

Reliability Enhancement and Power Loss Reduction in Distribution System by Optimal Reconfiguration (A case study of Kombolcha Distribution Network)

A Thesis submitted to the Department of Electrical and Computer Engineering of Hawassa University in partial Fulfillment of the Requirements for the Degree of Master of Science in Power System and Energy Engineering.

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DISTRIBUTION SYSTEM BY OPTIMAL RECONFIGURATION
(A CASE STUDY OF KOMBOLCHA DISTRIBUTION NETWORK)**

**BY
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**A THESIS SUBMITTED TO DEPARTEMENT OF ELECTRICAL AND
COMPUTER ENGINEERING, HAWASSA INSTITUTE OF TECHNOLOGY,
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HAWASSA UNIVERSITY
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I the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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Abstract

The purpose of power system is to provide an adequate and secured electrical supply to its customers as economical as possible with reasonable level of reliability. In distribution system, reliability and power loss are the major issues for the consumers and utility. This thesis presents a research work on the reliability assessment and optimal reconfiguration of Kombolcha radial distribution network to minimize the overall distribution losses, to enhance reliability and improve the voltage profile by using a proposed MSSO algorithm and ETAP. In the power flow analysis, the effectiveness of the proposed MSSO algorithm is conducted and compared in two cases (before reconfiguration and after reconfiguration) of Kombolcha distribution at line-3, which is severe. A modeling of electrical system elements were first developed to have a complete single line diagram of the existing network using ETAP. The reliability enhancement is measured and analysis by different reliability indices that include SAIFI, SAIDI and EENS. Reliability index values have been compared with standard benchmark values and comparison clearly indicates that Kombolcha feeder-3 distribution system is extremely unreliable. Generally, after optimal reconfiguration of the network, power loss of the system is minimized by 60%, SAIFI has been reduced by 85% as compared with the average reliability index value of the system in the base years. Similarly, SAIDI and EENS have been reduced by 86% and 70% respectively.

Key words: Distribution Network, Reconfiguration, Reliability Enhancement, Power Loss Reduction, Optimization.

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List of Abbreviation

AC	Alternative Current
ACO	Ant Colony Optimization
AENS	Average Energy Not Supplied
ASAI	Average Service Availability Index
ASUI	Average Service Unavailability Index
ACR	Automatic Circuit Reclosers
BMIC	Binary Modified Imperialist Competitive
BPSO	Binary Particle Swarm Optimization
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
CIC	Customer Interruption Costs
DG	Distribution Generation
DNR	Distribution Network Reconfiguration
ETAP	Electrical Transient Analysis Program
EEPCO	Ethiopian Electric Power Corporation Organization
EEU	Ethiopian Electric Utility
EENS	Expected Energy Not Supply
ETB	Ethiopian Birr
FA	Feeder Automation
FCEP	Fuzzy Controlled Evolutionary Programming
GA	Genetic Algorithm
Hr	Hour
I	Current

IEEE	International Electrical and Electronics Engineering
KDS	Kombolcha Distribution System
KV	Kilo Volte
KVA	Kilo Volt Ampere
KW	Kilo Watt
KWH	Kilo Watt Hour
MSSO	Modified Shark Smell Optimization
MW	Mega Watt
MWH	Mega Watt Hour
NGO	Non Governmental Organization
OF	Objective Function
P	Real Power
PSO	Particle Swarm Optimization
SPSO	Selective Particle Swarm Optimization
Q	Reactive Power
RDS	Radial Distribution System
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
SMC	Sequential Monte Carlo
SS	Secondary Substation
SSO	Shark Smell Optimization
USD	US Dollar
V	Voltage

Chapter 1

Introduction

1.1 Background

The distribution systems act as medium providing final links between the electric utility and customers. The main reasons of unavailability in supplying electric energy to users are the existence of failures in distribution system components. In real world, most of failures occur in the distribution voltage level. There are so many strategies to enhance reliability and power loss in distribution network such as [1, 2] installation of highly reliable equipment for protection like reclosing and switching, automation, acceleration of restore processes by employing faster crew, faster fault prophecy techniques & fewer equipment failures to avoid contingencies. There are different techniques used for reliability enhancement and power loss minimization such as distribution feeder reconfiguration, placement of distributed generation (DG) sources, maintenance prioritization and the placement of smart grid technologies such as micro phasor measurement units and Flexible AC Transmission System (FACTS) devices.

Reconfiguration of distribution network is one of the most important strategies among reliability and power loss improvement schemes. Normally, two types of switches are usually installed in distribution systems along the main line and laterals. These are normally closed switches and normally open switches. The switch used to isolate a faulted section (unhealthy) of the system from the healthy part is sectionalizing and tie switch recovers loads that have been disconnected by transferring some of loads to other supporting distribution feeders without violating operation and engineering constraints.

The main aim of distribution network reconfiguration, which is to change the open/close status of sectionalizing and tie switches, is done in order to achieve a radial operating structure that optimizes certain objectives while satisfying operational constraints without islanding any load to satisfy both customer and Ethiopian utility company [1]. Since the status of both switches has a main cause on branch power flows as well as on interruption durations in the event of a system failure, power losses and reliability of a distribution system can be effectively improved by reconfiguration [3]. A great deal of work has been done in literature on network reconfiguration (also known as system reconfiguration). In distribution networks mainly with the objective function of active power loss reduction and reliability enhancement. The fact that the cost of active power losses occupies considerable amount of operation cost and reliability mainly affects the cost and satisfaction of customers and the utility. Recently distribution system automation has captured the attention by different researchers and utility companies over the last decade. Even if, a lot of research have been undertaken and many works are still ongoing at the moment on distribution system automation, due to technological innovations and increasing connection of distributed energy source in to existing distribution network. The thesis is focused on developing an optimal reconfiguration model for a radial distribution network at Kombolcha distribution network by using modified shark smell as a case study. Reliability means the probability that a system or components perform their assigned task for a given period under the operating conditions stumbled upon during its anticipated life time.

To achieve an acceptable level of reliability, quality and safety at an economic price, the utility have to create and improve the systems reliability continuously depending upon the requirement of the customers. Reliability assessment methods allow the evaluation of the reliability of systems. The methods provide important information on how to improve a systems life to reduce safety risk and hazards [1, 3]. From these main components of electrical power, distribution system is a largest part of network in electrical power system. It can be defined as the part of power system this distributes power to various customers in ready to use form at their place of consumption. So, utilities have to ensure reliable and efficient cost effective service, while providing service voltages and power quality within the specified range.

Ethiopian electricity sector (EEPCO) constitutes relatively a very poor distribution system in several utilities. Despite the realization of the importance of the distribution sector, the performances of Ethiopian distribution utilities have not been measured empirically so far by the

organization. The performance evaluation of the distribution sector is important in order to assess the impact of reform measures. Usually engineers try to achieve the required reliability level with minimal cost.

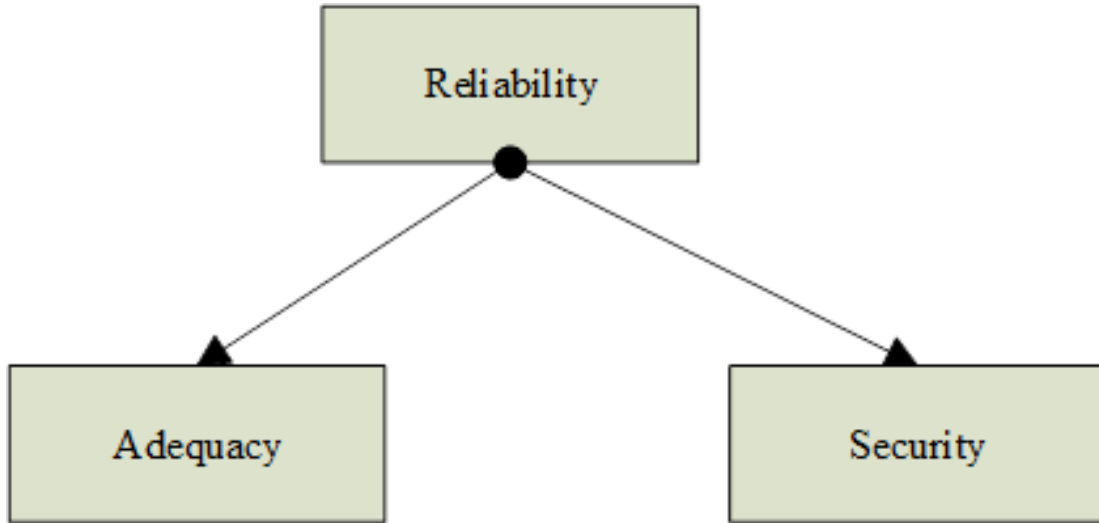


Figure 1.1: General categories of reliability.

In figure 1.1 shows a basic category of distribution reliability i.e adequacy and security. Adequacy relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. These include the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities required to transport the energy to the actual consumer load points. Security relates to the ability of the system to respond to disturbances arising within that system. Most of the probabilistic techniques presently available for power system reliability evaluation are in the domain of adequacy assessment.

1.1.1 Optimization

System optimization has always been a favourite topic in academia, but until recently had little applicability to distribution systems. With the exponential increase in computation power, applying optimization techniques to practical distribution reliability and power loss problems are becoming feasible and a deeper understanding of optimization is warranted. More importantly, it will provide a theoretical foundation so that optimization techniques can be properly applied to distribution systems and increase the probability of providing higher reliability and less power loss at lower cost. For distribution system reliability, optimization problems generally take one

of two forms. The first is to minimize cost while satisfying all reliability, power loss and voltage profile constraints. The second is to minimize customer interruptions subject to cost constraints. Optimization is the process of making something better than initial. All engineer and scientist conjures up a new idea and optimization improves on that idea. Optimization consists in trying variations on an initial concept and using the information gained to improve on the idea. A computer is the perfect tool for optimization as long as the idea or variable influencing the idea can be input in electronic format. Feed the computer some data and out comes the solution.

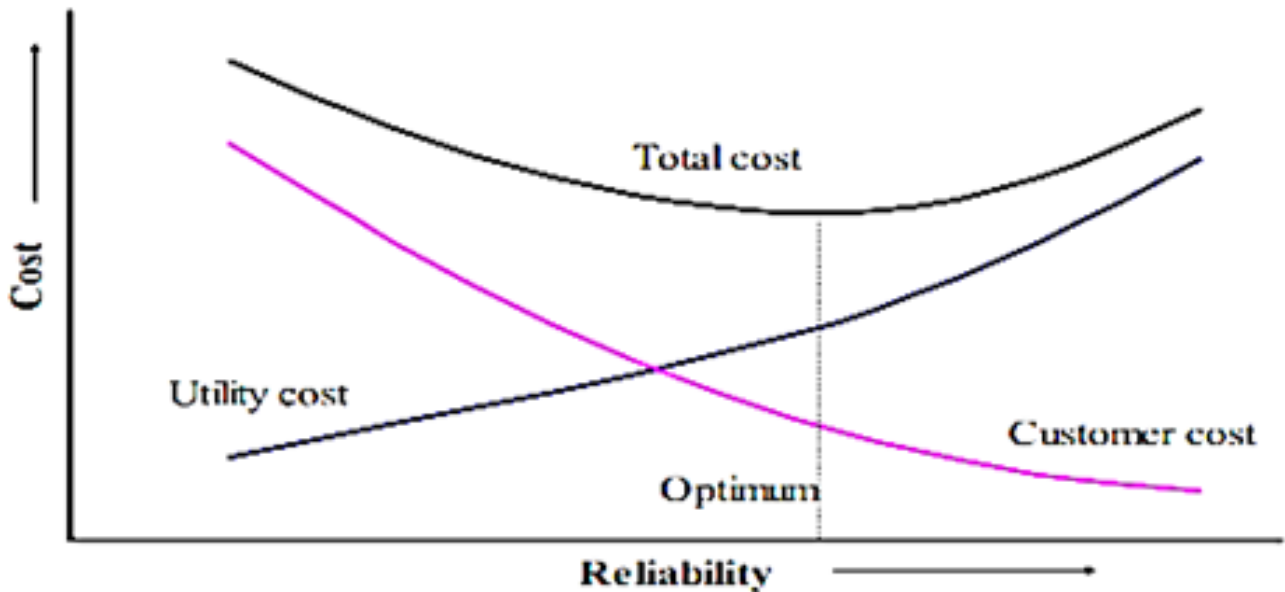


Figure 1.2: General relation between cost and reliability of distribution network.

