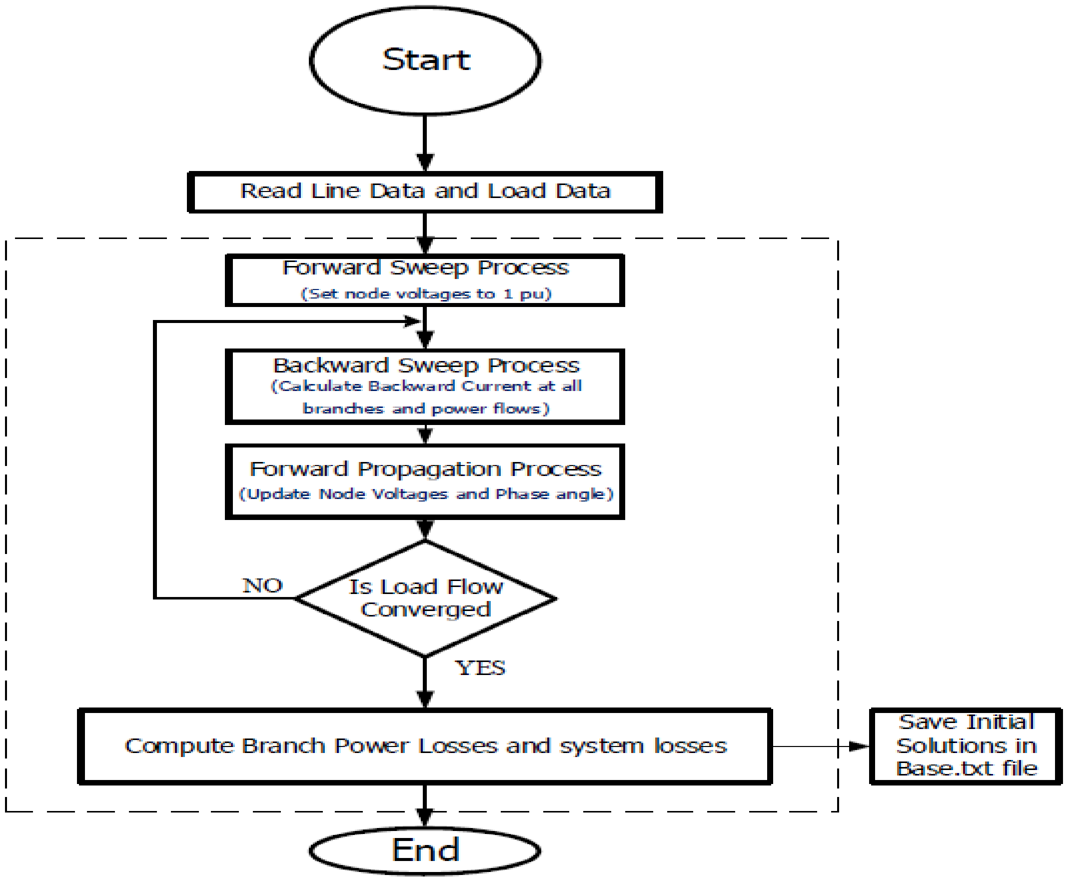

Figure 3.5: Flow chart of base case power loss and system loss computation

The complete methodology for analysis and planning of reconfiguration in radial distribution system is represented as flow chart in Figure 3.4. The technical analysis performed for RDS insights into the weakness and strengths of the system with power losses in each buses and the voltage of specified buses. Hence, the integration planning process becomes decisive for the outcomes.

The proposed methodology starts with the input of line data and bus data of the RDS. The voltage of each buses of network is set to 1.00 pu, and then the branch currents are calculated via backward sweep propagation using Equation 2.5 & Equation 2.6. The magnitude of voltage and phase angle are updated by using Equation 2.7 in forward sweep propagation. The backward and forward sweep propagation is iteratively continued until the convergence criteria meet. In the proposed methodology, convergence criterion is to iterate the backward and forward sweep propagation for 100 iterations. The updated voltages and currents with the computed power losses are taken for base condition values for the RDS network without reconfiguration.

3.9. Line loss Calculation

The technical analysis performed for RDS insights into the weakness and strengths of the system with power losses in each buses, and respective bus voltage and hence the integration planning process becomes decisive for the outcomes. The above power loss calculation methodology can be explained by those steps as

Step1: Starts with the input of line data and bus data of the RDS;

Step2: The voltage of each buses of network is set to 1.00 pu;

Step3: Backward sweep propagation using Equation 2.5 and Equation 2.6, the branch currents are calculated;

Step4: The magnitude of voltage and phase angle is updated using Equation 2.7, in forward sweep propagation;

Step5: Backward and forward sweep propagation is iteratively continued until the convergence criteria are met;

Step6: Computed power losses by updated voltage and current after iteratively converged value;

Step7: Finally Computed power losses and voltage level are saved initial solutions in Base.txt file;

Step8: End the calculation.

The proposed methodology starts with the input of line data and bus data of the RDS. The voltage of each buses of network is set to 1.00 pu and then the branch currents are calculated by backward sweep propagation using Equation 2.5 and Equation 2.6. The magnitude of voltage and phase angle is updated using Equation 2.7 in forward sweep propagation. The backward and forward sweep propagation is iteratively continued until the convergence criteria are met. In the proposed methodology, convergence criterion is to iterate the backward and forward sweep propagation for 100 iterations. The updated voltages and currents with the computed power losses are taken for base condition values for the RDS network without reconfiguration. The computed power losses and voltage level are saved initial solutions in Base.txt file. In this thesis, IEEE

33 test bus RDS line parameter and line data tabulated shown in Appendices A here in. Then also used the Pulchowk DCS data to find the existing status of the system.

3.10. Reconfiguration of existing distribution network

There are normally two types of switches used in network reconfiguration which are sectionalizing switches (normally closed) and tie switches (normally open).

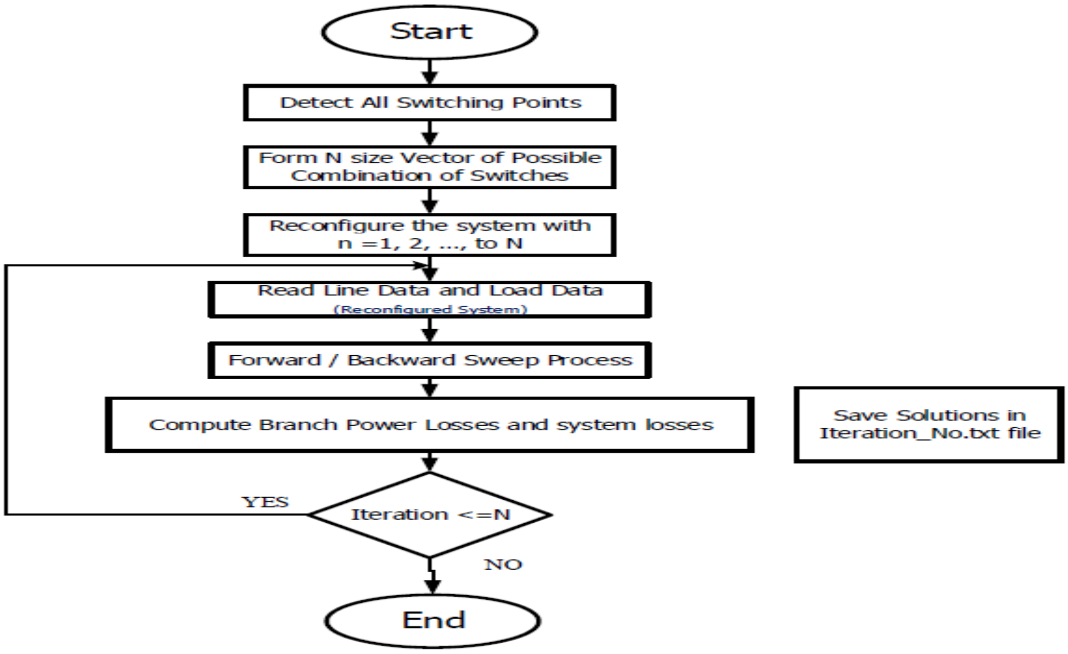

Figure 3.6: Load flow chart for reconfiguration model analysis

In this methodology, this process started after the base case power loss and system voltage, this process starts with detecting all the switching (sectionalizing switches and tie-switches) points for the radial feeder system (RDS).Then make the N size of vector of possible combination of switches to make reconfiguration system of the different option of radial feeders. After that read the line data and load data of reconfigured system then similarly forward/Backward sweep process is applied to calculate branch power losses and system losses and save the solutions in iteration No.txt file of each branch, and then iteration is repeated for N times.

3.11. Enhanced reconfigured model selection

From the above base case and possible reconfiguration of save data of N set of switching point vector of different reconfiguration feeders. From the N set of solutions in Iteration.txt file are compared with the Base.txt file. The rank has been reconfigured the system according to maximum loss reduction pattern, and then finally identified the optimized solution from them N reconfigured option of distribution System.

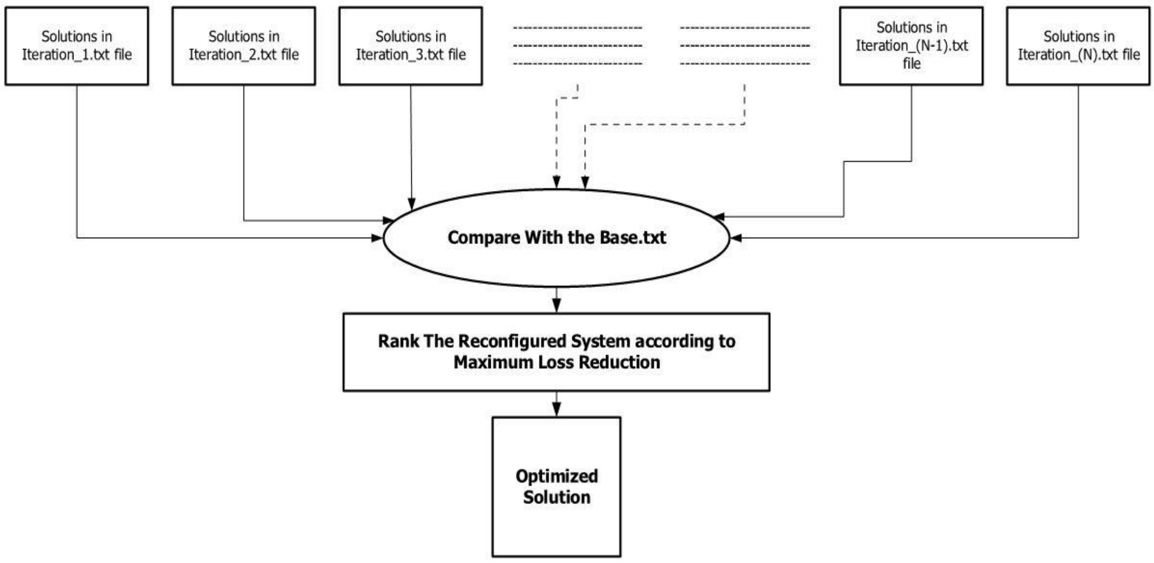

Figure 3.7: flow chart for ranking the Reconfigured system according to maximum loss reduction.

The voltage regulation limit in Equation (3.1) is considered from rule 40 of Electricity Rules, 2050 (1993) (NEA, "Electricity Rules , 2050 ") and IEEE standard (IEEE, 1993).

$$0.95\ pu \leq \ V_{bus} \leq 1.05\ pu$$ Equation 3.1

The objective function or fitness function of proposed methodology is to minimize the total active power loss under given constraints and conditions. The objective function is the sum of total losses of the RDS and is given in Equation 3.2. The power loss (P_{loss}) of the branch is evaluated from branch current (I) and branch resistance (R) as $P_{loss} = I^2R$.

$$Fitness\ function = \sum_{i=1}^{total} P_{i,loss}$$ Equation 3.2

The fitness function is evaluated for each particle of population and after the initialization of personal best (*Pbest*) and global best (*Gbest*), the position and velocity of a particle is updated using given Equation 3.3 and Equation 3.4 and then *Pbest* and *Gbest* are updated.

$$v_{id} = w \times v_{id} + c_1 * rand() * (p_{id} - x_{id}) + c_2 * rand() * \left(p_{gd} - x_{id}\right)$$ Equation 3.3

$$x_{id} = (x_{id} + v_{id})$$ Equation 3.4

$$w = w_{max} - \frac{w_{max} - w_{min}}{Maximum\ Iteration} \times Iteration\ No.$$ Equation 3.5

The optimized solution is evaluated after number of iterations defined. In this thesis, number of iteration is defined 1000 and the inertia weight (w) is varied for each iteration using Equation 3.5.5 The inertia weight has maximum and minimum value of 0.4 and 0.9 respectively (IEEE, 1993). The optimal solution gives the minimum loss under subjected constraints, position of sectionalizing switches and tie-switches with its' operation and individual bus voltages and losses.

3.12. Capital Budgeting Decisions

➢ **Payback period**

The payback period is the most basic and simple decision tool for the capital investment. (Stamalevi, 2015) Defined payback period as the period, usually expressed in years which it takes for the project's net cash inflows to recover the original investment. The usual decisions rule is to accept the project with the shortest payback period. Payback method does not measure overall project worth because it does not consider cash flows after the payback period. According to Stamalevi (2015) payback period provides only a crude measure of the timing of project cash flows. The payback period is probably best served when dealing with small and simple investment projects. The author observed that the simplicity of payback period method should not be interpreted as ineffective. If the business is generating healthy levels of cash flow that allow a project to recoup its investment in a few short years, the payback period can be a highly effective and efficient way to evaluate a project. It is the time in which the initial outlay of an investment is expected to be recovered through the cash inflows generated by the investment.

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Net Cash Flow per Period}}$$

Here, it uses two other figures in this calculation – the PV or Present Value and the CF or Cash Flow. It begins from the first year as the starting point.

It needs to specify a set discount rate for the calculation. This can be worked out in the following way:

$$\text{Net Present Value (NPV) / Discounted Cash Flow (DCF)} = \frac{\text{Actual Cash Flow}}{[1+i]^{n}}$$

i- the discount rate used.

Where discount rate is taken as 8% for social sectors and Governments Originations (NRB, 2018)

n - the time period relating to the cash inflows.

Discounted Payback Period (DPP) = A + B/C

Where A = is the last time period where the cumulative discounted cash flow (CCF) was negative

B = is the absolute value of the CCF at the end of that period A

C = is the value of the DCF in the next period after A.

- **Decision analysis for payback period**

If the longer will be the payback period of a project, the higher will be the risk. Between mutually exclusive projects having similar return, the decision should be to invest in the project having the shortest payback period.