As shown in figure 1.2, the utility cost, i.e. investment, maintenance and operating cost increases while the socio economic customer interruption cost decreases with increase in the level of service reliability. The total cost is the sum of the two curves.

1.2 Statement of the Problem

Distribution networks are usually considered the simplest kind of power system than others. The most attention, regarding performance evaluation or reliability analysis and power loss minimization had been put into power generation and transmission. However, in most power systems, around 80% of customer interruption is due to distribution system failure and more

than 80% power loss occurred at distribution system. This makes both the assessment and enhancement of reliability and power loss reduction on distribution network more significant. Every interruption of power in a given area leads to several losses. Power interruptions can result in fatalities, injuries, cause for water supply interruption, loss of communication, days of lost productivity and thousands of dollars in production losses and equipment repairs. Even though, the source cause of failures in distribution system can be reduced and improved with low capital compared to the outage costs incurred by the customer and utility, minimizing the total cost and maximizing system reliability is a difficult task. To evaluate the power outage costs, to analysis the main cause of failures and identify relevant enhancement techniques reliability assessment is the first concern. Optimization and placement of protection devices, sectionalizes and switches in the distribution feeder has significant impact in reliability enhancement and power loss reduction, this will be further evaluated along with the outage mitigation techniques for the distribution system in Kombolcha. Therefore, this thesis, focus on the distribution system of Kombolcha, particularly targeting on selected feeder based on more interruption occurred and by identify critical loads like hospitals and other sensitive types of loads at Kombolcha district's distribution system.

1.3 Objectives

1.3.1 Main objective

The main objective of this thesis is to develop an optimal reconfiguration for radial distribution network, using modified shark smell with a view of enhancement of reliability and reduction of power loss a case study of Kombolcha distribution substation.

1.3.2 Specific objectives

- To assess reliability indices of the existing network of Kombolcha distribution.
- To obtain optimal placement of tie switches by using modified shark smell for power loss minimization and reliability enhancement.
- To design and select tie switches based on line and fault current ratings.

- To analyze the total loss cost and cost benefit of both utility and customer.

1.4 Significant of the Thesis

This thesis output a significant importance of measuring the existing network performance of reliability and power loss, which provide best solution as well as serving as a benchmark for the prediction of the future Kombolcha electrical distribution network.

In general, it has the following advantages:

- To indicate the influence of power interruption on the economy of customers and utility.
- Assess average duration, frequency of power interruption and total power losses per year in the system.
- Enhancement of reliability and power loss minimization using optimal placement of tie switches by modified shark smell and ETAP.

1.5 Scope of the Thesis

The thesis, focus on assessment and enhancement of reliability and power loss reduction of distribution network at Kombolcha distribution system. The parameter used to determine the reliability indices are SAIFI, SAIDI, EENS, voltage profile and power loss to enhancement of distribution network of Kombolcha on selected feeder by optimal placement of tie switches using modified shark smell optimization and ETAP.

Generally, the scopes of this thesis are:

- Assessment of existing system of Kombolcha distribution network.
- Analysis reliability index of Kombolcha distribution, compare the results and evaluate to select the feeder for further improvement.
- The system optimal reconfiguration, which includes tie switches using modified shark smell optimization to power loss minimization and reliability enhancement.
- Finally, determine the total cost loss of utility after enhancement and make a comparison of existing system.

1.6 Methodology

The following activities are performed in this thesis:

Literature review: A number of journals, articles and papers on power distribution system power loss reduction, reliability assessment and improvement, feeder reconfiguration and other related works have been reviewed.

Assessment: Assessment of Kombolcha distribution system, understanding and adopting the system as a whole.

Data collection and analysis: Two years (2010-2011 E.C) interruption data has been collected from Kombolcha. The feeder length, number of poles, number and ratings of transformers has been collected from the existing system and the districts. The collected data has been used to clearly analyze the problems of the feeder under study.

System design: The distribution system is represented using single line diagram and improved network topology reconfiguration with tie switch has been developed.

1. Reliability indices and power losses have been calculated for the existing selected feeder and then modified the system.
2. Based on the result of this analysis and assessment, reconfigured network with inserting of switches have been evaluated for potential reliability enhancement and power loss minimization using ETAP and modified shark smell for determine the optimal place.
3. The system has been designed and simulated using latest electrical software, ETAP 12.6.0 and matlab.
4. The objectives of the thesis are to minimize SAIFI, minimize SAIDI and minimize total cost (including customer interruption cost and utility investment cost) & power loss reduction of Kombolcha distribution system.
5. The optimal topology is achieved tie switch can be installed in one of the feeders to allow for system reconfiguration.
6. Several methods have been developed to determine the best topology for a distribution system. These include heuristic methods, linear programming, neural networks, expert sy-

stems, fuzzy logic, simulated annealing and genetic algorithms. For this thesis, modified shark smell is used since it can produce fast results with best accuracy.

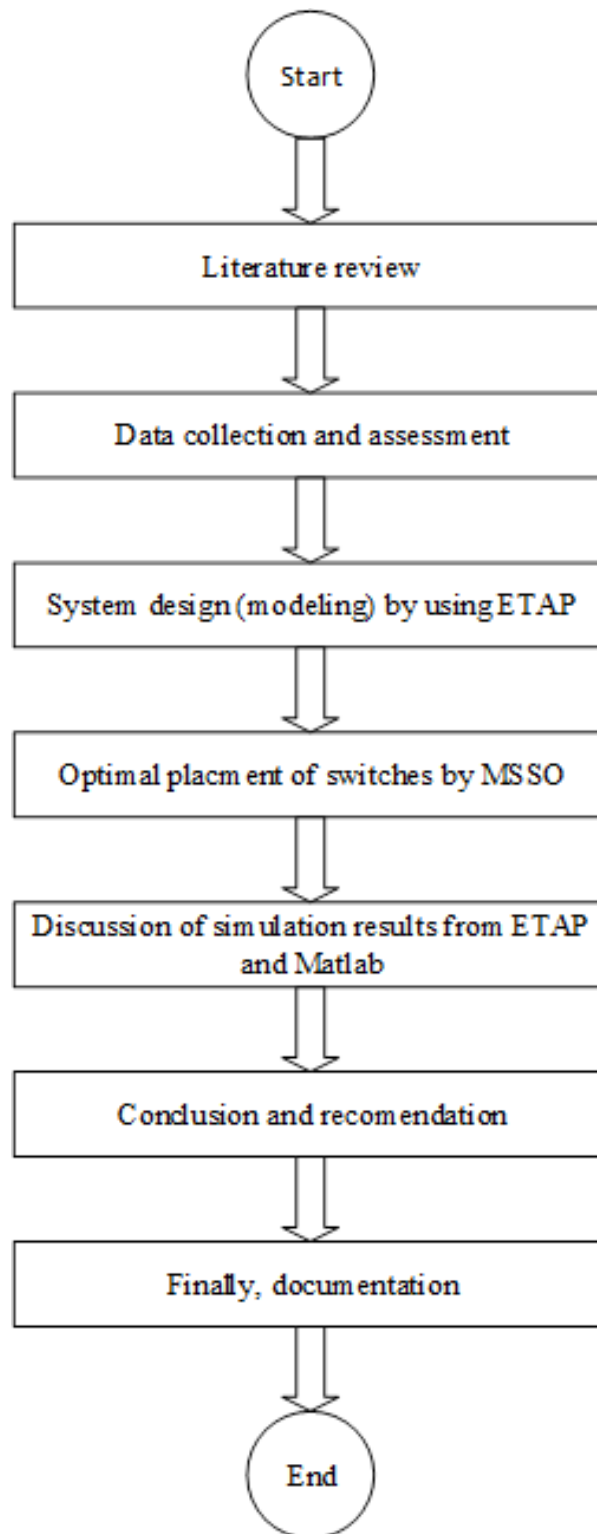


Figure 1.3: The flow chart of thesis.

1.7 Thesis Outline

The content of this thesis is briefly explained as follow:

Chapter one provides a brief description about background, statement of the problem, objectives, scope, significant & methodology of the thesis. Chapter two discussed about distribution literature review of reliability, distribution network configurations, power loss reduction and system reconfigurations methods. Reliability analysis, reliability evaluation, methods of reliability improvement and power loss reductions in distribution system for optimization purpose are explained briefly in this chapter. In chapter three deals about SSO and MSSO optimization methodology are clearly discussed. In chapter four focus on data collection, analysis and ETAP modeling. Chapter five described about simulation results and discussions are presented. Finally, conclusion recommendation and future work were presented in chapter six. The bibliography and appendices include, substation power interruption reports, load distribution of selected feeder.

Chapter 2

Literature Review

2.1 Introduction

Electric power is a basic element in any modern society because the life of human being directly or indirectly depends on electric power [1]. The availability of a reliable electric power delivery at a reasonable cost is very important for the economic growth and development of a country. Electric power utilities throughout Ethiopia, therefore; endeavor to meet customer demands as economically as possible at a reasonable service of reliability. To meet customer demands, the power utility has to evolve and the distribution system have to be upgraded, operated and maintained accordingly [3]. The economic and social effects of loss in electric service have significant impacts on both the utility supplying electric energy and the end users of electric service. The power system is vulnerable [4] to system abnormalities, such as control failures, protection or communication system failures and disturbances such as; lightning and human operational errors. Therefore, maintaining a reliable power supply is a very important issue for power systems design and operation.

2.2 Distribution System

Electric power system transfers electricity from the generation station (plant) to the end consumers. The power can be transmit in to the customers through different stages from generation, transmission, distribution and finally to the loads as shown in figure 2.1. A distribution network transmits power from the transmission system to the consumers' loads at low voltage levels. In Ethiopia

distribution transformers are used to step down the voltage from 33 kV or 15 kV to 380 V for the three phase consumers or 220 V for the single phase consumers [5].

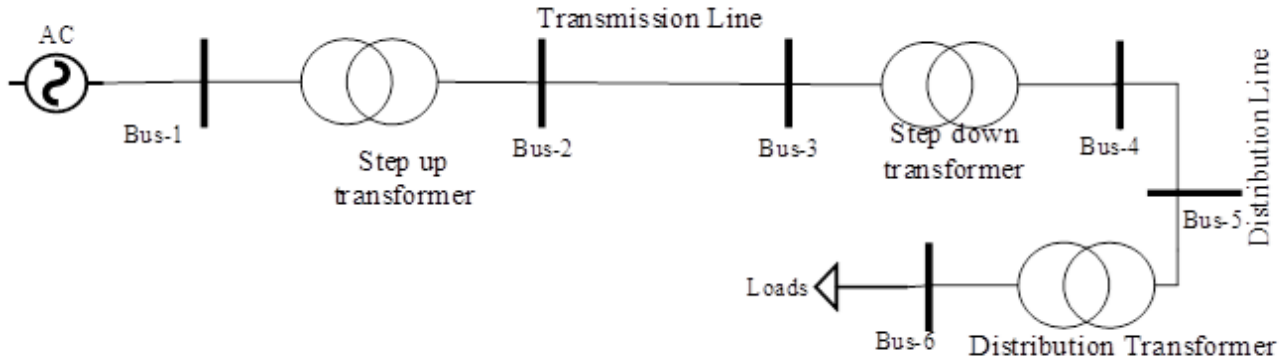


Figure 2.1: Single line diagram of a power system from generation to loads.

- **Distribution substation:** It is the end terminal of power system component, which used to connect substation to loads of the system. The purpose of distribution substation is to step down the voltage level to a standard value.
- **Primary distribution:** Feeders come out of the substation to the secondary distribution systems. They are normally radial with a unidirectional power flow from the substation to loads.
- **Distribution transformers:** These are mainly three phase and pole mounted. The transformers step down the primary voltage for distribution over the secondary mains to the consumers service.
- **Distributors and service mains:** Distributors are connected at the secondary of the transformers and feed power to different consumers by means of service main.

Feeders feed power from various points without distributors tapping from different points, thus the current at the sending end is equal to the current at the receiving end of the line. The distributors feed different consumers from different points; hence the current varies along the entire length. The types of consumer loads associated with in power systems are divided into industrial, commercial and residential as shown in figure 2.2.

Induction motor loads constitute a major portion of industrial loads while commercial and

residential loads consist largely of lighting, compressors, cooling and heating [6]. Power usage varies throughout the day and it must be always available to consumers on demand at any time. The load demand at each location in the distribution system varies according to the power usage at a given time and it is never constant. During peak demand time, the generating station has to increase power supply to match the power demand.

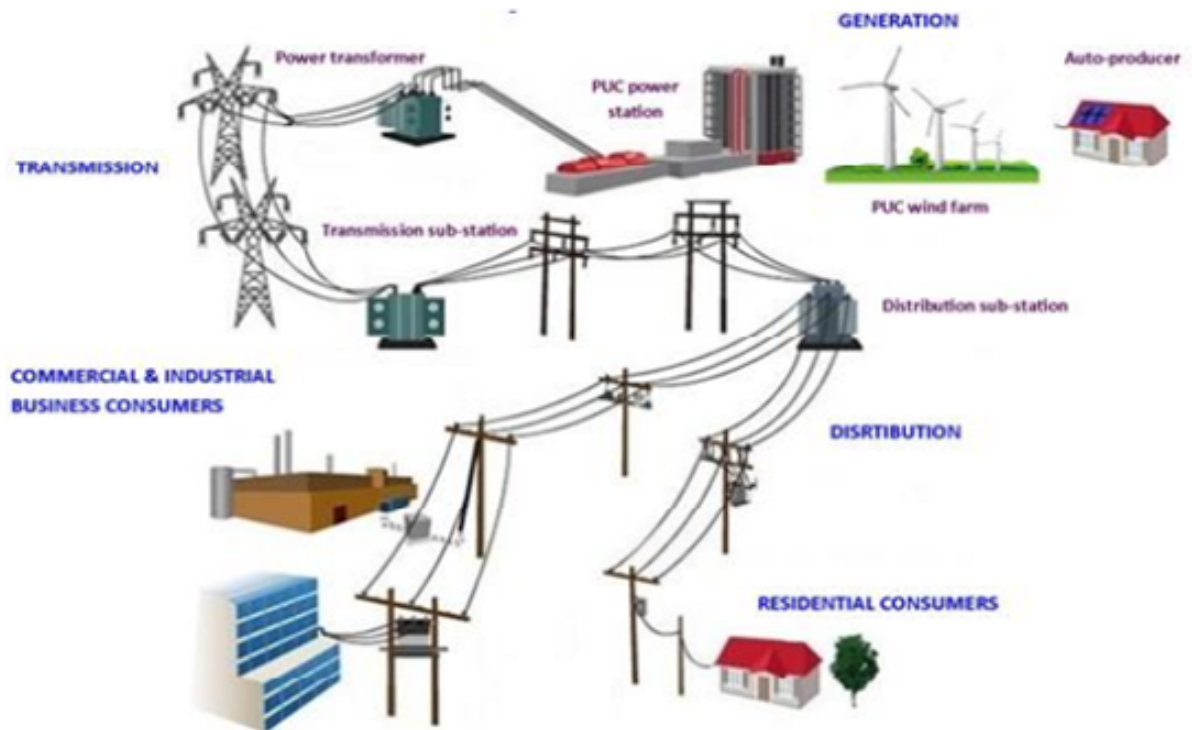


Figure 2.2: Structure of the electrical sector [7].

In power system from the three components distribution system has a least reliable and high power loss, so that a well planning of distribution system is very necessary to meet the customers at different forecast loading figures and supply reliability.

Reconfiguration of distribution system can be categorized in to three major categories.

- Radial configuration
- Loop configuration
- Mesh configuration

2.2.1 Radial configuration

Radial distribution system is simple and easy type of configuration and most of distribution systems are configured with such type of configurations. In Ethiopia throughout the country electric power distribute in distribution system by radial configuration, due this the system is very low reliable. The figure 2.3 shown is a radial network of distribution system, which is single end radial fed system i.e the load can get power from one source with single line. In radial configuration the power from the primary substation is directly connected to the load with a single route and all feeders separated. The load estimation and sizing of the system for such network become simpler due to the simple system design.

Generally, the installation for fault protection system become easy to be set up and the potential for fault current to occur are reduced. From other type of configuration radial type mostly chosen due to it is simple and very cheapest to be constructing easy to analyze and also it is easy to reconstruct again. Even if, radial configuration have different advantages there are also different weakness when using radial network.

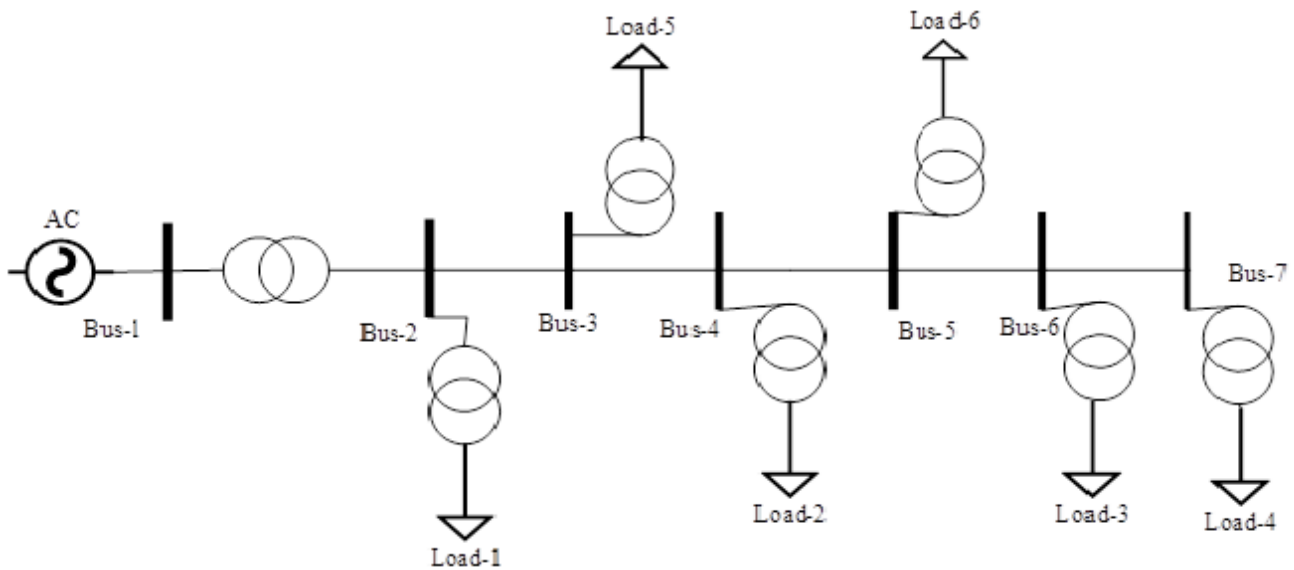


Figure 2.3: The radial distribution configuration.

The distributor point will be heavily loaded that near to the feeding. When a power failure occurs, the entire line power will be interrupted. The failure must be fixed before restore the power meaning that the supply restoration will depend on the fault repair time. When the load on system changed, the consumers at the end of distributor would be subjected to serious voltage

fluctuations due to non-alternative route for supplying power.

2.2.2 Loop configuration

A loop configuration or also known as double end fed network where the power can be supplied through all service areas before returning back to the original point. The loop circuit start from main substation bus then going through the area to be served and returns back to main substation. The loop network can either be connected to the same source or more than one source. To provide a better supply reliability, the service substations can be fed from two sources as shown in figure 2.2.

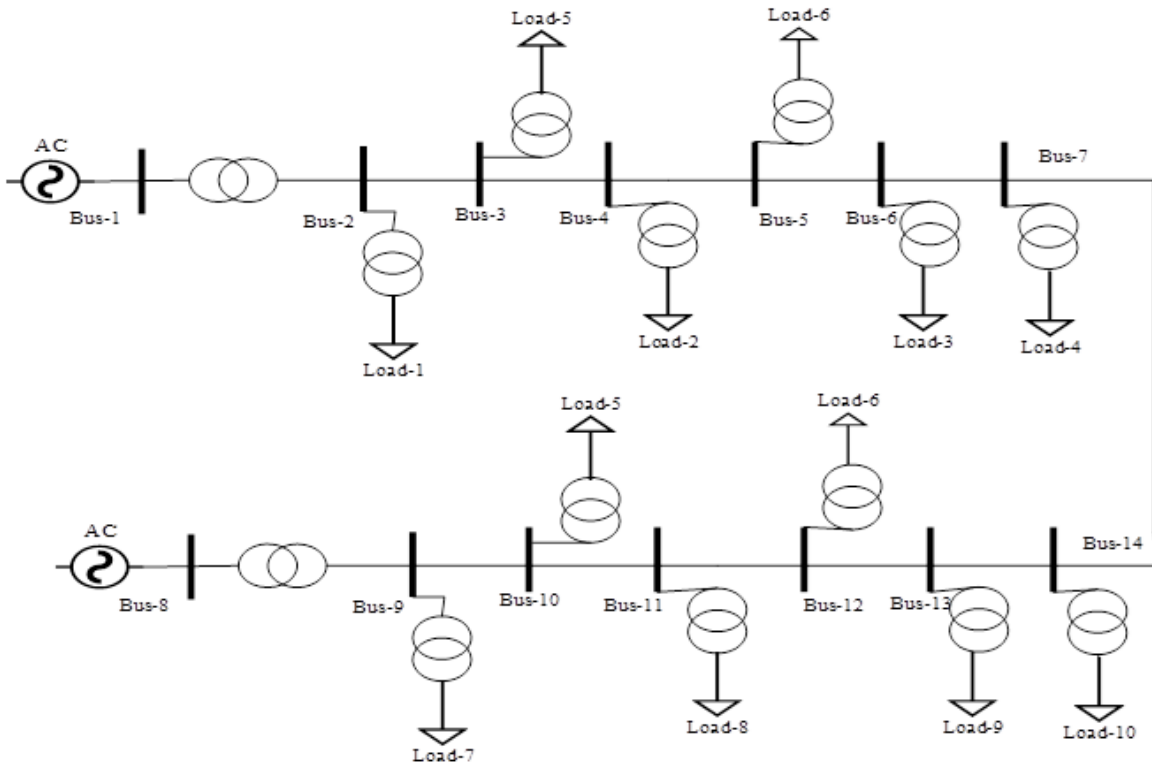


Figure 2.4: The loop distribution configuration.

A loop configuration distribution network can be operated either in open loop or closed loop system. The configuration acts as radial system when operating in open loop. Hence, the direction of supplying power from main substation to service substations can easily be changed simply by changing the switches status.

In case a supply from one direction fails, the power will be fed to service substations from the

other end. The supply can be restored after the faulty portion of component is isolated by simply closing the normally open switches or opening the normally closed switches. Therefore, the supply restoration will be faster and the additional routes provided by loop system make it more reliable compared to radial system. This condition makes the system has less voltage fluctuations at consumers terminals. However, this system is more expensive because more switches, circuit breaker and conductors are required to construct this system.

2.2.3 Mesh configuration

A mesh configuration network system or also known as ringed network system. It is the combination of different loop systems in one network. This network reconfiguration is interlocking loop systems, which are the most reliable system but the most complicated among the network configuration.