When deciding whether to invest in a project or when comparing projects having different returns, a decision based on payback period is relatively complex. The decision whether to accept or reject a project based on its payback period depends upon the risk appetite of the management.

Management will set an acceptable payback period for individual investments based on whether the management is risk averse or risk taking. This target may be different for different projects because higher risk corresponds with higher return thus longer payback period being acceptable for profitable projects. For lower return projects, management will only accept the project if the risk is low which means payback period must be short. (Stamalevi, 2015)

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CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. IEEE 33 Bus test system

The RDS configuration of IEEE 33 bus system presented in Figure 3.3 has branches sub-divided from bus 2, bus 3, and bus 6. The bus 2 has branch that includes four buses 19, 20 21, and 22, bus 3 has branch that includes three buses 23, 24, and 25, and bus 6 has branch which includes eight buses from bus 26 to bus 33 as shown in Figure 3.2. The total load of the system is 3715 kW and 2300 kVAR with maximum active load of 420 kW at bus 24 and bus 25 and maximum reactive load of 600 kVAR at bus 30, and minimum active load of 45 kW at bus 11 and minimum reactive load of 10 kVAR at bus 15. In this system also, the reference bus is bus 1 and has no any load with bus voltage 1.0000 pu. The line data and load data of the network is tabulated in Appendix B.

Load flow of the system is one with base voltage of 11 kV and base power of 100 MVA. The load flow analysis using forward / backward sweep algorithm is used which results the voltage, current, active and reactive power flow, and active and reactive power losses at each bus. The voltage profile, active and reactive power losses of each bus is presented

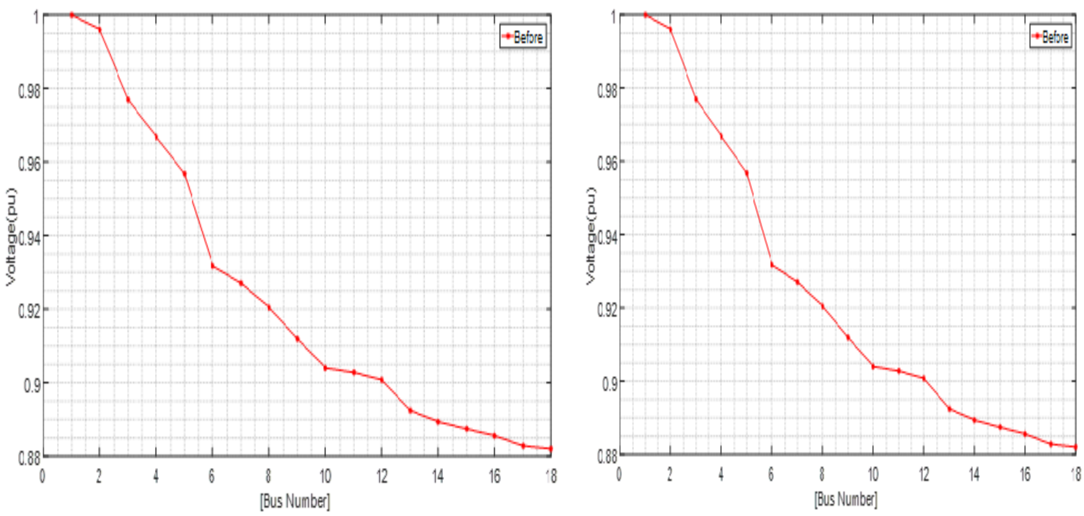

Figure 4.1: voltage Profile of IEEE 33 Bus before configuration of two branch segment.

The maximum value of bus voltage is found 1.0000 pu of reference bus and minimum bus voltage is 0.88202128pu at bus 18 which is located at farthest end of the first branch of IEEE 33 bus system. The bus voltage from bus 1 to bus 18 is going on decreasing order and then for the second branch 19 bus start from bus number 2 with the voltage of 0.977pu. This shows the bus 19 connected from bus 2 which is near abut reference bus 1 and hence voltage is better for 19 bus and after bus 19, the voltage is again decreases gradually because the voltage drop increases toward far point from reference bus. For the overall IEEE 33 bus system of single line diagram above shows the bus 18 is the farthest end of the RDS configuration. The voltage of buses (bus 6 to bus 18 and bus 26 to bus 33) lies in between 0.88202128pu to 0.94983254pu and are lower than specified voltage constraint' lower limit. The bus voltage profile of IEEE – 33 bus system is presented in Figure 4.1. It has total 21 buses whose voltage does not satisfy the voltage regulation limit.

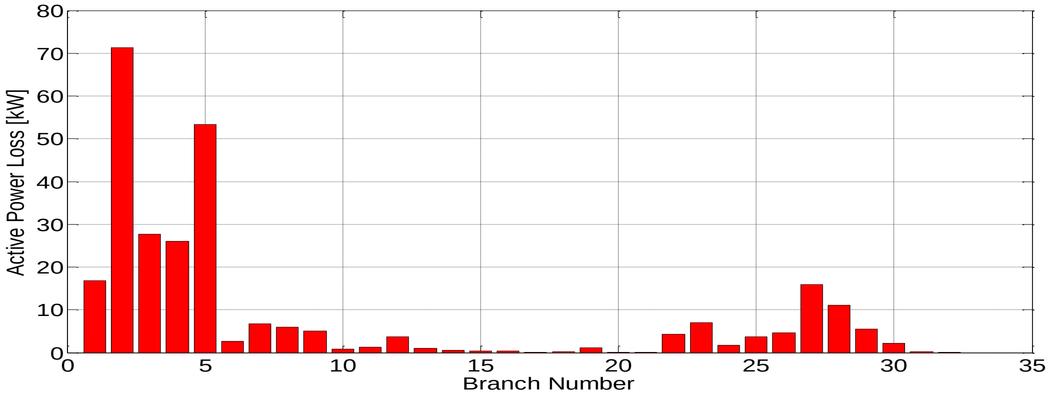

Figure 4.2 : Active Power loss of IEEE 33 Bus system before configuration.

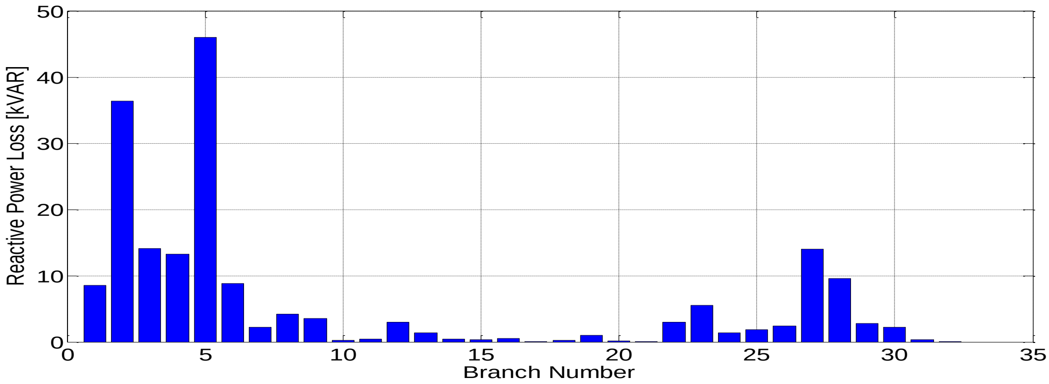

Figure 4.3 : Reactive Power loss graph of IEEE 33 Bus system before configuration

In the base case of IEEE 33 bus system, the line and bus data has been input and analyzed through sweep algorithm. The active and reactive power losses associated with each bus is found to be different as shown in Figure 4.2 and Figure 4.3 . The maximum active power loss in branch 2 is 71.394kW and minimum loss in branch 32 is 0.0186kW found. This power loss varies with line current variation and branch resistance. The reactive power loss is found maximum at branch 5 is 46.011kVAR and minimum in branch number 32 is 0.0289kVAR found. The total active and reactive power loss in IEEE 33 system has been found to 281.59kW and 187.96kVAR respectively. It is 7.57% loss of total active power of the system and 8.17% of reactive power of the system as shown in graphical view in Figure 4.4

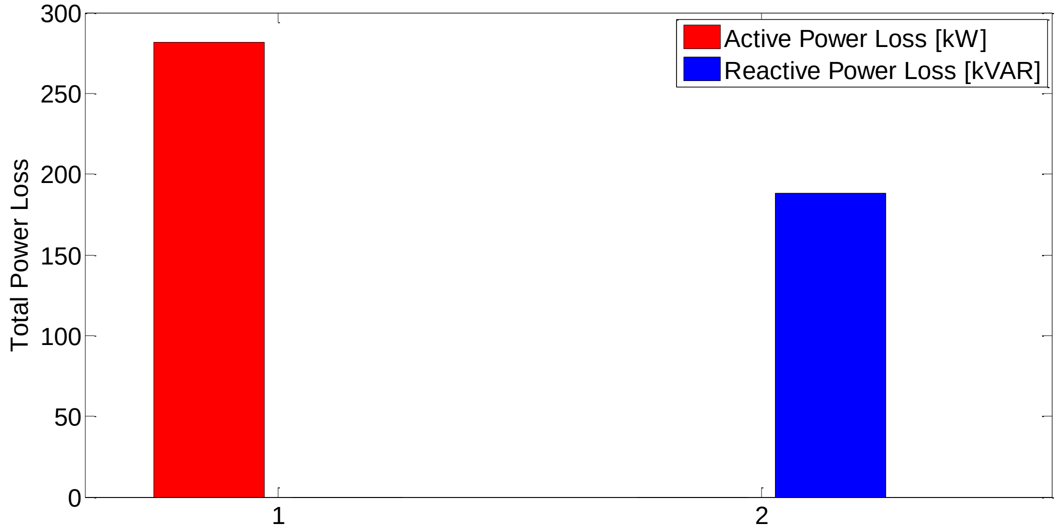

Figure 4.4 : Total Active and reactive power loss of IEEE 33 Bus system before configuration

4.2. Reconfiguration of IEEE 33 Bus test system

In IEEE – 33 bus system, different option of switching case has been analyzed on a base case by making different radial flow root with the help of tie /sectionalizing switches improvement found form comparison base on power loss and voltage profile improvement. Among the possible case of reconfiguration, the power loss has been changed with different case of configuration set as shown table in Appendix B. The best case of reconfiguration has been found at case 13 of configuration has 208.497kW and lowest voltage is 0.9244pu at bus 22. In the base case, power loss is 281.5877W and voltage level lowest at 18 buses is 0.882pu. In case1: connecting line 34 by tie-switches and sectionalizing switches, power loss reduces to 272.2739kW and voltage drop improved to 0.886985pu. In case 2, 3, 4 & 5: power loss are 237.3184kW, 400.99kW, 260.9929kW & 228.802kW and voltage drop 0.894374pu, 0.894374pu, 0.852181pu & 0.921821pu respectively. Similarly reconfiguration have been done up to 15 cases, this analysis shows the power loss variation somehow. The maximum power loss associate in 4 case configuration and power loss has been found are 400.99kW and 296.73kVAR,this analysis clear that reconfiguration may have higher power loss due to making new model of distribution with large line length of voltage drop associate more line losses and hence reconfiguration is not only sufficient to upgrade system profile and power losses so the various possible reconfiguration are analyzed and find the enhanced case of configuration on the basis of power loss minimization and voltage profile upgrade. This analysis is based on the objective function of system power losses minimization with approaches switching limits. From this analyzed, the case 13 is found to be most enhance reconfiguration model has power loss is reduced by 25.96% and voltage drop is improved by 5.66% at bus 18 and 4.8% at lowest voltage level of base case and optimal case.

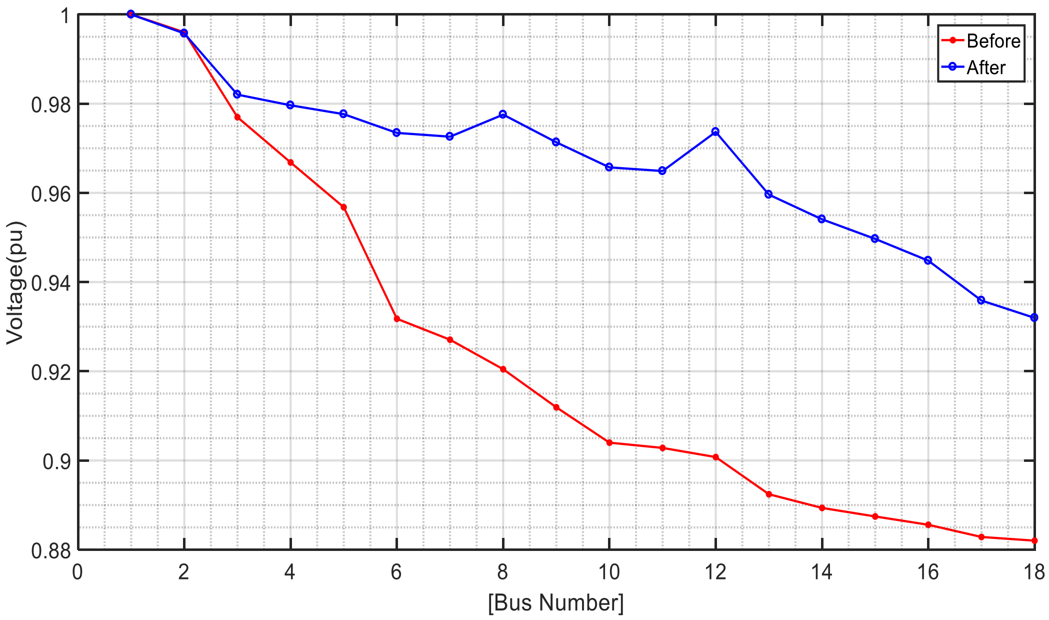

Figure 4.5 : Voltage profile of IEEE 33 bus of first segment before & after reconfiguration.