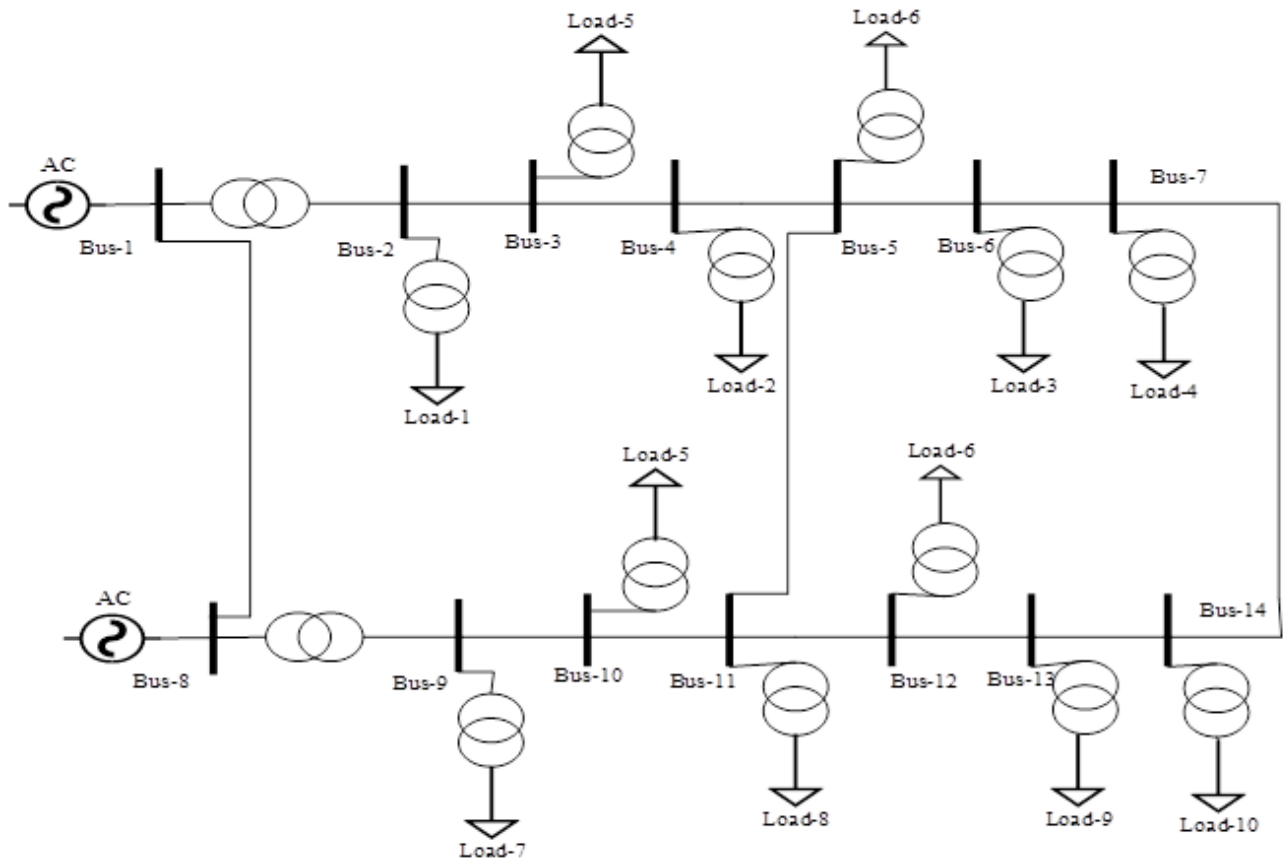


Figure 2.5: A mesh distribution configuration.

The service feeders can be supplied from more than one main substation. The existence of multi-

ple path between all levels in mesh network system can make the network immediately and automatically re-routed its supply path when there is a power failure. The complexity of the system makes the mesh configuration be the most expensive system to be constructed. For this reason it is normally used only in congested and high load density areas.

2.3 Power Loss of Distribution Network

Currently most utility highly affected with electrical power loss, electricity supply losses in power system consist of technical and non-technical losses [1]. 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 non-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. 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 loss in the distribution system is mostly due to copper losses since these losses are functions of the square of current flowing through the line as shown in (2.1).

$$P_{loss} = I^2 * R \quad (2.1)$$

Where P_{loss} - active power loss of the system

I- current

R- resistance

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.

$$S = V * I \quad (2.2)$$

Where S- apparent power

V- voltage

I- current

Unbalanced loading of the phases can also result in higher line losses. If one of the phases were 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.

In recent years, there has been a continuous need to accommodate higher loads and overcome delays in the construction of new generating facilities arising from environmental concerns and higher investment costs. There are three basic methods to reduce distribution system losses:

2.3.1 Reduce equivalent resistance

Reduce the equivalent resistance of the distribution network conductors; power loss in the conductor is given by $P_{loss} = I^2 * R$ (from equation 2.1). By reducing the value of R results in a proportional reduction in the power losses. This can be done by replacing the small size conductors both (overhead lines and underground cables) with a larger cross sectional area, as the resistance is inversely proportional to the cross sectional area, or by installing auxiliary conductors to work in parallel with the existing ones. Although these methods could give a large loss reduction, it is not cost effective and it is not used unless there is a special need, as the cost of conductors and their installation are usually in excess of the cost of the energy saved.

2.3.2 Placement of compensating capacitors

The reactive power flow in power system produced losses. These losses can be kept to a minimum by applying compensating capacitors in distribution points, to inject reactive power and thus compensate for the inductive load power. Using this method, the reactive power flowing in the system conductors are reduced, and consequently the losses there from. As the compensating capacitors affect the losses due to the reactive power component, their effect is more pronounced when the power system has a low power factor. Additional advantages of the installation of cap-

acitors include the boosting of voltage. This is to provide the feeder with the prescribed voltage range within the maximum and the minimum allowable values, respectively at light and heavy load conditions and improving the power factor.

The optimum size and location of the capacitor can be determined based on the maximum cost savings in the energy loss and on the peak power loss reduction on the condition that the voltage limits are not violated. The trend in recent years has been to install the capacitors in the primary distribution feeders rather than in the substations. This trend has been due to both the availability of pole mounted equipment and because it is more economical to place the capacitors close to the reactive loads.

2.3.3 Network reconfiguration

The third method to reduce the power and energy losses on distribution systems is by system reconfiguration. Reconfiguration of the distribution system can be used as a planning tool as well as a real time control tool. Most of the distribution systems are reconfigured radially, and modifying the radial structure of the distribution feeders from time to time, by changing the open/closed states of the switches to transfer loads from one feeder to another, may significantly improve the operating conditions of the overall system.

Feeder's reconfiguration allows the transfer of loads from heavily loaded feeders to relatively lightly loaded feeders and from higher resistance routes to lower resistance routes to obtain the least $I^2 * R$, where the resistance route is the total resistance from the source to the load point. Such transfers are effective not only in terms of altering the level of loads on the feeder being switched, and reducing the losses, but also improving the voltage profile along the feeders and affecting reductions in the overall system power losses; studies and experiments on feeder reconfiguration are ongoing in several utilities.

2.4 Reliability

The purposes of power system reliability assessment are to provide qualitative analysis and indices in power supply reliability for the operation and planning system. After the qualitative analysis, it is very important to find out weak network components.

In recently, there are only two approaches analytical approach and Monte Carlo Simulation approach, used to calculate the reliability indices.

2.4.1 Reliability index

Different types of reliability indices can be done for the analysis of reliability to all electrical power parts (components) i.e. generation, transmission and distribution and comparing the reliability of different electric utility companies. Reliability indices are statistical aggregations of reliability data for a set of loads, components or customers.

Distribution reliability needs well defined units of measurements, which is known as metrics. The power system reliability is one of the features of power system quality in addition to required voltage and constant frequency. The electric power utility has developed different performance measures of reliability assessment or reliability indices. These reliability assessment indices are including measures of outage duration, frequency of interruptions, number or customers involved or their lost power or energy and the response time.

Now a day IEEE defines the generally accepted reliability indices in its standard values. These standards distribution and transmission reliability indices and factors that affect their calculation are collected and presented [1].

- **System Average Interruption Frequency Index (SAIFI)**

It tells how many sustained interruptions an average customer will experience in one year. For a fixed number of customers, the only way to improve SAIFI is to reduce the number of sustained interruptions experienced by customers.

$$SAIFI = \frac{\text{Total number of interruption}}{\text{Total number of customer served}} \quad (2.3)$$

- **System Average Interruption Duration Index (SAIDI)**

It is a measure of how many interruption hours an average customer will experience over the course of a year. For a fixed number of customers, SAIDI can be improved by reducing the number of interruptions or by reducing the duration of these interruptions. Since both of these reflect reliability improvements, a reduction in SAIDI indicates an improvement in reliability.

$$SAIDI = \frac{\text{Total duration of all interruptions in customers}}{\text{Total number of customer served}} \quad (2.4)$$

- **Customer Average Interruption Duration Index (CAIDI)**

It is a measure of how long an average interruption lasts, and is used as a measure of utility response time to system contingencies. It can be improved by reducing the length of interruptions, but can also be reduced by increasing the number of short interruptions. Consequently, a reduction in CAIDI does not necessarily reflect an improvement in reliability.

$$CAIDI = \frac{\text{Sum of customer interruption duration}}{\text{Total number of customer interruption}} \quad (2.5)$$

- **Average Service Availability Index (ASAI)**

It is the fraction of time the customer has power during the reporting time. A higher ASAI value indicates higher levels of reliability.

$$ASAI = \frac{\text{Customer hours service available}}{\text{Customer hours service demand}} \quad (2.6)$$

- **Customer Average Interruption Frequency Index (CAIFI)**

Shows the trends in customers interrupted and used to determine the number of customers affected out of whole customer base.

$$CAIFI = \frac{\text{Total number of customer interruption}}{\text{Number of customer affected}} \quad (2.7)$$

- **Average Service Unavailability Index (ASUI)**

$$\frac{SAIDI}{8760 \text{ hours/yr}} \quad (2.8)$$

- **Expected Energy Not Supplied (EENS)**

$$EENS = \sum(L_i * U_i) \quad (2.9)$$

Where L_i is the average connected load at load point i

U_i is average annual outage time at load point i .

- **Average Energy Not Supplied (AENS)**

$$\frac{\sum(L_i * U_i)}{\sum N_i} \quad (2.10)$$

Where N_i is total number of interruptions.

The above five indices equations are customer oriented indices and the last two equations are load and energy oriented indices. These indices can be used not only to assess the past performance of a distribution system but also to predict the future system performance.

2.5 Optimization Techniques

This thesis reports a complete review of the currently available optimization techniques on network reconfiguration, DG and capacitor for optimal location and sizing.

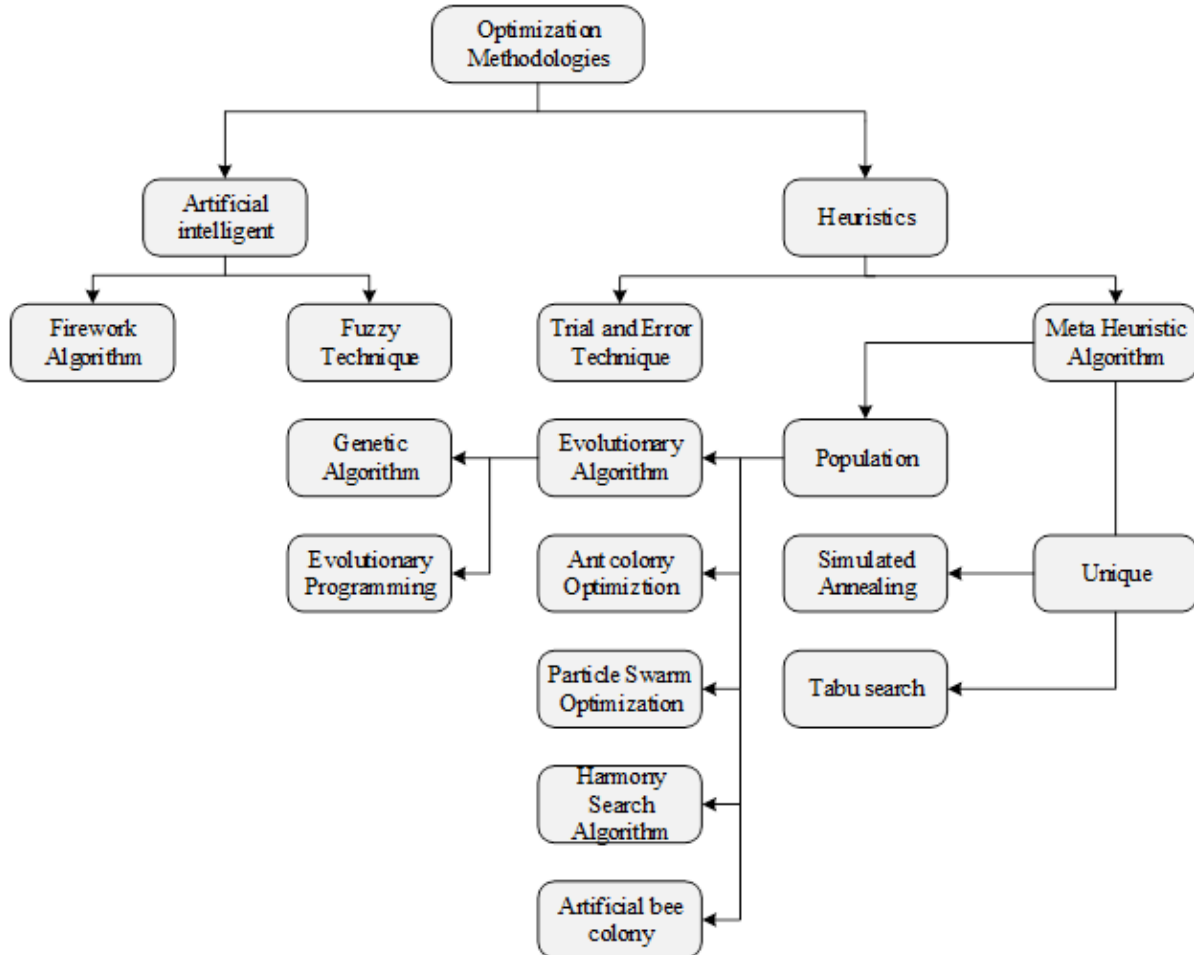


Figure 2.6: Optimization methodologies of distribution network reconfiguration.

2.5.1 Heuristic Optimization

Heuristic methods have been proposed [8, 9] for finding the optimal or near optimal solution with fast computational time. Usually the heuristic technique requires a fewer number of iterations compared to any analytical method. One of the heuristic methods to reach an optimal configuration for minimizing system losses were proposed. They considered all the possible switching options that may lead to a reduction in losses, calculated the losses and determined which option leads to minimum losses. Switching option means closing a normally open tie switch

& opening a normally closed sectionalizing switch to restore the radiality of the distribution system. In [10] based their method on results given by [11], these results show that the switching options that may lead to reduction in the system losses can be reduced to a workable number after disregarding those options that may lead to an increase in the system losses, lead to voltage limit violation, current excess or customer outages. Therefore, the proper switching options can be predicted before calculating the losses. This can be performed by calculating the system voltages and then the open switches with negligible voltage differences across are disregarded from switching options because closing these switches does not lead to a reduction in the losses. To obtain a reduction in the system losses the switches having large voltage differences are considered. Then the transfer of the loads should be from the low voltage side of the switch to the higher voltage side. This means that the two voltage drops from the substation to the open switch ends are calculated and it is necessary to transfer loads from the higher voltage drop side to the lower voltage drop side. Using this technique the number of considered switching options is reduced. Even this method gives good results for system reconfiguration it is still difficult regarding the large number of switching options considered and the optimal solution is not guaranteed to be reached especially for a very large system. In addition, a drawback of this method is that the final solution depends mainly on the original configuration.

2.5.2 Ant Colony Optimization

Ant colony optimization (ACO) is based on social behaviour of ant. In real world, ants initially wander randomly, and upon finding food return to their colony while laying down pheromone trails. If other ants find such a path, they are likely not to keep travelling at random, but instead follow the trail laid by earlier ants, returning and reinforcing it, if they eventually find any food. The more time it takes an ant to travel down the path and back again, the more time the pheromones have to evaporate. A short path, by comparison, gets marched over faster and thus the pheromone density remains high as it is laid on the path as fast as it can evaporate. Thus, when one ant finds a good (short) path from the colony to a food source, other ants are more likely to follow that path and such positive feedback eventually leaves all the ants following a single path.

2.5.3 Particle Swarm Optimization

The Particle Swarm Optimization (PSO) is inspired by the social behaviour of a flock of migrating birds trying to reach an unknown destination. In PSO, each solution is a bird in the flock and is referred to as a particle. A particle is analogous to a chromosome in GAs. As opposed to GAs, the evolutionary process in the PSO does not create new birds from parent ones. Rather, the birds in the population only evolve their social behaviour and accordingly their movement towards a destination. Each bird looks in a specific direction and when communicates together, they identify the bird that is in the best location. Accordingly, each bird speeds towards the best bird using a velocity that depends on its current position. Each bird, then investigates the search space from its new local position, and the process repeats until the flock reaches a desired destination. In [12] used selective particle swarm optimization (SPSO) for loss reduction. This algorithm is a simple modification to the binary particles warm optimization (BPSO). The search space of the algorithm is a set of branches (switches) which are normally closed or normally opened, this search space may be dissimilar for different dimensions. The process of solving reconfiguration problem is divided in to two steps. First, finding search spaces after closing all switches and second, using SPSO to find switches that would be opened. The presented technique is applied to a 33 node system and a 69 node system. The results obtained via SPSO are compared with some previous methods to demonstrate the effectiveness of the proposed algorithm.

2.5.4 Genetic Algorithm (GA)

Many researchers are done optimal reconfiguration of distribution system to improve of reliability and power loss by using GA. In [13] the paper has presented an effective application of practical distribution system automation by using genetic algorithm optimization. One location may satisfy an objective function subject to a specific reliability index. However, adding reliability index as a constraint can result in different optimum locations.

2.5.5 Fuzzy Logic

In [14] the paper described a better calculation strategy which allows to determining of both the optimal number and placement of all sectionalizing and tie switches in MV of a radial distribution system, in correspondence to technical, regulatory and economical aspects. A formulation that

takes into account the investment, maintenance and power interruption costs has been developed, seeking for a reduction in total costs while taking care of the regulatory and technical aspects. In [15] the paper seen discussed the application of a fuzzy logic design based on coordinated voltage control for a distribution network connected with distribution generation (DG). In practical the connection of distribution generation has created a challenge in the distribution system operators to make the voltage in the system within it acceptable levels. In [16] the paper come with a new technique of evolutionary search methodology is proposed for analysing a minimum power loss of radial configuration of distribution system as the whole, to enhancement its performance of evolutionary programming by using fuzzy controlled evolutionary programming (FCEP). In [17] this paper presented a new and simple algorithm for solving the distribution network reconfiguration (DNR) outages. His algorithm is a simple modification from binary particle swarm optimization (BPSO) called selective particle swarm optimization (SPSO). In [18] the paper detail about distribution network reconfiguration is aimed at maximizing the reliability of power supplied to the customers with considering of reliability indexes. He selected from different types of optimization (BPSO), is used to determine optimal configuration of switches in network in order to maximize reliability indexes at load points. In [19] the paper an algorithm is developed for determining the restoration plan for radial distribution system, the reliable plan among the available alternatives is determined by reliability analysis using fuzzy reasoning technique. In [20] Reliability of Distribution using Fuzzy Logic for Modelling of Transformer and Line Uncertainties, reliability assessment of distribution system, based on historical data and probabilistic methods, leads to an unreliable estimation of reliability indices since the data for the distribution components are usually inaccurate or unavailable. Fuzzy logic is an efficient method to deal with the uncertainty in reliability inputs. From his work, the EENS index along with other commonly used indices in reliability assessment are evaluated for the distribution system using fuzzy logic design.

2.5.6 Shark Smell Optimization (SSO)

Shark Smell Optimization (SSO) is a meta heuristic GA developed by Abedinia et al., based on the shark's ability to catch prey by its strong sense of smell. A shark has one of the most effective senses and can detect a single drop of blood up to a kilometer away. This algorithm is inspired

by the hunting behavior of a shark and its ability to smell an injured animal from miles away. The mathematical modelling movement of the shark is based on the following assumptions [21];

- When a target is wounded and results in bleeding into the sea. The target source is assumed to be fixed since its velocity is negligible in comparison with the shark's movement.
- There will be a regular injection of blood into the sea with odor particles getting stronger as the shark gets near the injured prey. The effect of water flow on distorting odor particles is neglected.
- Only one injured blood source in the search area of the shark will result in one odor source.

In [22], proposed the SSO algorithm to optimally locate and size the shunt capacitors required in the distribution system to achieve the minimum cost function due to energy loss and reactive power consumption. The reactive power losses were reduced by installing shunt capacitors in the distribution system. Capacitor placement is greatly influenced by the size, location and type of shunt capacitor to be installed for the optimum use of the capacitors.

The SSO algorithm performed better compared to the other algorithms from the literature and it gave optimum results with a simpler formulation that satisfied the constraints.

Table 2.1: Summary of optimization technique

Algorithm	Source of code	Advantage	Disadvantage	Reference
Tabu Search	Fred W. Glover in 1986. It employs local search used	Can avoid entrapment in local optimal solutions	Relatively difficult to code because of many parameters to be adjusted has lower precision factor	[23]
Evolutionary Algorithm	It is based on biological evolution	Can efficiently find the global optimum solution	Relatively difficult to code, premature convergence, can get trapped into local optima, has lower precision factor	[24]
Quantum Firefly Algorithm	It is based on the flashing characteristics of fireflies.	Simple to understand & code.	Can get trap into local optima and slow convergence	[25]
Simulated Annealing	It is based on the physical process of crystallization	Robust, easy to implement, can yield reasonably good results.	Relatively lower performance for determining the global optimum, consumes significant computational time	[26]
Genetic Algorithm	It is based on the theory of evolution.	Can handle integer and solve multi dimensional parametric problems.	Increase in execution time is observed with increase in chromosome length. Needs improvement to generate feasible radial structure	[27]

Modified Plant Growth Simulation Algorithm	Tong et.al in 2005, inspired by plant growth mechanism.	Fewer parameters to adjust	Fewer work related to Network Reconfiguration.	[28]
Bat Algorithm	It is based on the echolocation operation of small bats.	Can solve highly non linear, large scale problem.	Can become problematic for higher dimensional problems as it has quick convergence rate at early stage of the iteration.	[29]
Cuckoo Search Algorithm	Yang and Deb in 2009. It is based on the brood parasitism of cuckoo birds.	Easy to code, few parameters tuning.	Slow convergence fewer literature examples.	[30]

2.6 Switches

Sectionazer and tie switches:

Sectionizers are protective devices that are used in medium voltage distribution systems to automatically isolate faulted sections once an upstream recloser or breaker has interrupted the fault current. The self contained protective devices are usually installed downstream of a recloser in the distribution circuit. Similarly, the tie switch is normally open switch applied for network reconfiguration. In case of power failure, distribution network is routed to alternative power supplying path by the use of tie switches. Both switches do not have the capacity to break the fault current and are usually used in conjunction with other backup devices such as reclosers and circuit breakers that have the ability of breaking the fault current. Sectionalizers are simple, flexible, convenient, safe and economical means of isolating faulty circuits. There are available in different operating modes, capacity and functionalities, and most of them can be configured to the desired number of counts as well as the amount of actuating current. Since different applications are unique in one way or another it is important to select the sectionalizer that

address the needs of that particular installation and use this with the appropriate protection devices. This ensures the best level of protection that allows other healthy circuits to continue with their normal operations.

Automatic Sectionalizers:

Automatic sectionalizers automatically de-energize a faulted section so that non faulted line sections can be safely energized. It helps to overcome the coordination problems of other protection devices like fuse and reclosers near substations. When the fault current exceeds the pre set value, the sectionalizers will open instantaneously in order to isolate the fault to restore power back to non faulted line segment customers. This also helps to save the fuse from blowing which is also known as a fuse saving scheme.

Recloser:

In electric power distribution, automatic circuit reclosers are a class of switchgear, which is designed for use on overhead electricity distribution networks to detect and interrupt momentary faults. Also known as reclosers or auto reclosers, ACR are essentially high voltage rated circuit breakers with integrated current and voltage sensors and a protection relay, optimized for use as an overhead network distribution protection asset. For overhead distribution networks, the majority of faults are transient, such as lightning strike, surges or foreign objects coming into contact with the exposed distribution lines. By this logic, 80% of outages can be resolved by a simple close operation. Reclosers are designed to handle a short close-open duty cycle, where electrical engineers can optionally configure the number of attempted close operations prior to transitioning to a lockout stage.