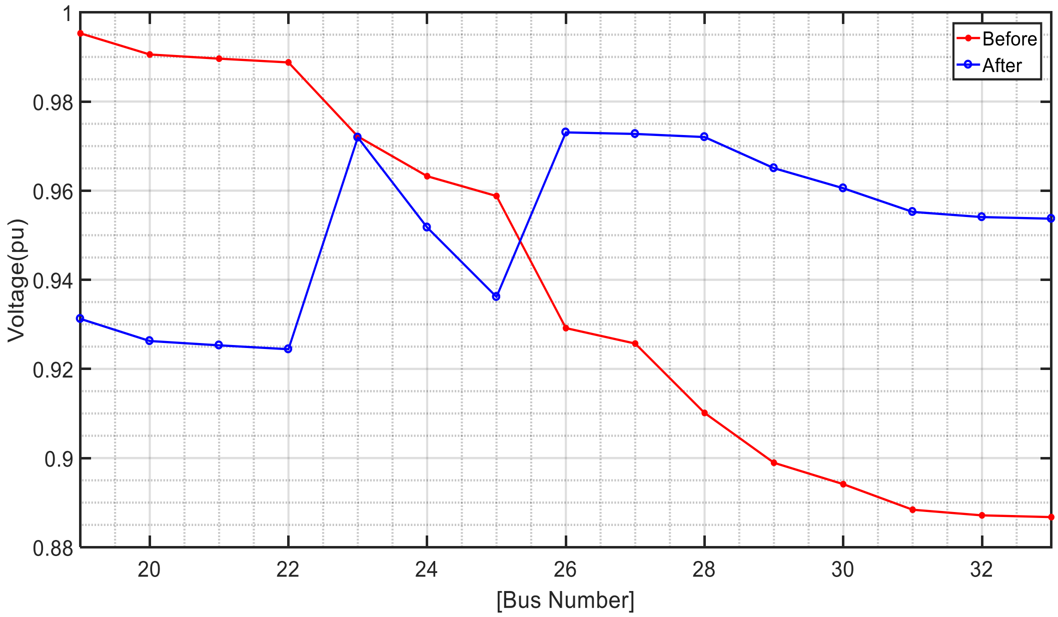

Figure 4.6 : Voltage profile of IEEE 33 bus of second section before & after reconfiguration.

The voltage profile of the IEEE 33 bus system comparison between base case and most optimal case after reconfiguration of system with tie/SESW switches arrangement for the load flow in the system without isolating any bus. In the Figure 4.1 shows the IEEE 33 bus base case with two branching as describe separately in base case Figure 4.1 then the comparison is done base on base case graph. The two separate graph of the section after reconfiguration to the base case is analyzed. This shows the lowest level of voltage in base case is at bus 18 then after reconfiguration with tie switches arrangement lower voltage level become at bus 22 of the system. This mean the overall voltage of the system upgrade by 4.8% but individual bus voltage somewhere decreases or increases is depends upon the system reconfiguration shown in Figure 4.5 & Figure 4.5 above. This two separate graph is drawn of the same system voltage profile drawn separately for more clearance in analysis. After reconfiguration of the system profile has been changes and different section of IEEE 33 bus has been connected for enhancement of system from other part as define tie switches as in Figure 3.3 with dotted line. After reconfiguration of system with available switches the most optimal case has been found. The optimal case is obtained with available tie switches 33, 35 & 37 connected at case 13 of the system. The voltage level of bus 18 after reconfiguration become 0.932pu and hence voltage level upgrade after reconfiguration also.

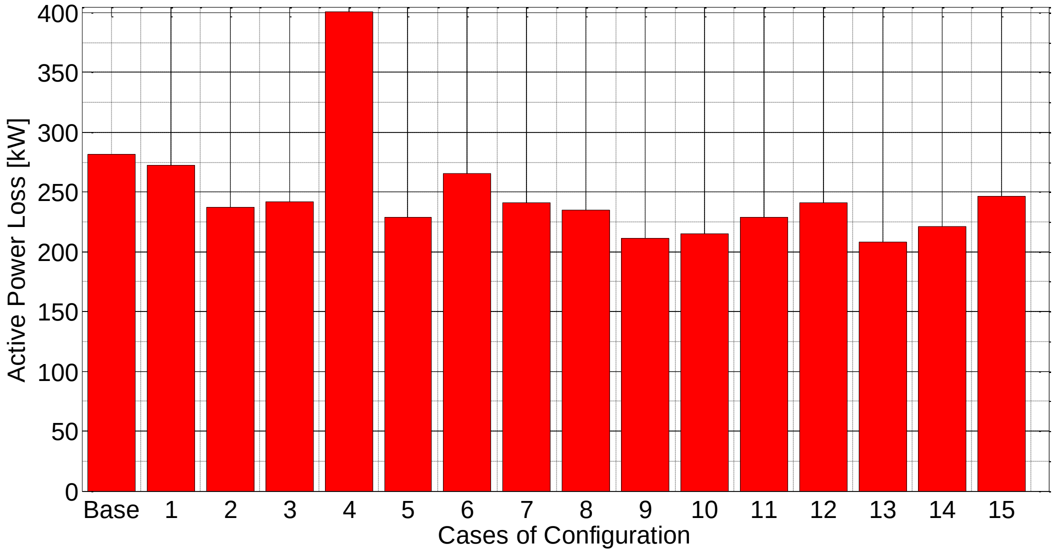

Figure 4.7 : Active power loss of 15 reconfigure case of IEEE 33 test Bus system.

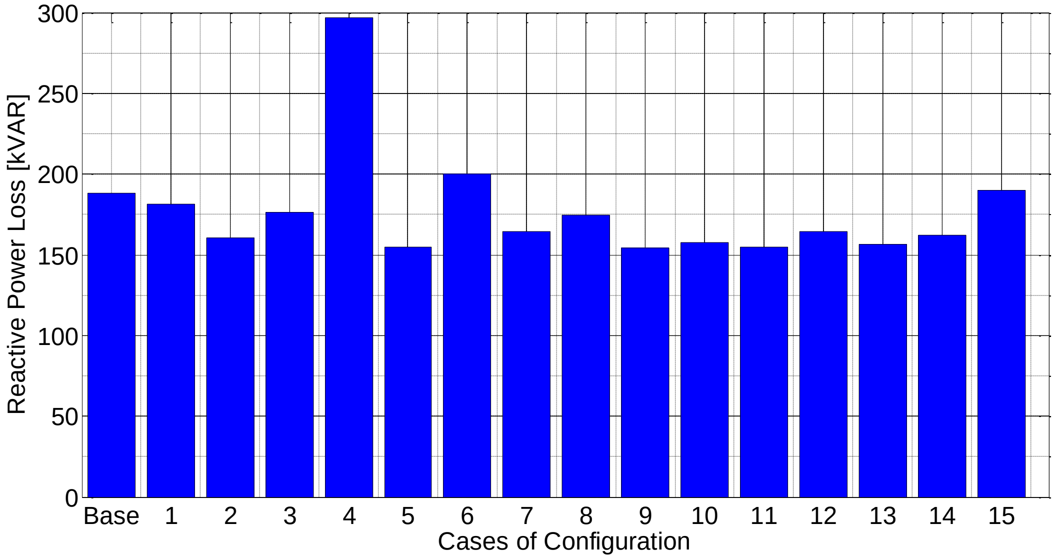

Figure 4.8 : Reactive power loss of 15 possible reconfiguration of IEEE 33 test Bus system.

The proposed paradigm finds the enhanced reconfiguration model of IEEE 33 test bus system. With the 15 possible case of reconfiguration, the most enhanced model of reconfiguration is case 13 found and its found minimization of active power losses is analyzed with forward and backward sweep algorithm in the distribution using GA approach. The allocation of SESW and tie-switches for restructure of distribution is done. From the 15 possible cases of distribution model analysis, the model 13 is found most enhanced model of distribution with reduced active power losses of whole distribution by 25.96% from existing base case of IEEE 33 bus system. The voltage level is improved by 5.66% from base case at bus 18 and overall system lowest level voltage is improved by 4.8%.The graphical data represented in Figure 4.5, Figure 4.6, Figure 4.6 & Figure 4.8. Therefore determine the enhanced reconfiguration model for distributions with proper arrangement and location of SESW and tie- switches for loss minimization and the obtained result is within the satisfactory limit of IEEE 33 bus system of corresponding researches and hence this model is verified. This model is also analysis to the Pulchowk DCS network for the reconfiguration for the research.

4.3. Load Flow Analysis of Pulchowk DCS Network base case System

The RDS configuration of Pulchowk DCS 142 bus base case system has different 8 feeder came through substation and branches sub-divided from different points and hence run radially. The feeder 1 has branch that includes four buses 2, 3, and 4, feeder 2 start from bus 5 has include buses from 6 to 20, feeder 3 start from 21 bus has include 17 bus in between 21 to 38 bus, and similarly other feeder shown in Table 4.1 here in

Table 4.1 Pulchowk DCS feeder represented with bus number.

Feeder Name	Feeder No.	Total no of bus included	Feeder start bus no.	Feeder end bus no.
Patan-Jawalakhel	1	4	1	4
Patan-Mangalbazar	2	15	5	20
Patan-pulchowk	3	17	21	38
patan – Pharping	4	12	39	51
Patan – Ringroad	5	9	52	60
Patan – Sainbu	6	16	61	77
Teku – Pulchowk	7	20	78	98
Thapathali-Patan	8	25	99	124
Thapathali – Sanepa	9	18	124	142

The feeder 4 star from 39 has include 12 bus from 39 to 51 bus, feeder 5 start form 52 has include 9 bus from bus no.52 to 60 no. bus , feeder Teku – Pulchowk /feeder no.7 has include 20 buses which is star from bus no.78 to end bus no 98 ,feeder thapathali-Patan /feeder no.8 has include 25 bus which star from bus no.99 to end bus no. 124 and Thapathali-Sanepa /feeder no. 9 has includes 18 bus which is start from the bus no 124 to the bus no.142 as shown in Table 4.1. The total load of the system is 14132 kW and 10599 kVAR with maximum active load of 200 kW at bus 10, 17, 95, 100, 109 and 127 and maximum reactive load of 150 kVAR at bus 30, and minimum active load of 45 kW at bus 11 and minimum reactive load of 10 kVAR at bus. In this system also, the reference bus is bus 1 and has no any load with bus voltage 1.0000pu. The line data and load data of the network is tabulated in Appendix B.

Load flow of the system is one with base voltage of 11 kV and base power of 100 MVA. The load flow analysis using forward / backward sweep algorithm is used which results the voltage, current, active and reactive power flow, and active and reactive power losses at each bus. The voltage profile, active and reactive power losses of each bus is presented here in.

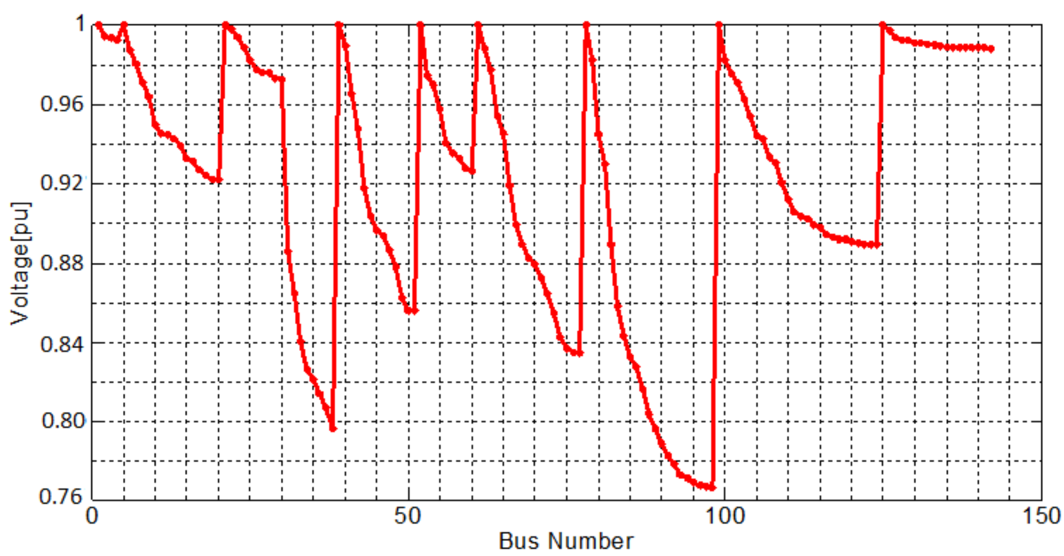

Figure 4.9 : voltage profile of Pulchowk distribution system base case.

The maximum value of bus voltage is found 1.0000pu of reference bus and minimum bus voltage is 0.7694pu of bus 98 which is located at farthest end of the feeder 7. The bus voltage from starting of feeder to bus of feeder which is located at farthest end is going on decreasing order and then increases for next feeder from 1pu and the near about similar pattern of decreasing voltage and the bus voltage profile of Pulchowk DCS 142 bus system is presented is shown in graph in Figure 4.9.

The power loss of the system is calculated at full load condition of bus data. The line data and load data of the network is tabulated in Appendix C. The power loss in each line section between the buses is calculated by using the power loss calculation formula of Equation 3.5. The power loss associated in each section is different which generally depend on the line length, conductor type, bus voltage and line loading. The active power loss in each bus section of 142 bus of 141 line section which shown in graph here in in Figure 4.10, The active power loss lowest at the line of bus branch of 50 and 51 which is about 0.00048kW and the maximum power loss in the line of bus branch of 81 and 82 which is 57.81kW. The individual part of power loss in 142 bus system of Pulchowk DCS is shown in graph Figure 4.10.

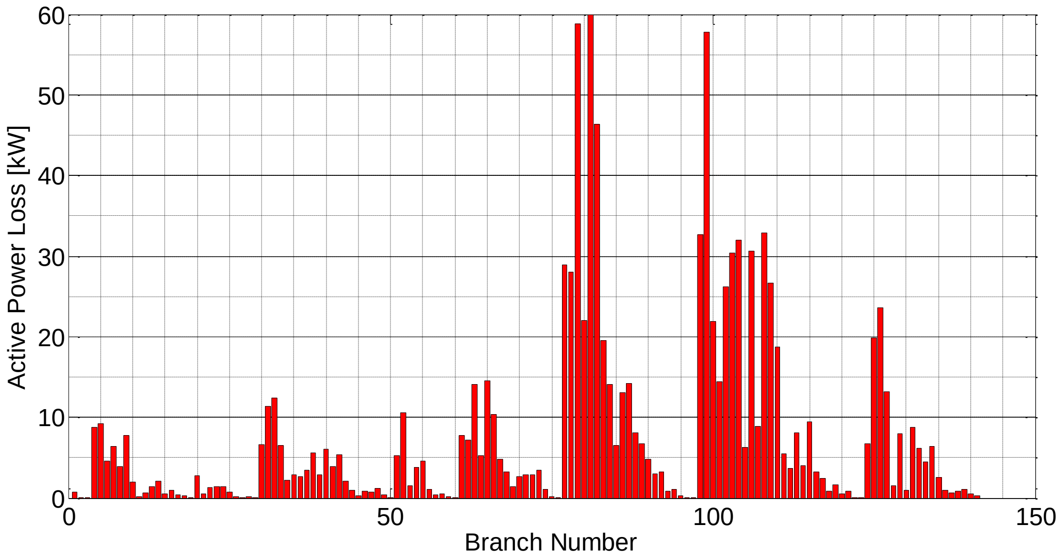

Figure 4.10 : Active power loss of base case 142 bus pulchowk distribution system before configuration.

The reactive power loss associated in the system of 142 bus network RDS calculated which is tabulated in Appendix and their graph is shown in Figure 4.11 here in. The reactive power loss is mainly depend on the bus voltage and hence their loss is different in different bus line shown from graph. Their value varies lowest at bus 51 is 4.06462E-05kVAR and maximum at bus 100 is 5.38kVAR shown in Figure 4.11.

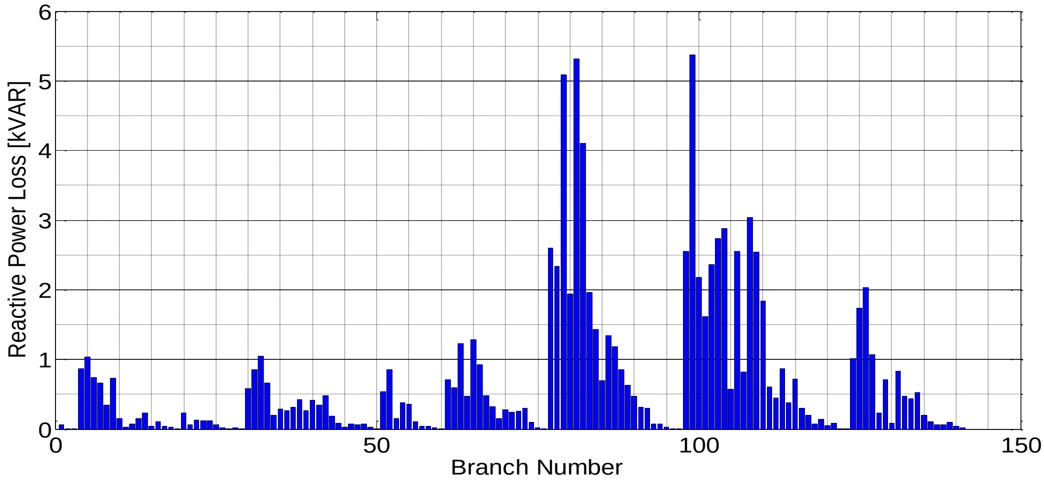

Figure 4.11 : Reactive power loss of base case 142 bus pulchowk distribution system before configuration.

The total active power loss and reactive power loss associated in this system before configuration is the sum of power loss in each branch of bus which can be calculated from the Equation 3.5. The total active power loss associated in the system is found 1073.038kW and reactive power loss is 98.0151kVAR which is graphically shown in Figure 4.12.

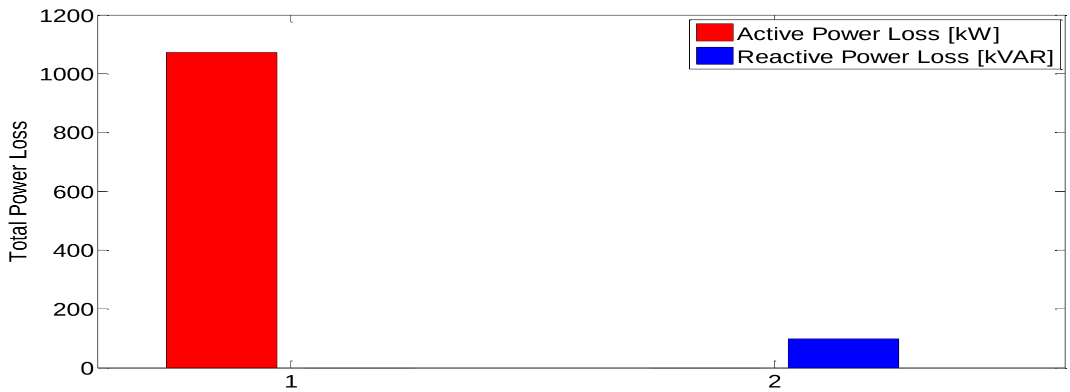

Figure 4.12 : Total power loss of Pulchowk DCS network before configuration

4.4. Reconfiguration of 142 bus Pulchowk DCS Network

The reconfiguration of the system has been done on the basic of topological lining of feeder bus location that has been taken from GIS data of Pulchowk DCS. All those set of reconfiguration in Table 3.2 has been analysis as analysis in base case procedure, the result has been found different with respect power loss and voltage drop in each case of reconfiguration. The active power loss is associated with different possible case of reconfiguration as shown in Figure 4.13. This shows that active power loss in each reconfiguration is differ from other due to their configuration model of re-route their radial structure of each feeder.

The data on table shown in Appendix D, are differ from each other. The tabulated data shows the active and reactive power in different set of reconfiguration. The base case of Pulchowk distribution of radial network of loss associated of 1073.04kW and 98.02kVAR active and reactive power respectively. From the table higher power loss is associated in case 1 of reconfiguration with 1119.57kW active power losses and 102.89kVAR reactive power losses in the reconfigured case. Among those possible cases of reconfiguration set of network of Pulchowk DSC of existing system of comparison the case 12 is found to be best case of configuration with active power loss in this system has 597.78kW and reactive power loss has 54.36kVAR. this shows that active power loss has been reduced of 44.29% of actual existing case of configuration and reactive power loss has been reduced of 45.54%, this shows that the reconfiguration of existing network able to reduce the power losses of the system. The graphical view of the all cases of active and reactive power loss has been shown in Figure 4.13 and Figure 4.14 here in.

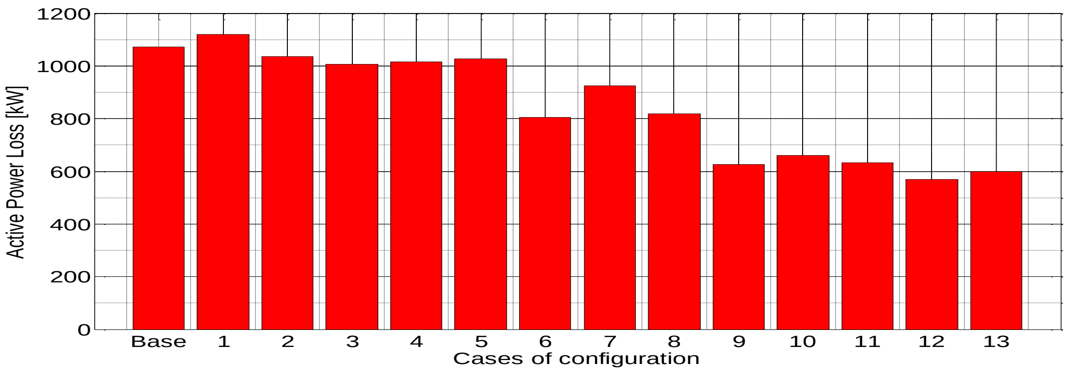

Figure 4.13 : Active power losses of Pulchowk DCS of 13 possible case of reconfiguration

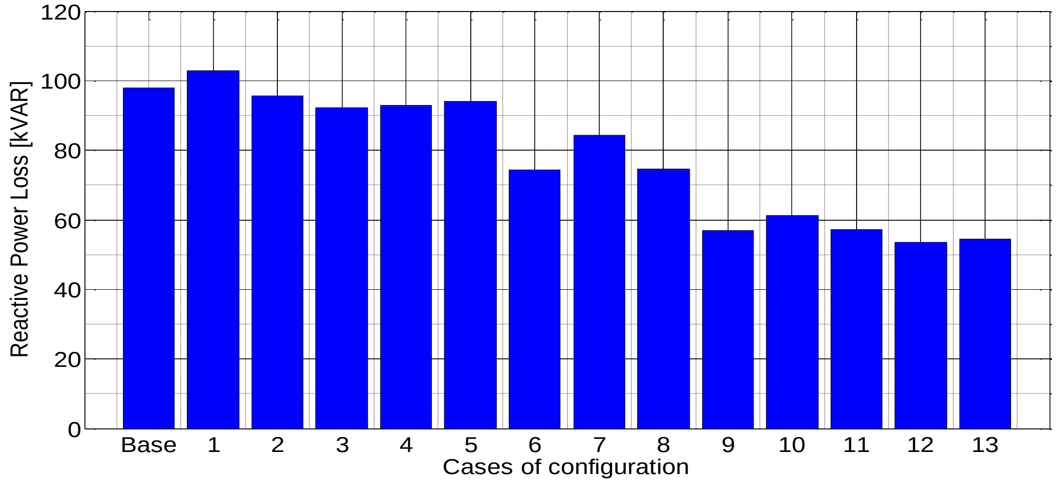

Figure 4.14 : Reactive power loss of Pulchowk DCS of 13 possible case of reconfigure

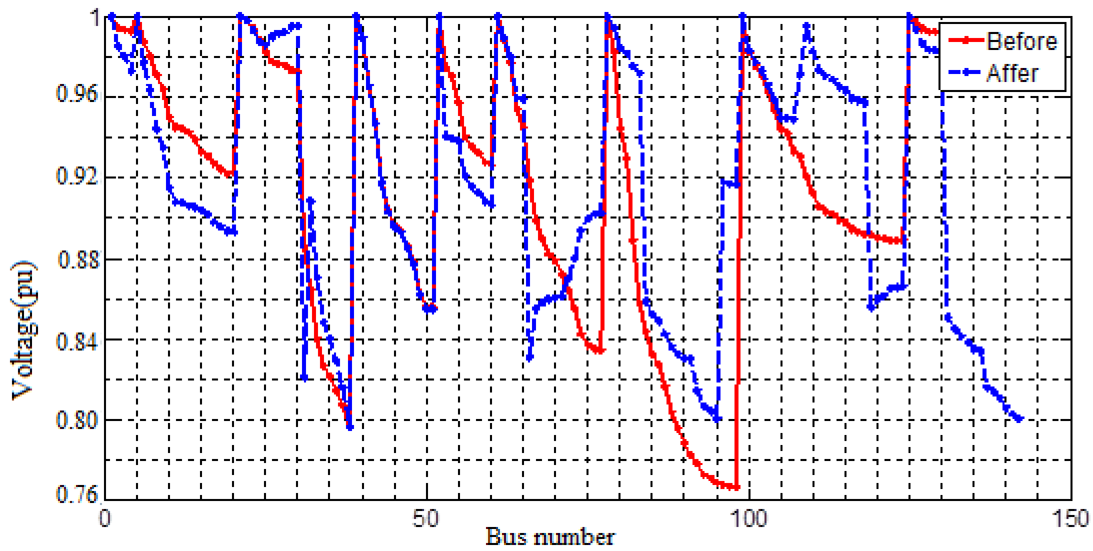

Figure 4.15 : Voltage profile of Pulchowk DCS network before and after reconfiguration

Since in the graph shows the voltage profile of the Pulchowk DCS network of 142 bus system of existing case of running at the field (before) and after reconfigure of best model. The voltage drop is reduced in enhanced model after reconfiguration of this network and voltage is improved to 3.85% at lowest voltage level of 0.7954pu. This analysis of Pulchowk DCS network of 9 feeder of each radial system shows that the existing system of network has containing comparatively more loss and voltage drop and also found that this existing model can be used with re-structuring (reconfiguration) by allocating and re-arranging the tie-switches and sectionalizing switches. From this study the enhanced model has been found with minimum power loss and voltage drop in the system network of distribution running radially.

4.5. Financial Analysis

- **Investment costs**

Reconfigured structure of Pulchowk DCS network of most enhanced model from the analysis is proposed model. The proposed model is considered for capital investment. The total investment cost is estimated to be US$ 148,213.31 (NRP 1,68,37,031.50 rupees).

The project costs are segregated into two categories: (i) supply materials for installation required costs and ii) installations of structural in the side costs. Supply materials for installation costs amount to NRP 1,40,77,854.00 rupees. The supply materials installation required costs are estimated at NRP 24,41,750.00 rupees see in Appendix H. It is initially assumed that there is a zero risk of cost overrun. The sub-component (i) investment costs includes the financing of the investment to rehabilitate and improve of the installed distribution line structure is consider 1.5% per annual (NEA, A year book 2075/076, 2019) these costs are to be covered by the project. All imported capital items are exempt from any import duty or VAT. The Project has selected a technical design for the making restructure of the Pulchowk DCS network line with SESW and tie-switches structure are estimated as detail is shown in Appendix - H.

The financial analysis of the structure is calculated with their discounted payback period of investment returned from loss reduction units sell. The saving energy from the Pulchowk DCS network of reconfiguration structure has been found to 237537 units per month. The amount will be saved after selling those saving units of energy is found to be NRP 2370572.82 rupees per month. For the units selling rate has to be found NRP 9.355 rupee form the energy selling report of Pulchowk DCS for F/Y 2075/076. The operation and maintenance cost of electrical distribution line is taken 1.5 % annual. (NEA, 2019), the useful life of distribution enclose (switches) taken as 16 year, the salvage asset is 3%. (Powerwater, 2018), MARR of the investment is taken as 8%. (NRB, 2018). This shows the detail calculation for NPV.IRR and payback period of the investment of the proposed reconfiguration network system made with tie-switches and SESW switches proper allocation and sequences.

Form the cash flow analysis, the NVP of the financial investment is NPV 228,974 million. And the IRR of investment is calculated to 150% and the discounted payback period of the investment is estimated to 0.63 years. The IRR of the investment is high that means the investment is in good scenario for the investment and also the discounted payback period of the investment has been calculated and payback period of the investment is found to be 7 months and 15 days (0.63 year). This shows that the investment of the project is significantly low with respect their return form loss reduction of the Pulchowk DCS network.

The proposed paradigm finds the enhanced reconfiguration model of Pulchowk DCS distribution network and its found minimization of active power losses in the distribution using GA approach. The allocation of SESW and tie-switches for restructure of distribution is found. From the 13 possible cases of distribution model, the model 12 is found most enhanced model of distribution with reduced active power losses of whole distribution by 44.29 % from existing base case. The voltage level is improved by 3.85% from base case. The graphical data represented in Figure 4.13 and Figure 4.15 and also from the financial analysis, the IRR and the payback period of the investment are 150% and 0.63 years. This shows the analyzed model of reconfiguration is financially feasible. The detail analysis is shown in Appendix H.