The recloser, with its opening/closing characteristic, prevents a distribution circuit being left out of service for temporary faults. Typically, reclosers are designed to have up to three open close operations and after these, a final open operation to lock out the sequence. The counting mechanisms register operations of the phase or ground fault units, which can also be initiated by externally controlled devices when appropriate communication means are available. The operating time (current) characteristic curves of reclosers normally incorporate three curves, one fast and two delayed. Coordination with other protection devices is important in order to ensure that, when a fault occurs, the smallest section of the circuit is disconnected to minimize disruption of supplies to customers.

Generally, the time characteristic and the sequence of operation of the recloser are selected to

coordinate with mechanisms upstream towards the source. After selecting the size and sequence of operation of the recloser, the devices downstream are adjusted in order to achieve correct coordination. The first shot is carried out in instantaneous mode to clear temporary faults before they cause damage to the lines. When installing protective device it is necessary to take into account the following factors:

- Maximum load current
- Minimum short circuit current within the zone to be protected by the re-closer
- Coordination with other mechanisms located upstream towards the source & down stream towards the load
- Sensitivity of operation for ground faults
- System voltage

2.7 Power Flow Analysis

In power engineering, the power flow analysis (load flow) is an importance tool involving numerical analysis applied to a power system. Unlike traditional circuit analysis, a power flow study usually uses simplified notation such as a one line diagram and per-unit system, and focuses on various form of AC power (i.e reactive, real and apparent) rather than voltage and current. The advantage in studying power flow analysis is in planning the future expansion of power systems as well as in determining the best operation of existing systems. Power flow analysis is being used for solving power flow problem. There are different methods can be used to solve power flow analysis. The methods are Newton Raphson method, Fast Decoupled method and Gauss Seidel method.

In a power system, real power (P) and reactive power (Q) flows from the generating source to the loads through the branches and buses. Load flow studies provide a systematic mathematical approach to determine bus voltages, phase angles, power flows, loads and operating conditions of a power system. Power flow analysis was carried out before and after the network reconfiguration to calculate the nodal voltages, current, power flows and power losses in the system using the Fast Decoupled method. The load flow operation had to be performed for each iteration of the

new configuration identified by the proposed MSSO algorithm to determine the new operating point.

$$I_n = \frac{P_n + Q_n}{V_n} \quad (2.11)$$

For radial network applying KCL in at the buses, the complex load flow equations can be expressed as follows

$$P_N = \sum_{n=1}^{NL} |z_{n,n+1} V_n V_{n+1}| \cos(\Theta_{n,n+1} + \delta_n - \delta_{n,n+1}) \quad (2.12)$$

$$Q_N = -\sum_{n=1}^{NL} |z_{n,n+1} V_n V_{n+1}| \sin(\Theta_{n,n+1} + \delta_n - \delta_{n,n+1}) \quad (2.13)$$

Power loss of any line between buses n and $n + 1$ can be determined by

$$P_{loss (n,n+1)} = R_{n,n+1} \left(\frac{P_{n,n+1}^2 + Q_{n,n+1}^2}{|V_{n+1}|^2} \right) \quad (2.14)$$

$$P_{Tloss} = \sum_{n=1}^{NL} P_{loss (n,n+1)} \quad (2.15)$$

Power loss after reconfiguration is

$$P'_{loss (n,n+1)} = R_{n,n+1} \left(\frac{P'_{n,n+1}{}^2 + Q'_{n,n+1}{}^2}{|V'_{n+1}|^2} \right) \quad (2.16)$$

$$P'_{Tloss} = \sum_{n=1}^{NL} P'_{loss (n,n+1)} \quad (2.17)$$

The difference of power loss before and after reconfiguration will give the net power loss reduction given by

$$\Delta P_{Tloss} = \sum_{n=1}^{NL} P_{loss (n,n+1)} - \sum_{n=1}^{NL} P'_{loss (n,n+1)} \quad (2.18)$$

2.8 Related Works

The literature review for this thesis looks at the relevant work done by other researchers on radial distribution networks that lead to the fulfilment of the development of this work. Various studies that have been carried out on reliability and power loss challenges in distribution networks. In [31] has assessed the overall performance of Indian distribution utilities. This paper presents the measurement of technical efficiency for performance evaluation of electricity distribution utilities in India after the implementation of EA 2003. Evaluating average annual unsupplied energy and system average interruption duration index (SAIDI) for a radial distribution network with arbitrary allocation of sectionalizes and tie lines based on the genetic algorithm has been

presented in [32]. The binary programming in [33] and genetic algorithm in [34] identify type and location of the protective devices on a distribution feeder based on the objective of minimizing the system average interruption frequency index (SAIFI). Several intelligent algorithms have been used to solve the problem of optimal placement of switches and protective devices in distribution networks. In [35] propose a novel algorithm for feeder automation (FA) planning. It can be used to find optimal number and locations of automated feeders and tie switches to minimize the customer interruption costs (CIC). In [36] his thesis the reliability assessment of Bahir Dar city distribution system on 15 kV selected four feeders is done. Monte Carlo simulation systems and ETAP software is used to assess and simulate the overall behavior of the distribution system reliability indices. The researcher also recommend that the improvement techniques such as reconnection of the scheme and replacing old components are economical alternatives for further improvement using additional recloser, sectionalizer switches and load break switches in cost effective locations are the main alternatives. In [37] has applied a novel assessor for distribution system reliability, a reliability analysis algorithm for radial operated (with respect to substation), and reconfigurable, electrical distribution systems. The algorithm takes into account equipment power handling constraints. In [38] has applied reliability studies for distribution system using fuzzy expert system, in this paper, an algorithm is developed for determining the restoration plan for radial distribution system. The reliable plan among the available alternatives is determined by reliability analysis using fuzzy reasoning technique. In [39] the paper deals on, network reconfiguration for reliability worth enhancement in distribution system by simulated annealing 2014. It has been done on reliability enhancement by developing a new algorithm simulated annealing considering worth analysis that provides an indirect measure for cost implication associated with power failure. In this work provides to minimize customer interruption cost with the constrains that in all load points have to be electrical power supplied and radially connected. In [40] a new method for improving reliability and line loss in distribution networks 2010, in 20th Australasian Universities Power Engineering Conference. In his paper done on both reliability and power loss in distribution system by using DG and capacitor allocated and sized optimally for improving lines. They used hybrid particles swarm optimization technique which is heuristic and applied on IEEE 69 bus test system which has good result. In [41] a new optimization frame work to solve the optimal feeder reconfiguration and capacitor placement problems in 2015. In his paper a new optimization frame work based bat algorithm used to solve the optimal distribution network

reconfiguration by shunt a shut capacitor placement and sizing, in this work the objective was to minimizing of active power losses. In [42] Power distribution system improvement planning under hurricanes based on a new resilience index (2018), the paper has been used radial system of IEEE 33 bus network as test. A problem is formulated as a stochastic two stage optimization. The first stage decisions are the number of each resilience improvement strategy limited to a predetermined budget. Genetic algorithm is applied to solve the first stage. The objective of the second stage is maximizing the social welfare which is solved by an innovative approach. In [43] optimization of distribution network configuration using evolutionary algorithm approach 2017, in this paper propose on a new optimization technique of robust for distribution network reconfiguration, that can be regarded as a modification of evolutionary algorithm (EA). By evolutionary algorithm has been applied to solve system total cost with simultaneously minimizing of power loss and voltage profile improvement. The paper done on IEEE 69 bus system of distribution network model is used in the test which results optimal non dominated solutions. In [44] a new method for distribution network reconfiguration analysis under different load demands 2017, in this work considering two cases: first reconfiguration was accomplished using optimal switches by optimal framework based on constant loads. Second, lists of the configurations set obtained from the first part, as well as other different optimization methods proposed earlier under constant load demand were taken as test switches. The study was applied to a 33 bus test distribution network, which is exceedingly used as test examples for solving reconfiguration problems. In [45] optimal allocation of remote control switches in radial distribution network for reliability improvement 2016, the paper presents differential search algorithm to improve reliability optimization problem of radial distribution system. In this paper remotely control switches have been formulating and solving by differential search algorithm. In [46] assessing the contribution of automation to the electric distribution network reliability 2018, in this paper has been targeted on reliability index improvement with automation of secondary substation (SS). In automation process lies in the use of non ideal communication channels, latency and availability are considered. In [47] distribution network reconfiguration for power quality and reliability improvement using Genetic Algorithms 2018, in this paper has been done on two objectives of reliability and power quality improvement in distribution system by optimal configuration of radial distribution system. In this work single objective function has been done by GA optimization method. Finally the paper gives a flexible to a decision making to choose one from a given set of solutions which is very

important for both objectives under a normal condition. In [48] customer satisfaction based reliability on active distribution networks 2015, the paper has been done on radial distribution system reliability improvement of active distribution network considering customer satisfaction and utility benefits by reconfiguration. Optimization was done by using a Sequential Monte Carlo (SMC) simulation, the optimization processes is innovatively integrated with reliability evaluation and thus the impacts of customer satisfaction constrain are incorporated in reliability evaluation. In [49] reliability assessment of distribution system with the integration of renewable distributed generation 2016, in this paper the most recent study in renewable energy resources for improving of distribution system which contribute substantially to future energy generation owing to the rapid depletion of fossil fuels. The reliability assessment is one of the most necessary indicators to measure the impact of DG in distribution system as well as to minimize the cost which is associated with power interruption. In [50] radial distribution network reconfiguration for power losses reduction based on improved selective BPSO 2019, in this paper has been done on radial distribution system power loss reduction by using improved selective binary particles swarm optimization on IEEE 33 bus system. The proposed technique presents a modification of the sigmoid function of the BPSO in order to control the rate of change the particle vector which leading to better exploration of search and better convergence of the population. Finally, in this paper the simulation results shows that the proposed method is very nice and achieve of a global optimal. In [51] repeat to optimal planning of battery systems for power losses reduction in distribution grids 2019, in this paper distribution power loss minimization is the main objective with network reconfiguration by integrating battery to the system. In fact, batteries can be opportunely integrated in the grid and managed in order to reduce the power losses, the penetration of the renewable distributed generation and contributing to voltage regulation through reactive power production from battery inverter.

Summary of literature review

Most of the papers focus on only a single problem solution such as reliability enhancement, voltage profile, power loss, and most focus on distribution network of IEEE, there is no combination solution study for the power loss minimization and reliability improvement in the real systems. Therefore, in this thesis, the multi objective and real system power loss and reliability enhancement problem is performed on the radial distribution of Kombolcha city.

Chapter 3

Shark Smell Optimization

3.1 Introduction

The optimization shark smell is design based on the shark's behaviour to attack its prey once it picks up the blood odor in a search space (sea). This inspires the optimization mechanism to be simulated with the aim of picking up the best solution in a given search space.

3.1.1 Initialization of SSO algorithm

When modelling, a population of initial solutions is randomly generated for an optimization problem in a feasible search area (sea), a source (prey) represents the optimal solution whilst the quality of the solution is represented by the odor strength at a position. The initial solution is given as;

$$X^1 = X_1^1, X_2^1, X_3^1, \dots, X_{np}^1 \quad (3.1)$$

$$X_i^1 = X_{i,1}^1, X_{i,2}^1, X_{i,3}^1, \dots, X_{i,np}^1 \quad (3.2)$$

Where;

$i = 1, 2, 3, \dots, np$, np is the population size.

X_i^1 is the i^{th} initial solution (position of the population vector).

3.1.2 Forward movement

As the blood is released in the water, the shark will move towards the target with a velocity 'V', guided by the smell of the stronger odor particles, hence leading to a high quality solution. In correspondence with the position vector, the initial vector is as follows;

$$V^1 = V_1^1, V_2^1, V_3^1, \dots, V_{np}^1 \quad (3.3)$$

$$V_i^1 = V_{i,1}^1, V_{i,2}^1, V_{i,3}^1, \dots, V_{i,np}^1 \quad (3.4)$$

The increase in shark's velocity is determined by the increase in the odor intensity. In each stage of $V_{i,j}^1$ the velocity limiter is given as follows;

$$|V_{i,j}^1| = \min[|\eta_k * R_1 * \nabla_{i,j}^k + \alpha_k * R_2 * V_{i,j}^{k-1}|, |\beta_k * V_{i,j}^{k-1}|] \quad (3.5)$$

Where

β_k - is a velocity limiter ratio for stage k.

η_k - is an element in $[0, 1]$.

α_k - is the inertia coefficient.