4.6. Result Verifications

The reconfiguration module develop in MATLAB using forward/backward sweep algorithm and genetic algorithm test on standard IEEE 33 bus system and voltage profile and line power losses are calculated and then reconfigured in different possible cases. The line power losses associated with different cases are compared with respect to line loss and best optimized network from those possible set of configuration is found. It is tested for standard IEEE 33 bus test distribution system. It is clearly seen that voltage profile of the system is improved by 4.8% and the active power loss of the system gets reduce by 25.96% by using the proposed model and found to be satisfactory result as compared to the result for distribution system reconfiguration using harmony search Algorithm (Mahato, 2018). Then the proposed methodology is used for Pulchowk DCS 142 bus distribution network system then the results, also explained in chapter 4, shows that voltage profile of the system is improved and also the total loss of system is reduced

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

- The analysis model has been made in IEEE 33 Bus system which is applied in Pulchowk DCS network and voltage profile and voltage profile and line power losses are calculated. The line losses of existing base case are presented, the minimum bus voltage is 0.7694pu at bus 98 of Pulchowk DCS multi feeder 142 bus network and active power loss associated in base case is found to be 1073.08kW which is 7.6 % of total 14132kW connected load.
- The line power losses associated with different reconfigured cases are compared with respect to line loss and best optimized network from those possible set of configuration is found. It is tested for standard IEEE 33 bus test distribution system and then applied to the Pulchowk DCS 142 bus distribution system which is Nepalese distribution system. From this model of testing for reconfiguration in different 13 possible case of reconfiguration of Pulchowk DCS network are made and hence found the power loss and voltage profile in each case of reconfiguration. Among those 13 possible cases of reconfiguration set of network of Pulchowk DSC of existing system of comparison, the comparison graph are represented with their voltage profile, active and reactive power losses of the different cases shown in Chapter 4. From this analysis, the case 12 is found to be best case of configuration with respect to the base case power losses.
- The optimized model among the possible set of model is found with respect to the power losses associated in each model of distribution network of Pulchowk DCS. It is found that the voltage drop is reduced in most enhanced model that is 12 case after reconfiguration of this network by 3.85% at lowest voltage level of bus. The active power loss in this system has 569.95kW which is 4.03% of total system power and reactive power loss has 54.36kVAR. This shows that active power loss has been reduced by 44.29% of actual existing base case power losses of configuration and hence power loss reduced by 3.57% of system power losses and reactive power loss has been reduced by 45.54%, Hence, it is concluded that, the optimal configurations of the distribution system can be

identified by using some computational techniques, that helps to reduce the system loss and voltage drop significantly.

- The capital investment to make the proposed reconfigured model is estimated with the cost of materials and installation charges and the return of the investment is the sales of loss reduction units of energy after reconfiguration of distribution system of Pulchowk DCS. The discounted payback period of the proposed model is found to be 8 months and 11 days.

Finally, it is concluded that the reconfiguration via SESW and tie switches can be located in optimal way in the Pulchowk DCS network for the voltage profile improvement, and system's loss reduction

5.2. Recommendation

Further study shall be carried out considering following different aspect as:

- This study is based on the system full load modeling, and it can be improved into time varying load of the system.
- The multiple objective functions can be used for reconfiguration optimization network and can be set the different models for various load.
- This study is only base on reconfiguration of existing distribution system with re-arrangement of switches. This can be further analyzed with DG sources in distribution system also.

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APPENDIX - A: Line parameter and line data of IEEE 33 bus system.

Branch No.	Sending Bus	Receiving Bus	Resistance(r) (Ω)	Reactance (x) (Ω)	Bus No.	Load (P) (kW)	Load (Q) (kVAR)
1	1	2	0.0922	0.047	2	100	60
2	2	3	0.493	0.2511	3	90	40
3	3	4	0.366	0.1864	4	120	80
4	4	5	0.3811	0.1941	5	60	30
5	5	6	0.819	0.707	6	60	20
6	6	7	0.1872	0.6188	7	200	100
7	7	8	0.7114	0.2351	8	200	100
8	8	9	1.03	0.74	9	60	20
9	9	10	1.044	0.74	10	60	20
10	10	11	0.1966	0.065	11	45	30
11	11	12	0.3744	0.1238	12	60	35
12	12	13	1.468	1.155	13	60	35
13	13	14	0.5416	0.7129	14	120	80
14	14	15	0.591	0.526	15	60	10
15	15	16	0.7463	0.545	16	60	20
16	16	17	1.289	1.721	17	60	20
17	17	18	0.732	0.574	18	90	40
18	18	19	0.164	0.1565	19	90	40
19	19	20	1.5042	1.3554	20	90	40

Branch No.	Sending Bus	Receiving Bus	Resistance(r) (Ω)	Reactance (x) (Ω)	Bus No.	Load (P) (kW)	Load (Q) (kVAR)
20	20	21	0.4095	0.4784	21	90	40
21	21	22	0.7089	0.9373	22	90	40
22	22	23	0.4512	0.3083	23	90	50
23	23	24	0.898	0.7091	24	420	200
24	24	25	0.896	0.7011	25	420	200
25	25	26	0.203	0.1034	26	60	25
26	26	27	0.2842	0.1447	27	60	25
27	27	28	1.059	0.9337	28	60	20
28	28	29	0.8042	0.7006	29	120	70
29	29	30	0.5075	0.2585	30	200	600
30	30	31	0.9744	0.963	31	150	70
31	31	32	0.3105	0.3619	32	210	100
32	32	33	0.341	0.5302	33	60	40

APPENDIX - B: Comparison table of IEEE 33 bus before and after reconfiguration

	Before reconfiguration				After reconfiguration			
Bus No.	Voltage (pu)	Power Loss (kW)	Reactive Power (kVAR)	Angle (RAD)	Voltage (pu)	Power Loss (kW)	Reactive Power (kVAR)	Angle (RAD)
1	1	0	0	0	0	0	0	0
1	0.995999397	0.075429168	0.059148009	-0.012715058	0.995748159	18.91007228	9.639624698	0.000275048
2	0.976963612	0.214167974	0.204373707	0.000104212	0.982027997	37.45850739	19.07876513	0.0022899
3	0.966820893	0.399277136	0.291579846	-0.010463304	0.979629582	1.510530478	0.769297489	0.002247227
4	0.956785416	0.357138905	0.476831696	-0.012453635	0.97764873	0.992082177	0.505282473	0.002138071
5	0.931771028	0.134194622	0.156773399	-0.001921865	0.973443296	1.643252362	1.41853409	0.000791635
6	0.927075214	3.649590707	1.858954084	0.004615291	0.97259916	0.081775404	0.270313141	-0.000125488
7	0.920461005	6.790874815	2.244215166	-0.001234564	0.97754827	11.62713129	11.62713129	-0.007113094
8	0.911919873	5.891788565	4.232935474	-0.003153124	0.971336227	3.171037714	2.278221271	-0.008681782
9	0.903994223	5.023042386	3.560394028	-0.00482262	0.965716013	2.56695405	1.819488503	-0.010023466
10	0.902815773	0.781535284	0.258391625	-0.004666489	0.964896902	0.374721175	0.123890521	-0.009954321

	Before reconfiguration				**After reconfiguration**			
Bus No.	**Voltage (pu)**	**Power Loss (kW)**	**Reactive Power (kVAR)**	**Angle (RAD)**	**Voltage (pu)**	**Power Loss (kW)**	**Reactive Power (kVAR)**	**Angle (RAD)**
11	0.900760275	1.244850768	0.411625334	-0.00442376	0.973666071	17.13843998	17.13843998	-0.008748431
12	0.892432025	3.771491856	2.967352244	-0.00684731	0.959605489	10.88977962	8.567912441	-0.012912645
13	0.889364153	1.032174686	1.358636141	-0.00885929	0.95407154	3.431333436	4.51661301	-0.016432809
14	0.88744748	0.506209589	0.4505351	-0.009838876	0.949678468	2.584493292	2.30024276	-0.018348107
15	0.885584813	1.108084168	0.99846914	-0.001468021	0.944797242	2.726174938	1.990841942	-0.019824229
16	0.882848132	16.80420917	8.566136996	0.000357154	0.935862617	3.810399523	5.08743024	-0.02594482
17	0.88202128	71.39385713	36.36307814	0.002380983	0.931967627	1.704141887	1.336307982	-0.027246399
18	0.995298549	27.66959709	14.09183852	0.004017113	0.931234377	0.244897173	0.233697607	-0.027579907
19	0.990552762	26.04064635	13.26289545	0.005687783	0.926260645	1.2675009	1.142115889	-0.029682245
20	0.989618909	2.678689795	8.854557932	-0.002028985	0.925290652	0.153516118	0.179345814	-0.030261669
21	0.988774416	0.058126865	0.076854719	-0.002398947	0.924417515	0.066502046	0.087928295	-0.030862092
22	0.972166602	4.299805789	2.938010028	0.001649492	0.971939953	18.71598599	12.78842749	0.003086693

	Before reconfiguration				After reconfiguration			
Bus No.	**Voltage (pu)**	**Power Loss (kW)**	**Reactive Power (kVAR)**	**Angle (RAD)**	**Voltage (pu)**	**Power Loss (kW)**	**Reactive Power (kVAR)**	**Angle (RAD)**
23	0.963241171	6.955867939	5.492656966	-0.000455254	0.951745039	33.85726301	26.73517283	0.00343717
24	0.958791242	1.743138033	1.363966601	-0.001500556	0.936160075	20.51102402	16.04941846	0.004930137
25	0.929159514	53.29961596	46.01077959	0.003600583	0.973071258	0.066150723	0.033694506	0.000753733
26	0.925689531	4.677282679	2.381431399	0.006059073	0.972726011	0.040800576	0.020773552	0.000714222
27	0.910118644	15.89749844	14.01651964	0.0084565	0.972026715	0.037052215	0.032668228	0.000410269
28	0.898939232	11.02764094	9.607019696	0.010650711	0.965048768	5.937926389	5.937926389	0.001048442
29	0.894137441	5.487312981	2.795015578	0.013366658	0.960537143	4.751113713	2.420025409	0.003310331
30	0.8884013	2.254286692	2.227912648	0.011429309	0.955236026	1.949321079	1.926514983	0.001523849
31	0.887137345	0.301669079	0.351607213	0.010891262	0.954069755	0.260818849	0.303994658	0.001034403
32	0.886745447	0.018636932	0.028977423	0.010709772	0.95370839	0.016111692	0.025051082	0.000870009

APPENDIX -C: Line parameter and line data of Pulchowk DCS network system.

Branch No.	Sending Bus	Receiving Bus	Resistance(r) (Ω)	Reactance (x) (Ω)	Bus No.	Load in KVA	Load (P) (kW)	Load (Q) (kVAR)
1	1	2	1.0883	0.0983	2	200	160	120
2	2	3	0.3912	0.0382	3	200	160	120
3	3	4	0.8427	0.066	4	100	80	60
4	1	5	0.4375	0.0433	5	100	80	60
5	5	6	0.4983	0.056	6	200	160	120
6	6	7	0.2887	0.0466	7	200	160	120
7	7	8	0.4805	0.0499	8	200	160	120
8	8	9	0.3569	0.0321	9	200	160	120
9	9	10	0.8752	0.083	10	250	200	150
10	10	11	0.3103	0.0238	11	100	80	60
11	11	12	0.0374	0.0041	12	100	80	60
12	12	13	0.1329	0.0148	13	100	80	60
13	13	14	0.3372	0.0377	14	100	80	60
14	14	15	0.6052	0.0669	15	200	160	120

Branch No.	Sending Bus	Receiving Bus	Resistance(r) (Ω)	Reactance (x) (Ω)	Bus No.	Load in KVA	Load (P) (kW)	Load (Q) (kVAR)
15	15	16	0.2062	0.0185	16	100	80	60
16	16	17	0.5344	0.0607	17	250	200	150
17	17	18	0.4815	0.0418	18	200	160	120
18	18	19	0.6712	0.0646	19	250	200	150
19	19	20	0.0977	0.0097	20	100	80	60
20	1	21	0.5562	0.0464	21	100	80	60
21	21	22	0.1295	0.0136	22	200	160	120
22	22	23	0.4564	0.0429	23	125	100	75
23	23	24	0.6179	0.0525	24	200	160	120
24	24	25	1.0337	0.093	25	100	80	60
25	25	26	0.7726	0.0667	26	150	120	90
26	26	27	0.3467	0.036	27	100	80	60
27	27	28	0.2298	0.0173	28	100	80	60
28	28	29	1.3007	0.1128	29	125	100	75
29	29	30	0.5442	0.057	30	100	80	60

Branch No.	Sending Bus	Receiving Bus	Resistance(r) (Ω)	Reactance (x) (Ω)	Bus No.	Load in KVA	Load (P) (kW)	Load (Q) (kVAR)
30	1	31	0.7171	0.0633	31	100	80	60
31	31	32	1.3689	0.1039	32	100	80	60
32	32	33	1.6931	0.1432	33	100	80	60
33	33	34	1.0257	0.103	34	100	80	60
34	34	35	0.4007	0.036	35	50	40	30
35	35	36	0.5663	0.0552	36	200	160	120
36	36	37	0.7274	0.0727	37	100	80	60
37	37	38	1.1242	0.1018	38	50	40	30
38	38	39	2.0642	0.1551	39	100	80	60
39	39	40	1.3279	0.1214	40	100	80	60
40	40	41	3.5917	0.2434	41	100	80	60
41	41	42	3.108	0.2796	42	100	80	60
42	42	43	6.0993	0.5488	43	100	80	60
43	43	44	3.6495	0.3283	44	50	40	30
44	44	45	2.1557	0.1939	45	50	40	30

Branch No.	Sending Bus	Receiving Bus	Resistance(r) (Ω)	Reactance (x) (Ω)	Bus No.	Load in KVA	Load (P) (kW)	Load (Q) (kVAR)
45	45	46	0.8412	0.0756	46	15	12	9
46	46	47	2.6764	0.2408	47	50	40	30
47	47	48	3.5509	0.3118	48	50	40	30
48	48	49	8.4468	0.5807	49	50	40	30
49	49	50	4.9794	0.3345	50	50	40	30
50	50	51	0.0143	0.0012	51	100	80	60
51	1	52	1.0321	0.1069	52	100	80	60
52	52	53	2.4783	0.2017	53	200	160	120
53	53	54	0.5355	0.0554	54	100	80	60
54	54	55	1.6764	0.1657	55	100	80	60
55	55	56	2.6353	0.207	56	200	160	120
56	56	57	1.2109	0.1253	57	100	80	60
57	57	58	0.7331	0.0659	58	100	80	60
58	58	59	1.5313	0.141	59	100	80	60
59	59	60	0.9311	0.0837	60	100	80	60

Branch No.	Sending Bus	Receiving Bus	Resistance(r) (Ω)	Reactance (x) (Ω)	Bus No.	Load in KVA	Load (P) (kW)	Load (Q) (kVAR)
60	60	61	0.3364	0.0318	61	100	80	60
61	1	62	0.7551	0.0679	62	100	80	60
62	62	63	0.7817	0.0653	63	100	80	60
63	63	64	1.755	0.1519	64	100	80	60
64	64	65	0.7582	0.0669	65	50	40	30
65	65	66	2.2326	0.1977	66	100	80	60
66	66	67	1.869	0.1656	67	50	40	30
67	67	68	0.9404	0.0946	68	100	80	60
68	68	69	0.7458	0.0754	69	50	40	30
69	69	70	0.3777	0.0403	70	100	80	60
70	70	71	0.847	0.0868	71	100	80	60
71	71	72	1.1496	0.0957	72	100	80	60
72	72	73	1.5406	0.1354	73	100	80	60
73	73	74	2.4176	0.217	74	200	160	120
74	74	75	1.6358	0.1471	75	200	160	120