$\nabla_{i,j}^k$ - is the gradient of the objective function $\frac{\partial(OF)}{\partial(X_j)}|_{X_{i,j}^k}$

R1 and R2 are random values, which give a more random search when determining the velocity reached by the gradient function and to broaden the search in the algorithm.

The considered sign for the value of $V_{i,j}^k$ depends on the direction of the selected term of the minimum operator. The velocity vector will determine the new position during the forward movement of the shark given by;

$$Y_i^{k+1} = X_i^k + V_i^k \Delta t_k \quad (3.6)$$

Where

$i = 1, 2, \dots, np$

$k = 1, 2, \dots, kmax$

Δt_k - time interval is assumed to be 1

3.1.3 Shark's rotational movement

The rotational movement allows the shark to narrow down the stronger odor particles in its forward movement. This process is called local search of the SSO algorithm modeled by (3.7);

$$Z_i^{k+1,m} = Y_i^{k+1} + R_3 * Y_i^{k+1} \quad (3.7)$$

Where

$$i = 1, 2, \dots, np$$

$$k = 1, 2, \dots, kmax$$

To model the rotational movement of the shark, the number of points M in the local search are connected to form closed contour lines, whereby the position of point m of each stage in the local search is $Z_i^{k+1,m}$. As the operator implements a local search around Y_i^{k+1} a random number R_3 is also generated.

3.1.4 Updating particle position

The shark's search path will continue with the rotational movement as it moves closer to the point with a stronger odor sense as shown in (3.8);

$$X_i^{k+1} = argmin\{OF(Y_i^{k+1}), OF(Z_i^{k+1}), \dots, OF(Z_i^{k+1,M})\} \quad (3.8)$$

$$i = 1, 2, \dots, np$$

X_i^{k+1} presents the next position of the shark or the candidate solution with the least objective function (OF) value.

The OF should be minimized from the obtained forward movement and rotational movement. The cycle will continue until k reaches the minimum value in the given population in a search space chosen for an optimization problem.

3.1.5 Proposed MSSO algorithm

In the proposed MSSO algorithm, there were two modifications made from the original SSO algorithm which permits the exploration and exploitation capabilities to improve the global search performance in achieving the (OF) of the network reconfiguration problem.

In the main loop of the algorithm, the gradient of the OF was removed from (3.5) in the velocity movement operator for the shark. Instead of finding the minimum of the gradient function from the velocity equation operator, the OF was introduced in the fitness loop which compares the current best position of the shark with the previous best. If the current fitness function is better than the previous it will be updated until the iteration stops. The global minima from all the particles in a search space will be selected as the global best. Since the shark's movement is non-linear in nature, this permits a sigmoid transformation shown in (3.9) to be introduced in the forward movement operator when a new position is obtained soon after (3.6), for a smooth search capability.

$$Sigfun^{k+1} = \frac{ta}{1 + e^{-Y_i^{k+1}}} \quad (3.9)$$

Where

ta - represents the branches in each loop.

The position value of the particles in each stage will settle at the nearest whole number among the given values in the loops created in the network.

3.1.6 Optimal reconfiguration using MSSO algorithm

The application of the proposed MSSO algorithm to the network reconfiguration problem is discussed here. The flow process of the proposed MSSO algorithm is as follows:

Step 1: The bus system data and MSSO algorithm parameters such as np, nv, M, η , β , α are generated.

Step 2: Initialization of the population vector for a given population size and $k = 1$. The initial open/closed switches of the network before configuration will present the solution vector, X_1 and the initial fitness (power loss).

Step 3: Each solution obtained per iteration (load flow) returns a fitness function (power losses) which is compared with the previous load flow and ensures that it is in the allowable limits of the system operation.

Step 4: The new position of the shark is determined from the forward movement by moving vector solution X_1 to a new position Y_i^{k+1} using (3.6).

Step 5: A sigmoid function is introduced to the new position of the shark Y_i^{k+1} to linearize the shark's movement and obtains a new position from the tap switches given in the loops.

Step 6: Perform rotational movements to determine the new position of the shark in a local search $Z_i^{k+1,m}$.

Step 7: The new position of the shark is determined by the forward and rotational movements. The best switching sequence with the least power losses in the network between the two movements will be identified and selected.

Step 8: If k is not equal to k_{max} , go to step 3.

Step 9: The global minimum of the fitness function is chosen at the last best position X^{Kmax} . The defined parameters shown in the table 3.1 for the proposed MSSO algorithm shown in the flow process can be fine-tuned depending on the size of the network or changes made to the system.

Table 3.1: Assumptions (parameters)

Parameter	α	η	β	M	Decision variable	Population size	Max.iteration
Values	0.6	0.9	2	50	5	70	100

Table 3.2: Characteristics of the MSSO algorithm

General algorithm	Real system	MSSO algorithm
Decision variable	Number of tie switches in the system	Particles which possible shark position
Initial solution	Initial tie switches	Initial position of shark
New solution	Tie switches	New position of shark
Best solution	Tie switches	Sharks position with best OF
Fitness function	Power losses	Odor particle intensity
Process of generating new solution	-	Forward & rotational movement
Selection	-	Shark's position selected operators
Constraints	Voltage, power & current limit	-

Table 3.2 explains the relationship of the algorithm and the real power system. A general algorithm shows how the general characteristics relate to the proposed MSSO algorithm with the real power system.

3.2 Mathematical Modelling of Distribution Network

When an optimization problem is constrained, it will mathematically determine the optimal allocation of scarce resources subject to a set of constraints. In order to maintain a radial topology, each loop in the network must have only one switch open at all times.

$$\text{minimize } F1 = \text{reliability indexes} \quad (3.10)$$

$$\text{minimize } F2 = \text{total power losses } (P_{Tloss}) \quad (3.11)$$

$$F2 = \sum_{n=1}^{NL} (K_n * R_n (\frac{P_n^2 * Q_n^2}{V_n^2})) \quad (3.12)$$

where

$n \in NL$ Subject to the following constraints;

The voltage limits must be retained within the allowed limits at the buses.

$$V_{m,min} \leq V_m \leq V_{m,max}$$

Feeder's capability must have power limits in the nth branch;

$$Kn/Pn/ \leq Pnmax \quad n \in NL \quad (3.13)$$

$$Kn/Qn/ \leq Qnmax \quad n \in NL \quad (3.14)$$

$$Kn/In/ \leq Inmax \quad n \in NL \quad (3.15)$$

The radial topology of the network must be maintained;

$$Tiesw = (NL - Nbus) + 1 \quad (3.16)$$

Where

Rn: Resistance in the nth branch.

Qn: Reactive power in the nth branch.

Pn: Real power in the nth branch.

Vm: Voltage magnitude at node m.

Kn: Status topology of the branches (if branch n is closed $K_n = 1$ and if it is open it is 0).

NL: Set of branches in the network.

Nbus: The total number of buses.

Tiesw: total number of switches

Chapter 4

Data Collection and Analysis

4.1 Introduction

Kombolcha is found in North center of Ethiopia, located in Dehub Wollo zone of the Amhara region. It has a latitude and longitude of $11^{\circ}5' N$, $39^{\circ}44' E$ / $11.083^{\circ}N39.733^{\circ}E$ respectively, with an elevation between 1842 & 1915 meters above sea level. Kombolcha old substation is located at Kombolcha town around Kuteba, which is the main substation to supply the whole Kombolcha, Dessie and small towns near Kombolcha including Batie and Harbu. In addition, there are so many industries supplied from this substation like BJI, Textile and others.



Figure 4.1: Existing substation of Kombolcha distribution network.

The city Kombolcha has different natural resources which attract tourists come to the city, it is also a place where different hotels and industrious are under construction. Currently data indicts in Kombolcha distribution system there are 20462 of total customers, from these 3354 of them are commercial customers, 16509 customers are residential, 332 of them are low voltage industry customers, 2 high voltage industrial, 215 of customers are staff of EEU, 14 customers are own consumption and 36 are street lights.

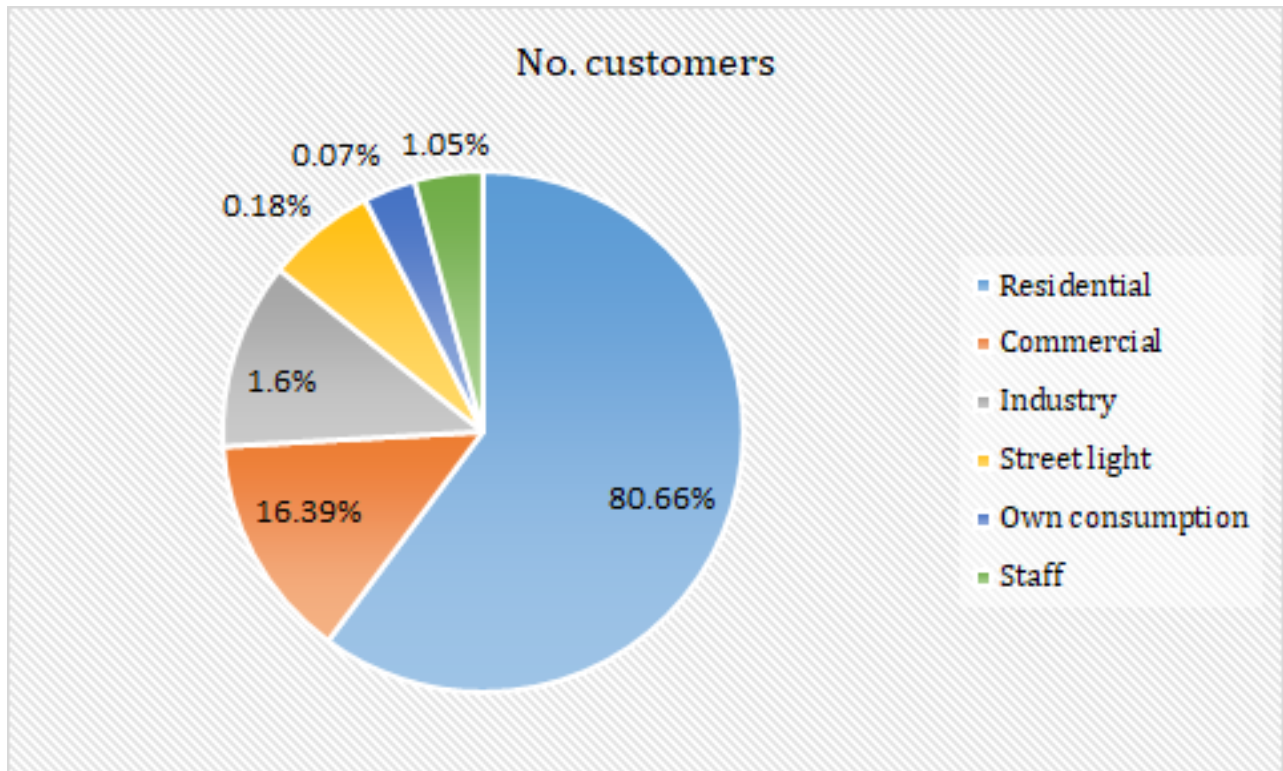


Figure 4.2: Total number of customer in Kombolcha distribution network.

These loads mainly supplied from old substation. The substations had 13 radially configured feeders are engaged to distribute primary voltage level power to the distribution transformer and industrial loads.