Branch No.	Sending Bus	Receiving Bus	Resistance(r) (Ω)	Reactance (x) (Ω)	Bus No.	Load in KVA	Load (P) (kW)	Load (Q) (kVAR)
75	75	76	1.0497	0.0944	76	100	80	60
76	76	77	0.675	0.0603	77	100	80	60
77	1	78	0.7551	0.0679	78	100	80	60
78	78	79	0.7817	0.0653	79	100	80	60
79	79	80	1.755	0.1519	80	200	160	120
80	80	81	0.7582	0.0669	81	100	80	60
81	81	82	2.2326	0.1977	82	100	80	60
82	82	83	1.869	0.1656	83	200	160	120
83	83	84	0.9404	0.0946	84	100	80	60
84	84	85	0.7458	0.0754	85	100	80	60
85	85	86	0.3777	0.0403	86	100	80	60
86	86	87	0.847	0.0868	87	200	160	120
87	87	88	1.1496	0.0957	88	100	80	60
88	88	89	0.7472	0.0784	89	200	160	120
89	89	90	0.8096	0.0756	90	200	160	120

Branch No.	Sending Bus	Receiving Bus	Resistance(r) (Ω)	Reactance (x) (Ω)	Bus No.	Load in KVA	Load (P) (kW)	Load (Q) (kVAR)
90	90	91	0.8006	0.0783	91	100	80	60
91	91	92	0.6034	0.0622	92	200	160	120
92	92	93	0.9816	0.0897	93	200	160	120
93	93	94	0.4346	0.0396	94	100	80	60
94	94	95	0.7409	0.0502	95	250	200	150
95	95	96	0.6883	0.0617	96	100	80	60
96	96	97	0.4078	0.0408	97	100	80	60
97	97	98	0.6765	0.0543	98	100	80	60
98	1	99	0.5665	0.0444	99	100	80	60
99	99	100	1.0627	0.0988	100	250	200	150
100	100	101	0.4679	0.0466	101	100	80	60
101	101	102	0.3289	0.0367	102	100	80	60
102	102	103	0.6379	0.0576	103	100	80	60
103	103	104	0.793	0.0713	104	100	80	60
104	104	105	0.897	0.0807	105	100	80	60

Branch No.	Sending Bus	Receiving Bus	Resistance(r) (Ω)	Reactance (x) (Ω)	Bus No.	Load in KVA	Load (P) (kW)	Load (Q) (kVAR)
105	105	106	0.1912	0.0172	106	100	80	60
106	106	107	0.998	0.0832	107	100	80	60
107	107	108	0.3156	0.0292	108	100	80	60
108	108	109	1.2639	0.1169	109	250	200	150
109	109	110	1.2902	0.1226	110	200	160	120
110	110	111	1.1095	0.1087	111	100	80	60
111	111	112	0.3657	0.0401	112	100	80	60
112	112	113	0.2728	0.0334	113	100	80	60
113	113	114	0.6832	0.0728	114	100	80	60
114	114	115	0.3902	0.0361	115	100	80	60
115	115	116	1.0516	0.0801	116	100	80	60
116	116	117	0.4209	0.0382	117	100	80	60
117	117	118	0.3711	0.0307	118	200	160	120
118	118	119	0.1835	0.0165	119	200	160	120
119	119	120	0.5923	0.0492	120	100	80	60

Branch No.	Sending Bus	Receiving Bus	Resistance(r) (Ω)	Reactance (x) (Ω)	Bus No.	Load in KVA	Load (P) (kW)	Load (Q) (kVAR)
120	120	121	0.2623	0.0249	121	200	160	120
121	121	122	0.8877	0.0825	122	250	200	150
122	122	123	0.2716	0.0244	123	100	80	60
123	123	124	0.4503	0.0378	124	100	80	60
124	1	125	0.2651	0.0402	125	100	80	60
125	125	126	0.8645	0.0754	126	100	80	60
126	126	127	1.1267	0.097	127	250	200	150
127	127	128	0.8188	0.0663	128	200	160	120
128	128	129	0.1204	0.0183	129	100	80	60
129	129	130	0.7108	0.0631	130	100	80	60
130	130	131	0.1002	0.009	131	100	80	60
131	131	132	1.04	0.0983	132	100	80	60
132	132	133	0.8599	0.0649	133	100	80	60
133	133	134	0.7478	0.0715	134	100	80	60
134	134	135	1.2818	0.1065	135	200	160	120

Branch No.	Sending Bus	Receiving Bus	Resistance(r) (Ω)	Reactance (x) (Ω)	Bus No.	Load in KVA	Load (P) (kW)	Load (Q) (kVAR)
135	135	136	0.7899	0.063	136	100	80	60
136	136	137	0.4022	0.0449	137	100	80	60
137	137	138	0.365	0.0363	138	100	80	60
138	138	139	0.7081	0.0472	139	100	80	60
139	139	140	1.3756	0.121	140	100	80	60
140	140	141	1.2131	0.0944	141	100	80	60
141	141	142	1.1871	0.1101	142	200	160	120

APPENDIX - D: Comparison table of Pulchowk DCS network before and after reconfiguration

Before configuration					After Configuration				
Bus No.	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**	**Bus No.**	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**
1	1	0	0	0	1	1	0	0	0
2	0.99871867	0.250584151	0.02263385	0.000794	2	0.996283696	0.250584	0.022634	0.000794
3	0.998440951	0.032435885	0.00316731	0.000964	3	0.995127055	0.032436	0.003167	0.000964
4	0.998244242	0.007765537	0.00060819	0.00109	4	0.99306726	0.007766	0.000608	0.00109
5	1	2.921381863	0.28913334	0.002824	5	1	2.921382	0.289133	0.002824
6	0.996936104	3.084092495	0.34659679	0.004699	6	0.996934125	3.084092	0.346597	0.004699
7	0.995243431	1.520194244	0.24537947	0.005632	7	0.995239601	1.520194	0.245379	0.005632
8	0.992768993	2.121540626	0.22032233	0.007195	8	0.992763995	2.121541	0.220322	0.007195
9	0.991119381	1.298362966	0.11677627	0.008276	9	0.991113922	1.298363	0.116776	0.008276
10	0.83747839	2.568369227	0.24357249	0.010655	10	0.957471914	2.568369	0.243572	0.010655

Before configuration					**After Configuration**				
Bus No.	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**	**Bus No.**	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**
11	0.836387301	0.669933753	0.0513839	0.011402	11	0.956380793	0.669934	0.051384	0.011402
12	0.836261565	0.070375773	0.00771499	0.011482	12	0.956255009	0.070376	0.007715	0.011482
13	0.835846127	0.215755373	0.02402693	0.011746	13	0.955839409	0.215755	0.024027	0.011746
14	0.834872916	0.46673053	0.05218191	0.012366	14	0.954865828	0.466731	0.052182	0.012366
15	0.833273808	0.704266176	0.07785097	0.013391	15	0.953266172	0.704266	0.077851	0.013391
16	0.832834902	0.160746626	0.01442198	0.013687	16	0.952827226	0.160747	0.014422	0.013687
17	0.831806075	0.32929333	0.03740289	0.014345	17	0.951798049	0.329293	0.037403	0.014345
18	0.831181344	0.140323884	0.0121818	0.01477	18	0.951173303	0.140324	0.012182	0.01477
19	0.830623339	0.079246594	0.00762713	0.015143	19	0.950615232	0.079247	0.007627	0.015143
20	0.830600083	0.000941677	9.35E-05	0.015158	20	0.950591973	0.000942	9.35E-05	0.015158
21	1	0.916021797	0.0764175	0.016341	21	1	0.915363	0.076363	0.01634
22	0.999627609	0.181841036	0.01909682	0.016589	22	0.999627651	0.181699	0.019082	0.016588

Before configuration					**After Configuration**				
Bus No.	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**	**Bus No.**	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**
23	0.998542804	0.445702188	0.04189444	0.017329	23	0.998543168	0.445286	0.041855	0.017327
24	0.997266818	0.462427255	0.03929023	0.01822	24	0.997267772	0.461934	0.039248	0.018217
25	0.995614332	0.461047408	0.04147955	0.019367	25	0.996284148	0.275213	0.023384	0.018906
26	0.994565643	0.250184097	0.02159886	0.020103	26	0.995235744	0.249838	0.021569	0.01964
27	0.994213244	0.061363123	0.00637171	0.020342	27	0.994883381	0.061278	0.006363	0.019879
28	0.994038469	0.02379243	0.00179116	0.020468	28	0.994708678	0.02376	0.001789	0.020004
29	0.993347634	0.064575965	0.00560019	0.020955	29	0.99401805	0.064487	0.005592	0.02049
30	0.993217425	0.005337676	0.00055907	0.021043	30	0.993887856	0.00533	0.000558	0.020578
31	0.911416784	2.221359505	0.19608431	0.023253	31	0.87782245	0.399781	0.03529	0.021481
32	0.876172598	3.775424259	0.28655605	0.02734	32	0.87557534	0.574025	0.043569	0.023008
33	0.870059729	4.124911403	0.34887916	0.032105	33	0.873178938	0.508902	0.043042	0.024596
34	0.836562592	2.187474691	0.21966452	0.034784	34	0.871954908	0.206512	0.020738	0.02537

Before configuration					After Configuration				
Bus No.	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**	**Bus No.**	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**
35	0.835304825	0.740578344	0.06653561	0.035778	35	0.871575647	0.04882	0.004386	0.025609
36	0.83358481	0.970321948	0.09458197	0.037124	36	0.871103903	0.050698	0.004942	0.025896
37	0.831719755	0.890751234	0.08902614	0.038593	37	0.840843732	0.007237	0.000723	0.026018
38	0.79912946	1.135953214	0.10286429	0.040694	38	0.810710695	1.098354	0.09946	0.027979
39	1	1.880156748	0.14127135	0.044457	39	1	1.817869	0.136591	0.031494
40	0.997422025	0.964437708	0.08817135	0.0466	40	0.997414683	0.932432	0.085245	0.033493
41	0.991442177	2.019197007	0.13683564	0.051904	41	0.99141045	1.952062	0.132286	0.038448
42	0.83691566	1.299787554	0.1169307	0.055818	42	0.956866756	1.256496	0.113036	0.042098
43	0.919501157	1.798916653	0.16186209	0.062371	43	0.919420007	1.738893	0.156461	0.048208
44	0.915937977	0.702158061	0.0631644	0.065584	44	0.915839495	0.678699	0.061054	0.051203
45	0.914090021	0.32152898	0.02892075	0.067267	45	0.913982071	0.31078	0.027954	0.052771
46	0.913468123	0.093654161	0.00841685	0.067836	46	0.913356886	0.090521	0.008135	0.053302

Before configuration					After Configuration				
Bus No.	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**	**Bus No.**	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**
47	0.911585127	0.270471333	0.02433474	0.069568	47	0.911463728	0.261422	0.023521	0.054916
48	0.879509966	0.249767292	0.02193175	0.0715	48	0.879376739	0.241406	0.021198	0.056717
49	0.875639417	0.381116524	0.02620097	0.075285	49	0.875479996	0.368351	0.025323	0.06025
50	0.873934702	0.12649567	0.00849757	0.076974	50	0.873763179	0.122258	0.008213	0.061826
51	0.873931388	0.000161456	1.35E-05	0.076977	51	0.873759844	0.000156	1.31E-05	0.061829
52	1	1.73633716	0.17984153	0.079781	52	1	1.677822	0.173781	0.064439
53	0.993709244	3.512197828	0.28584526	0.086179	53	0.993655824	3.393781	0.276208	0.070402
54	0.992576242	0.509844014	0.05274577	0.087298	54	0.992513752	0.492644	0.050966	0.071443
55	0.839442954	1.263805725	0.12491804	0.090449	55	0.959353892	1.221156	0.120702	0.074376
56	0.835233742	1.523729738	0.11968734	0.094916	56	0.955103324	1.472295	0.115647	0.07854
57	0.833820892	0.357857298	0.03702991	0.096359	57	0.953677715	0.345774	0.03578	0.079882
58	0.833146484	0.13876499	0.0124739	0.097069	58	0.952996708	0.134079	0.012053	0.080543

Before configuration					After Configuration				
Bus No.	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**	**Bus No.**	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**
59	0.832088458	0.163168666	0.01502435	0.098182	59	0.95192831	0.157658	0.014517	0.08158
60	0.831660823	0.044110666	0.00396527	0.098635	60	0.9514964	0.042621	0.003831	0.082002
61	1	0.003984571	0.00037666	0.098717	61	1	0.00385	0.000364	0.082078
62	0.997147659	2.603555387	0.23411656	0.101983	62	0.997107941	2.516461	0.226285	0.085119
63	0.994402564	2.387784321	0.19946567	0.10521	63	0.994322072	2.307934	0.192795	0.088127
64	0.838648759	4.710295501	0.40768882	0.112064	64	0.958479235	4.552836	0.39406	0.094513
65	0.836342123	1.770365034	0.15620868	0.114853	65	0.956135375	1.711209	0.150989	0.09711
66	0.919837018	4.842832346	0.4288399	0.122854	66	0.919520674	4.68105	0.414514	0.104564
67	0.914849347	3.464218471	0.30694199	0.129138	67	0.914443904	3.348545	0.296693	0.110418
68	0.9124231	1.602573277	0.16121165	0.132167	68	0.911974619	1.549073	0.15583	0.113238
69	0.910670439	1.061606426	0.10732787	0.134375	69	0.910190146	1.026181	0.103746	0.115293
70	0.879821143	0.488101979	0.05207972	0.135439	70	0.879325515	0.471817	0.050342	0.116283

Before configuration					After Configuration				
Bus No.	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**	**Bus No.**	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**
71	0.878118717	0.888323944	0.09103485	0.137605	71	0.877591338	0.8587	0.087999	0.1183
72	0.87611705	0.954467401	0.07945592	0.140275	72	0.875548926	0.922654	0.076808	0.120789
73	0.873765018	0.981060818	0.08622331	0.143417	73	0.873148585	0.948376	0.083351	0.123717
74	0.870608064	1.132733718	0.10167241	0.147671	74	0.839925368	1.095011	0.098286	0.127681
75	0.839189033	0.341091623	0.03067281	0.149603	75	0.838475859	0.329737	0.029652	0.129481
76	0.838734441	0.054754401	0.00492409	0.150224	76	0.838011406	0.052932	0.00476	0.130061
77	0.838588461	0.008803861	0.00078648	0.150424	77	0.837862244	0.008511	0.00076	0.130247
78	1	9.632574707	0.86617908	0.158015	78	1	9.367721	0.842363	0.137358
79	0.995601321	9.343560161	0.78052255	0.165748	79	0.995420297	9.088063	0.759179	0.144611
80	0.83622409	19.60481794	1.69685005	0.182818	80	0.955633361	19.07173	1.65071	0.160627
81	0.832543376	7.330501384	0.64680895	0.189805	81	0.951779832	7.133354	0.629414	0.167189
82	0.912371538	19.99162584	1.77028775	0.209977	82	0.91109653	19.45705	1.72295	0.186149

Before configuration					After Configuration				
Bus No.	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**	**Bus No.**	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**
83	0.874464259	15.43551389	1.36764104	0.226582	83	0.872756119	15.02478	1.331249	0.201776
84	0.87083518	6.524981917	0.65638376	0.23432	84	0.838921796	6.352773	0.63906	0.20906
85	0.838125064	4.712451193	0.47642641	0.240226	85	0.836053259	4.588562	0.463901	0.214623
86	0.836818217	2.16261189	0.23074731	0.243083	86	0.834669365	2.105963	0.224703	0.217313
87	0.834085349	4.371454328	0.44798375	0.249213	87	0.83176955	4.257361	0.436291	0.22309
88	0.830946057	4.732027224	0.39392398	0.256774	88	0.798420101	4.609359	0.383712	0.230231
89	0.79897205	2.716948929	0.28507601	0.261381	89	0.796318058	2.646713	0.277707	0.234577
90	0.787170054	2.237113109	0.20890038	0.26578	90	0.794392265	2.179568	0.203527	0.238733
91	0.782653748	1.607852094	0.15725059	0.2695	91	0.792770687	1.566681	0.153224	0.242247
92	0.778606511	1.010874247	0.10420348	0.272064	92	0.791650708	0.985039	0.10154	0.24467
93	0.77326961	1.078854536	0.09858726	0.275472	93	0.790216224	1.051375	0.096076	0.247893
94	0.772819772	0.279522624	0.02546962	0.276629	94	0.78973312	0.272419	0.024822	0.248988

Before configuration					After Configuration				
Bus No.	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**	**Bus No.**	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**
95	0.770204554	0.341297849	0.02312478	0.278317	95	0.789068871	0.332634	0.022538	0.250588
96	0.769178963	0.094383625	0.00846066	0.279167	96	0.788718746	0.091992	0.008246	0.251392
97	0.768747735	0.024857188	0.00248694	0.279501	97	0.788577889	0.024228	0.002424	0.251708
98	0.767164341	0.010310292	0.00082757	0.279781	98	0.788465447	0.010049	0.000807	0.251973
99	1	10.87535436	0.8523667	0.288499	99	1	10.72755	0.840783	0.260331
100	0.995696955	19.26964527	1.79151308	0.304485	100	0.995155815	19.01351	1.7677	0.275666
101	0.993996286	7.293447029	0.72638306	0.311066	101	0.993229673	7.20173	0.717249	0.281988
102	0.992824622	4.808908065	0.53659753	0.315554	102	0.991903622	4.749872	0.53001	0.2863
103	0.990827392	8.729110876	0.78820628	0.324059	103	0.959611235	8.624606	0.77877	0.294491
104	0.838525913	10.13087306	0.9108843	0.334341	104	0.956950439	10.0126	0.90025	0.304407
105	0.836127432	10.66958545	0.95990585	0.345641	105	0.954154308	10.54802	0.948969	0.315321
106	0.835650906	2.111314744	0.18992999	0.347972	106	0.953595353	2.087807	0.187815	0.317575

Before configuration					After Configuration				
Bus No.	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**	**Bus No.**	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**
107	0.833401105	10.20086991	0.8504132	0.359741	107	0.950926991	10.09004	0.841174	0.328971
108	0.832718995	2.975853107	0.27533242	0.363326	108	0.950116921	2.944237	0.272407	0.332444
109	0.830212694	10.95584944	1.01332289	0.377157	109	0.917114485	10.84212	1.002804	0.345861
110	0.918074307	8.902055834	0.8459092	0.38984	110	0.914517547	8.814346	0.837575	0.358187
111	0.91649817	6.242316449	0.6115726	0.39974	111	0.912581425	6.183109	0.605772	0.367825
112	0.915997148	1.841977179	0.20197781	0.402833	112	0.911967749	1.824781	0.200092	0.370836
113	0.915629815	1.222057605	0.14962142	0.40501	113	0.911521129	1.210827	0.148246	0.372954
114	0.914845833	2.701990063	0.28791697	0.410148	114	0.910549272	2.677556	0.285313	0.377962
115	0.91446629	1.350979524	0.12498811	0.412902	115	0.910068699	1.338932	0.123874	0.380651
116	0.91362919	3.157076322	0.24047339	0.419836	116	0.878976315	3.129298	0.238358	0.387434
117	0.913300927	1.08354737	0.09834048	0.422408	117	0.87855337	1.07409	0.097482	0.389948
118	0.913051571	0.808719086	0.06690293	0.424496	118	0.878226965	0.801704	0.066323	0.391992

Before configuration					After Configuration				
Bus No.	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**	**Bus No.**	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**
119	0.912946486	0.272957802	0.02454389	0.42535	119	0.878090397	0.270615	0.024333	0.392827
120	0.912693762	0.549286575	0.04562705	0.427527	120	0.877757218	0.544632	0.04524	0.394959
121	0.912590445	0.182727292	0.0173462	0.428363	121	0.877623047	0.181186	0.0172	0.395777
122	0.912354281	0.296456914	0.02755176	0.430322	122	0.877314465	0.29398	0.027322	0.397695
123	0.912323049	0.017917951	0.00160971	0.430589	123	0.877273372	0.017769	0.001596	0.397956
124	0.912298194	0.007427027	0.00062345	0.43081	124	0.877240334	0.007365	0.000618	0.398173
125	1	2.227694444	0.33780957	0.433763	125	1	2.222949	0.33709	0.401072
126	0.999340134	6.635488284	0.57873432	0.442992	126	0.998991704	6.623132	0.577657	0.410181
127	0.998633835	7.86432493	0.67705646	0.454486	127	0.997850625	7.851544	0.675956	0.421543
128	0.998283447	4.40819037	0.35694067	0.461834	128	0.997221638	4.403244	0.35654	0.428822
129	0.998192072	0.512316188	0.07786866	0.462796	129	0.997093795	0.511944	0.077812	0.429773
130	0.997955419	2.65874769	0.23602558	0.468121	130	0.996654927	2.657429	0.235908	0.435053

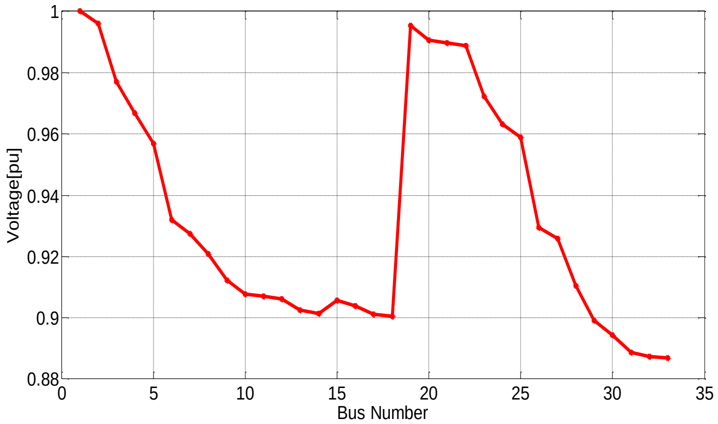
Before configuration					After Configuration				
Bus No.	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**	**Bus No.**	**Bus Voltage(pu)**	**Active Power loss (kW)**	**Reactive Power Loss (Q) (kVAR)**	**Power Angle**
131	0.997926146	0.326536641	0.02932964	0.468822	131	0.996599018	0.326444	0.029321	0.435748
132	0.997648276	2.922788945	0.27625976	0.475582	132	0.99206409	2.922657	0.276247	0.442459
133	0.997537762	2.059366417	0.1554284	0.480741	133	0.990757178	2.059694	0.155453	0.447591
134	0.997406648	1.504981895	0.14389704	0.484859	134	0.985469274	1.505491	0.143946	0.451686
135	0.997292684	2.132095345	0.17714788	0.491274	135	0.982110866	2.133161	0.177236	0.458076
136	0.997259624	0.840940614	0.06707084	0.494437	136	0.979957226	0.841555	0.06712	0.46123
137	0.997214916	0.327841168	0.03659888	0.49585	137	0.924858698	0.328115	0.036629	0.462636
138	0.9971917	0.218588665	0.02173909	0.496947	138	0.86679363	0.218795	0.02176	0.46373
139	0.9871917	0.294490263	0.01962991	0.498718	139	0.842734588	0.294804	0.019651	0.465499
140	0.985176664	0.366147628	0.03220694	0.501475	140	0.8306059	0.366584	0.032245	0.46825
141	0.982178721	0.18162895	0.01413385	0.503296	141	0.821453845	0.181861	0.014152	0.47007
142	0.978168643	0.078994585	0.00732651	0.504486	142	0.804482981	0.0791	0.007336	0.471258

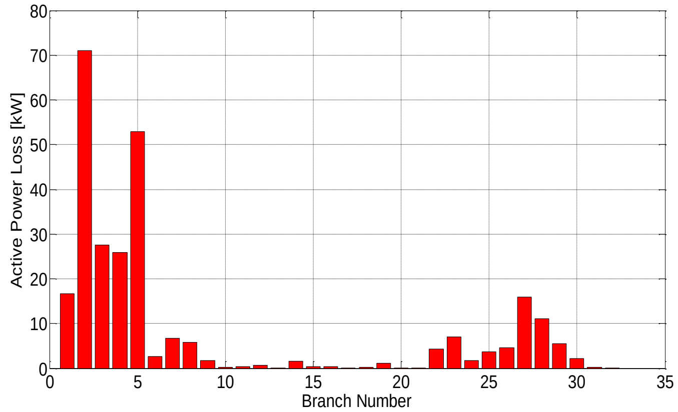
APPENDIX - E: Results of different 13 possible case of Pulchowk DCS power losses.

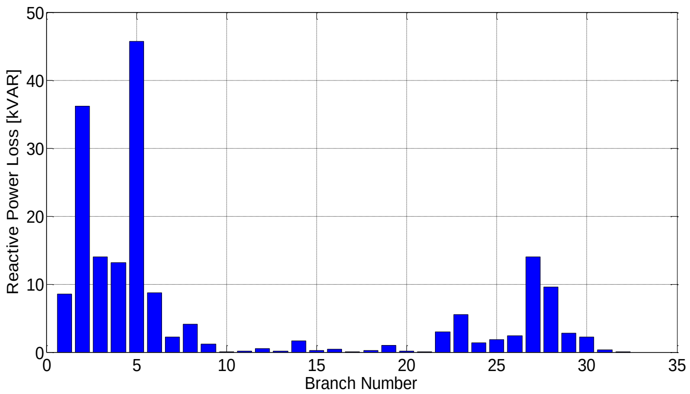
No.of cases	base	1	2	3	4	5	6	7	8	9	10	11	12	13
Active power loss(kW)	1073	1119.57	1036.29	1007.11	1014.82	1027.40	804.01	923.84	819.33	625.76	659.31	632.92	569.95	597.78
Reactive power loss(kVAR)	98.02	102.89	95.60	92.18	92.86	93.98	74.45	84.42	74.64	56.96	61.24	57.28	53.53	54.36

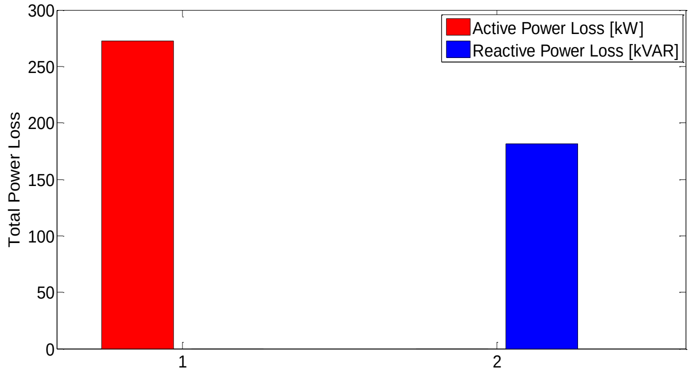
APPENDIX - F: IEEE 33 bus different configuration graph

Case 1:

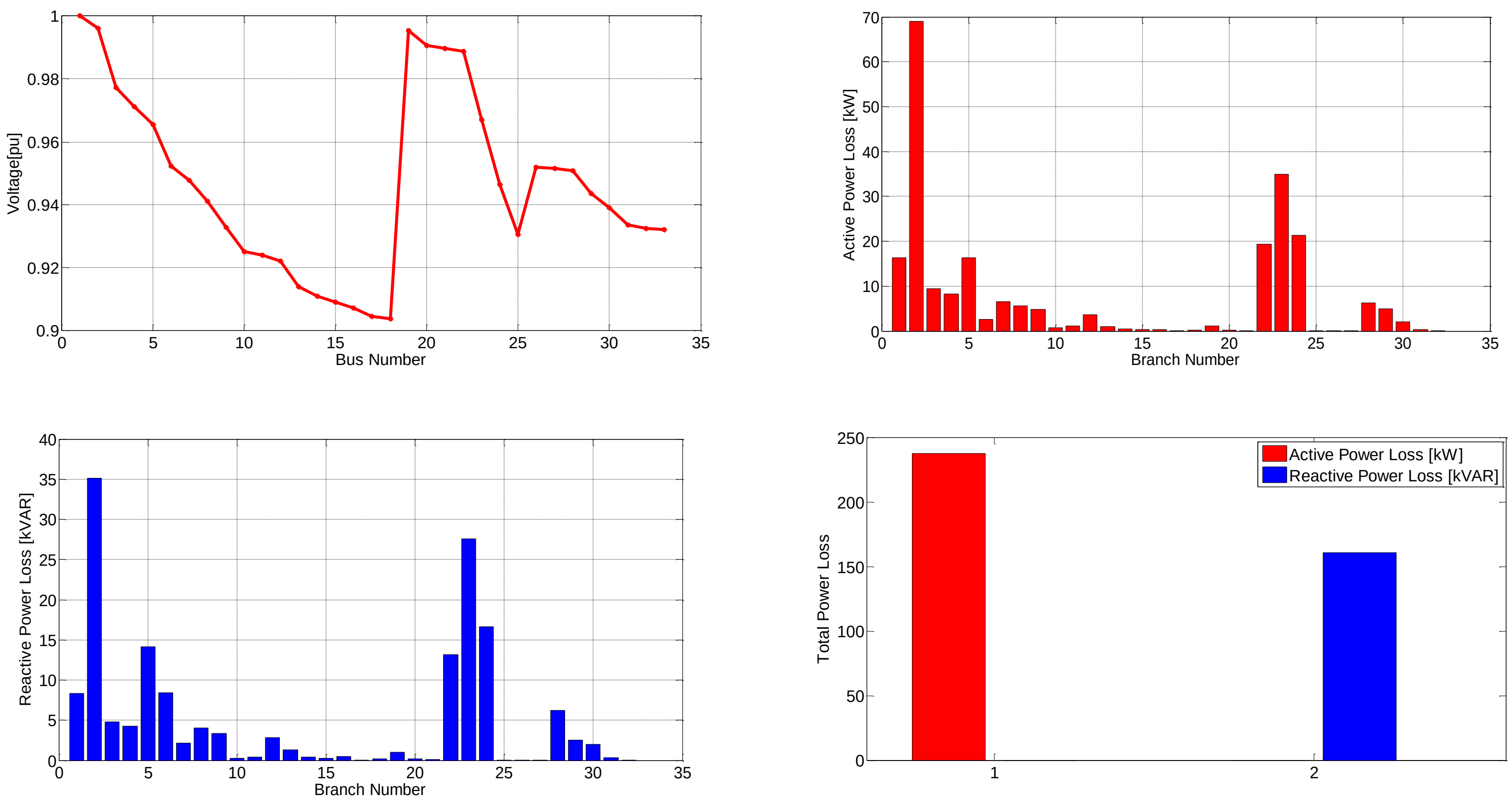




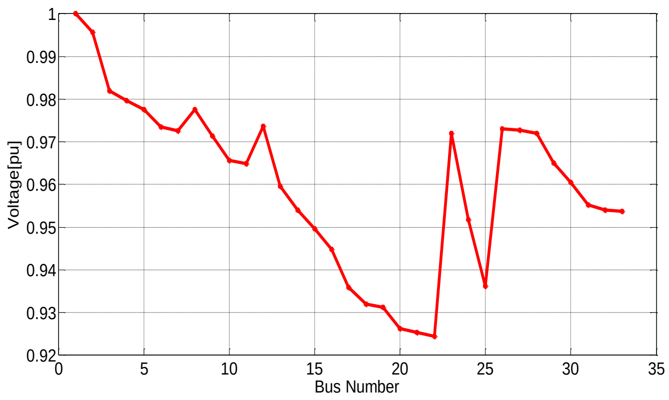


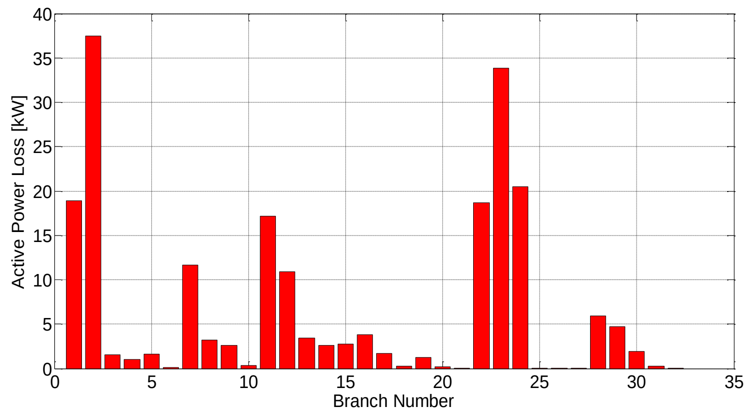


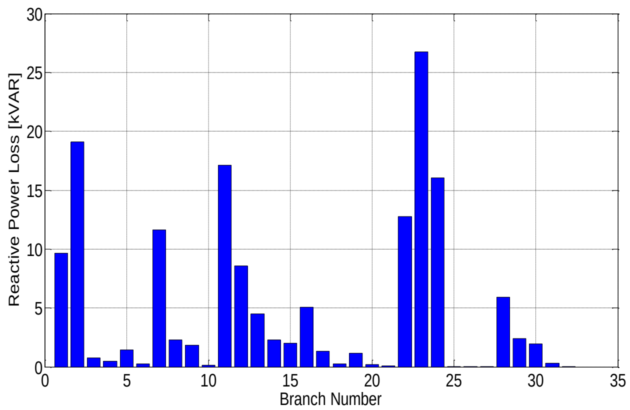
Case 2:

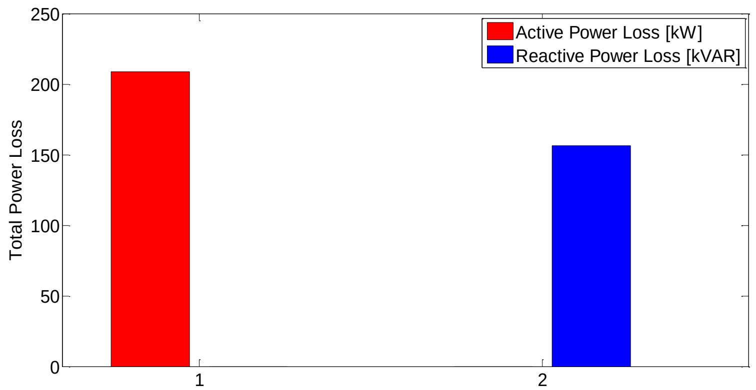


Case 13:

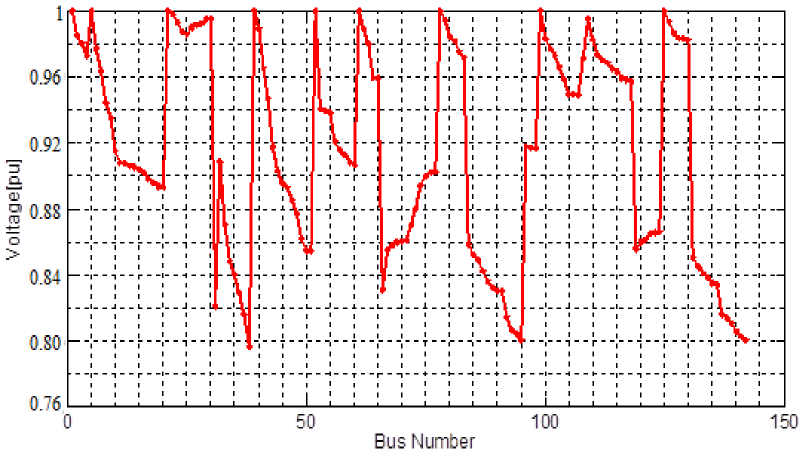

Voltage[pu]
Bus Number

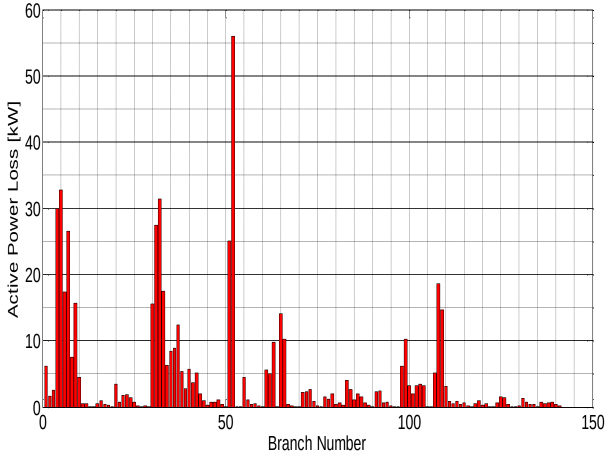

Active Power Loss [kW]
Branch Number

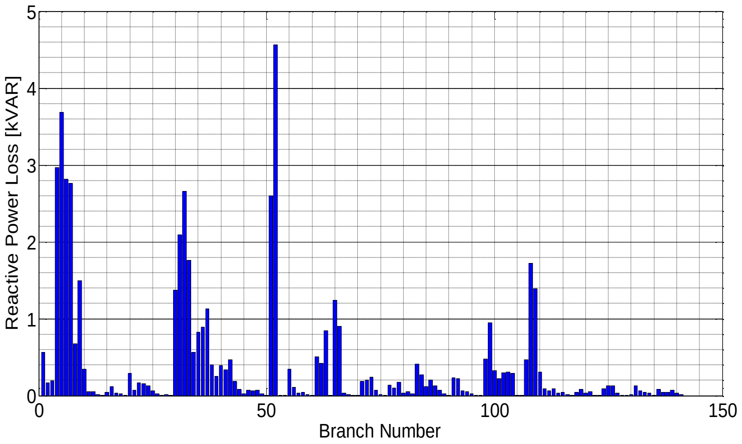

Reactive Power Loss [kVAR]
Branch Number


Total Power Loss
Active Power Loss [kW]
Reactive Power Loss [kVAR]

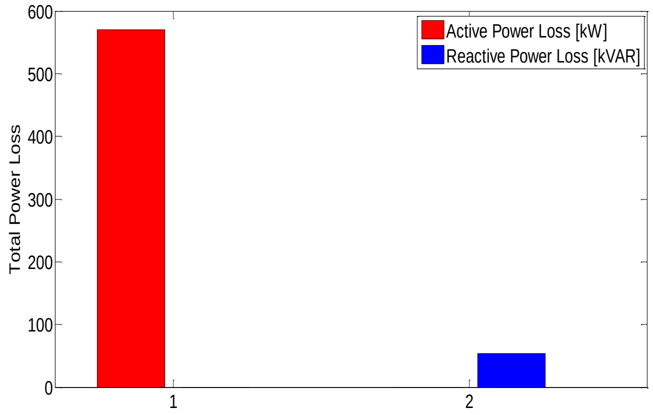
APPENDIX - G: Pulchowk DCS network different configuration graph







Reactive Power Loss [kVAR]
Branch Number
0
50
100
150
0
1
2
3
4
5



Active Power Loss [kW]
Reactive Power Loss [kVAR]
Total Power Loss
0
100
200
300
400
500
600
1
2

APPENDIX - H: Cost estimation of proposed network of Pulchowk DCS

S.No.	Item Description	Unit	Qty.	Amount(NPR)	Amount(NPR)
(1)	*(2)*	*(3)*	*(4)*	(5)	(6)
A	**Construction of reconfiguration of exiting line with Tie-switches and SESW Switches**				
1	Supply of Tie-switches switches of complet set with associaries	Set	24	335,000.00	8,040,000.00
2	Supply of SESW Switches set with associaries	Set	12	350,000.00	4,200,000.00
3	11 meter PSC pole	No.	35	25,000.00	875,000.00
4	Supply of ACSR Dog Conductor(100 Sqmm)	KM	3	60,118.00	180,354.00
5	11kv Disc Insulator with all Hardwae fittings & accessories complete suitable to ACSR Dog as per TS	Set	70	1500	105,000.00
6	11 KV Pin insulator with GI Spindle set	No.	110	1250	137,500.00
7	Complete earthing Set including copper wire,Rod,pipe & clamp	Set	24	15,000.00	360,000.00
8	Complete Pole Stay Set including stay insulator, stay wire & additional items required for road crossing etc	Set	15	12,000.00	180,000.00
Total material charge					**14,077,854.00**

Installation charges

S. No.	Item Description	Unit	Qty.	nstallation charges	
				Unit Charges	Total Charges
(1)	(2)	(4)	(5)	(6)	(7)
A	**Construction of reconfiguration of exiting line with Tie-switches and SESW Switches**				
1	installation of Tie-switches complet set	Set	24	32000	768000.00
2	installation of SESW switches complet set	Set	12	35000	420000.00
3	Erection of PSC POLE of 11M height with approved foundation type including erection of GI items, angles & bracings	No.	35	10,000	350000.00
4	Stringing of ACSR DOG conductors with Pin/Disc Insulator using preformed insulator binding fitting (including supply of preformed insulator binding fitting), fixing and fitting of all accessories like top bracket / A-clamp, V-cross arm, Top channel, cross bracing, back clamp, support clamp as per NEA standard	Meter	3000	56.25	168750.00
5	Erection of stay set complete	Set	15	13,000.00	195,000.00
6	Installation of 20mm dia 2500 mm long GI rod erthing	Set	36	15,000.00	540,000.00
Total Installation charge					**2,441,750.00**
!3 % VAT of total labour costs					**317,427.50**
Total Investment for the structure design of Pulchowk DCS reconfiguration network					**16,837,031.50**

Source: Center store of NEA 3-No.previlance office,Kathmandu,Nepal

APPENDIX I:-Table of cash flow of the proposed reconfiguration structure investment.

Years	Cash Flow	yearly O/M cost	Salvage value	Net Cash Flow	PV Cash	Discounted Cash flow	Remarks
0	(16,837,031.50)	0		(16,837,031.50)	(16,837,031.50)	(16,837,031.50)	
1	28,446,873.84	(252,555.47)		28,699,429.31	26,573,545.66	9,736,514.16	
2	28,446,873.84	(252,555.47)		28,699,429.31	24,605,134.87	34,341,649.03	
3	28,446,873.84	(252,555.47)		28,699,429.31	22,782,532.29	57,124,181.32	
4	28,446,873.84	(252,555.47)		28,699,429.31	21,094,937.30	78,219,118.62	
5	28,446,873.84	(252,555.47)		28,699,429.31	19,532,349.35	97,751,467.97	
6	28,446,873.84	(252,555.47)		28,699,429.31	18,085,508.66	115,836,976.64	
7	28,446,873.84	(252,555.47)		28,699,429.31	16,745,841.35	132,582,817.99	
8	28,446,873.84	(252,555.47)		28,699,429.31	15,505,408.66	148,088,226.65	
9	28,446,873.84	(252,555.47)		28,699,429.31	14,356,859.87	162,445,086.52	

Years	Cash Flow	yearly O/M cost	Salvage value	Net Cash Flow	PV Cash	Discounted Cash flow	Remarks
10	28,446,873.84	(252,555.47)		28,699,429.31	13,293,388.77	175,738,475.29	
11	28,446,873.84	(252,555.47)		28,699,429.31	12,308,693.30	188,047,168.59	
12	28,446,873.84	(252,555.47)		28,699,429.31	11,396,938.25	199,444,106.84	
13	28,446,873.84	(252,555.47)		28,699,429.31	10,552,720.60	209,996,827.44	
14	28,446,873.84	(252,555.47)		28,699,429.31	9,771,037.59	219,767,865.03	
15	28,446,873.84	(252,555.47)	(505,110.95)	29,204,540.26	9,206,489.06	228,974,354.09	
	Net Present value (NPV)				**228,974,354.09**		
	IRR of the investment				**150%**		
	Discounted payback period in years					**0.63**	

Source: (NEA, 2015-2016), (NRB, 2018) and (Powerwater, 2018)