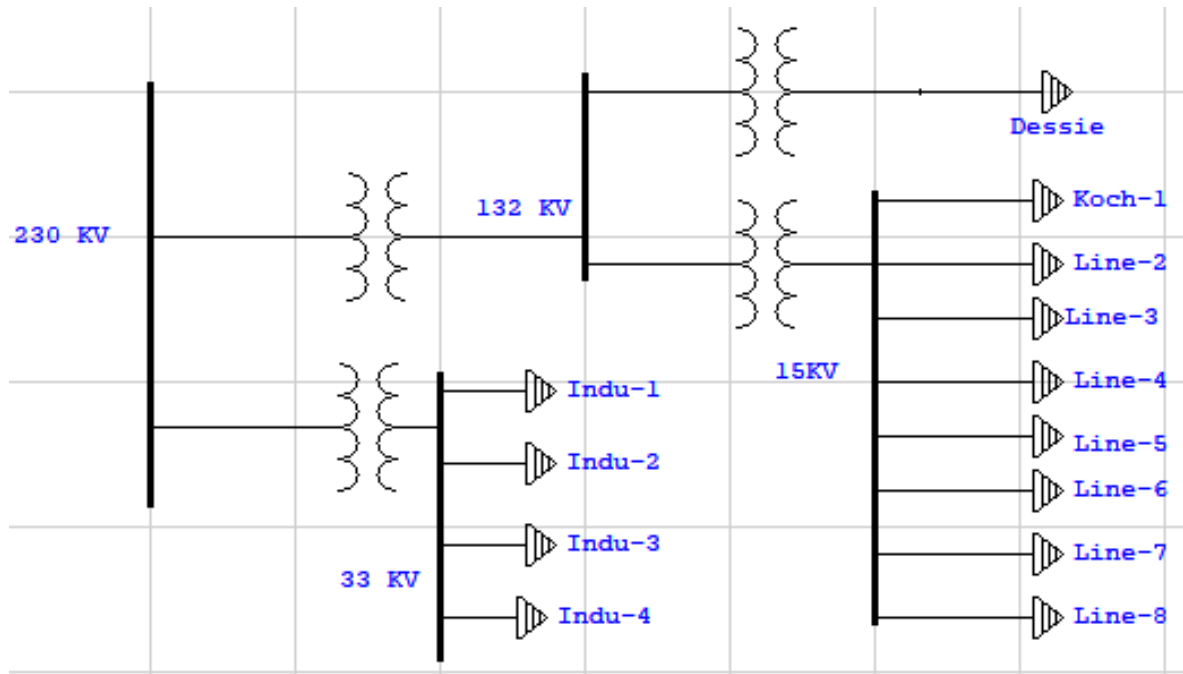


Figure 4.3: Single line diagram of Kombolcha distribution network.

4.2 Data Collection of Kombolcha Distribution System

In Kombolcha distribution network, the primary data necessary for this thesis are

- Length of the feeder
- Rating and type of each transformer
- Topology and layout of the system
- Conductor type, topography and others.
- Numbers of customers
- Total connected loads
- Duration of interruptions
- Frequency of interruptions

Table 4.1: Kombolcha distribution network type of breaker and its maximum loads

feeder name	Voltage ratings	Breaker type	Peak load(MW)
Line-1	15	Oil circuit breaker	3.2801
Line-2	15	Oil circuit breaker	3.525
Line-3	15	Oil circuit breaker	4.4842
Line-4	15	Oil circuit breaker	3.9859
Line-5	15	Oil circuit breaker	2.8441
Line-6	15	Oil circuit breaker	2.8068
Line-7	15	Oil circuit breaker	3.1057
Line-8	15	Oil circuit breaker	2.7611

Table 4.2: Kombolcha distribution network type of transformers with ratings

Feeders name	25	50	100	200	315	500	630	800	1250	Total
	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	KVA	
Line-1	6	5	6	7	4	0	2	0	0	30
Line-2	5	4	6	2	1	0	2	0	1	21
Line-3	10	6	5	6	5	1	2	1	1	37
Line-4	5	6	7	3	2	0	2	2	0	27
Line-5	0	0	0	1	1	0	1	2	2	7
Line-6	0	0	0	0	0	0	0	0	10	10
Line-7	0	0	0	0	0	0	0	0	2	2
Line-8	2	2	2	3	1	0	6	2	4	22

4.3 Reliability Assessment of KDS

For this thesis a case study area, power interruption data are mostly recorded in the form of interruption duration, interruption frequency and load reading of each feeder in hours. Based on the recorded data's it is simple to calculate the reliability indices of total interruptions experienced by customers of each feeder in a month or year. In Kombolcha distribution system reliability indices of 2010 and 2011 E.C are calculated by using analytical method. The figure 4.4 and

figure 4.5 are the reliability indexes result of SAIFI, SAIDI and EENS from analytical in 2010 E.C and 2011 E.C respectively.

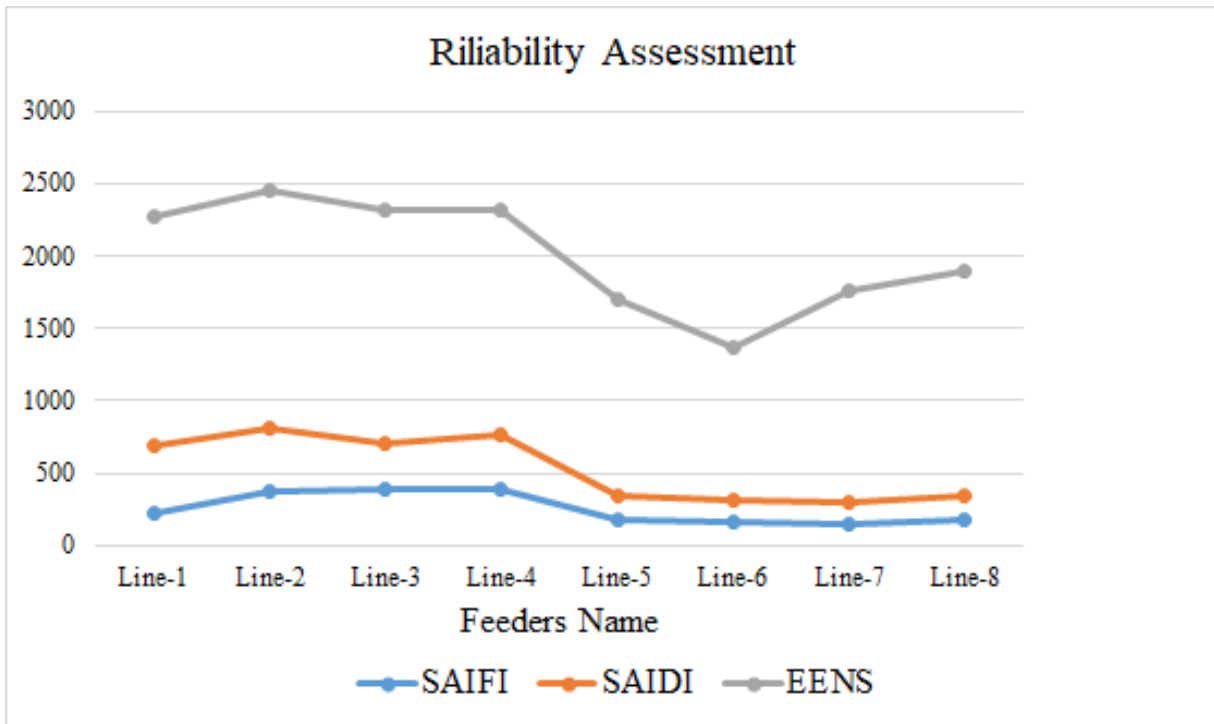


Figure 4.4: Reliability assessment of Kombolcha distribution system in 2010 E.C.

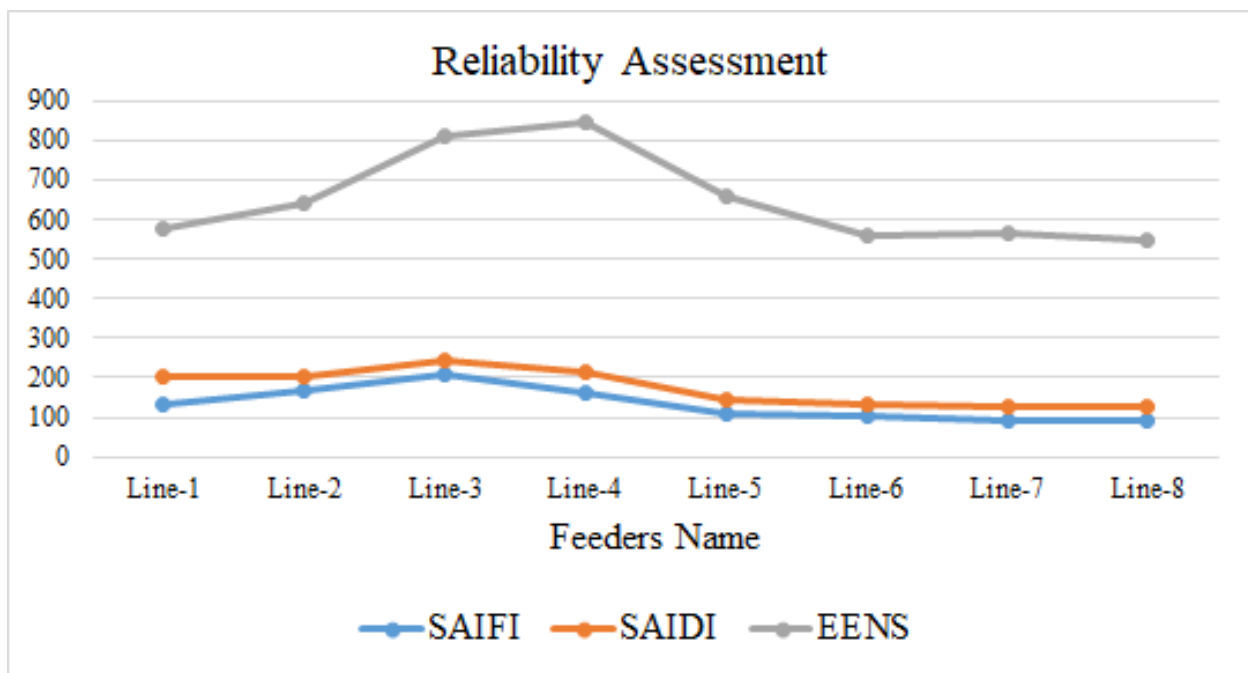


Figure 4.5: Reliability assessment of Kombolcha distribution system in 2011 E.C.

The result shows based on available data the reliability of the system is too poor. When the reliability index i.e SAIFI, SAIDI and EENS of Kombolcha distribution network compare to Ethiopian standard the result was too high value (less reliable).

4.4 Evaluation of Interruption Cost

Addressing of reliable electric power to each individual customer with a reasonable cost as well as quality levels have become the main precondition for development and economic growth for every country. Most developing countries are vulnerable to electric power supply interruptions.

The power interruption cost affects both the utility and customers, which are connected on that feeder. A total amount of economic losses in case of interruptions depends highly on the composition of the customers that experience interruptions. For both industries (small & high), electric power supply interruption costs are highly related to production losses and the costs involved in restoring production. These interruptions also cause electrical and other material damages and revenue losses for industries, commercial customers and for domestic individuals.

In wide spread and long lasting blackouts put the vulnerable society to the test and need additional expenses required to maintain tolerable living environment. This is hard to predicate the perfect values of interruption costs and economical losses, because of the properties of each customer are different. But in utility side power interruption cost is estimated by customer data, interruption data and cost per outage data. When number of customers considered for estimating the cost of power interruptions will have a significant impact on the magnitude of the estimate.

In Ethiopia Electricity Utilities (EEU) recorded all data and use different reliability indices for measuring their network performance. Energy is a very important term to analysis the interruption cost of the system for a typical year. The main factor used for cost estimation is the tariff price in ETB or Dollar per KWH for different types of loads.

In Ethiopian Electric Power Corporate, based on the marketing and sales process estimation manual, which is currently applicable, interruption cost or unsold electricity of utility is

$$Cost\ of\ Interruption = \Sigma interrupted\ (KVA) * \Sigma interrupted\ Hrs * 0.8 * 0.4407 \quad (4.1)$$

Where

KVA is Kilo Volt Ampere of the interrupted transformers

0.8 is power factor

0.4407 is price per KWh Ethiopian Birr unsold energy or interruption cost.

The tariff 0.4407 is taken from the average of the first block tariffs of domestic and commercial customers which most Ethiopian electricity customers are assumed to be grouped.

The cost of energy not supplied is calculated and summarized in figure 4.4, based on exchange rate of the Commercial Bank of Ethiopia on 17 Oct, 2019 @ 12 AM, which equates one US Dollar (USD) to 28.79 Ethiopian Birr (ETB).

$$Interruption\ cost = \sum_{i=1}^n (L_i * ID_i) * 1000 * 0.4407 \quad (4.2)$$

Where i = interruption event

n = all interruptions of Kombolcha distribution within a year

L_i = load (MW) recorded from Kombolcha on the nearest hour before event i

ID_i = Interruption Duration (hr.) for event i

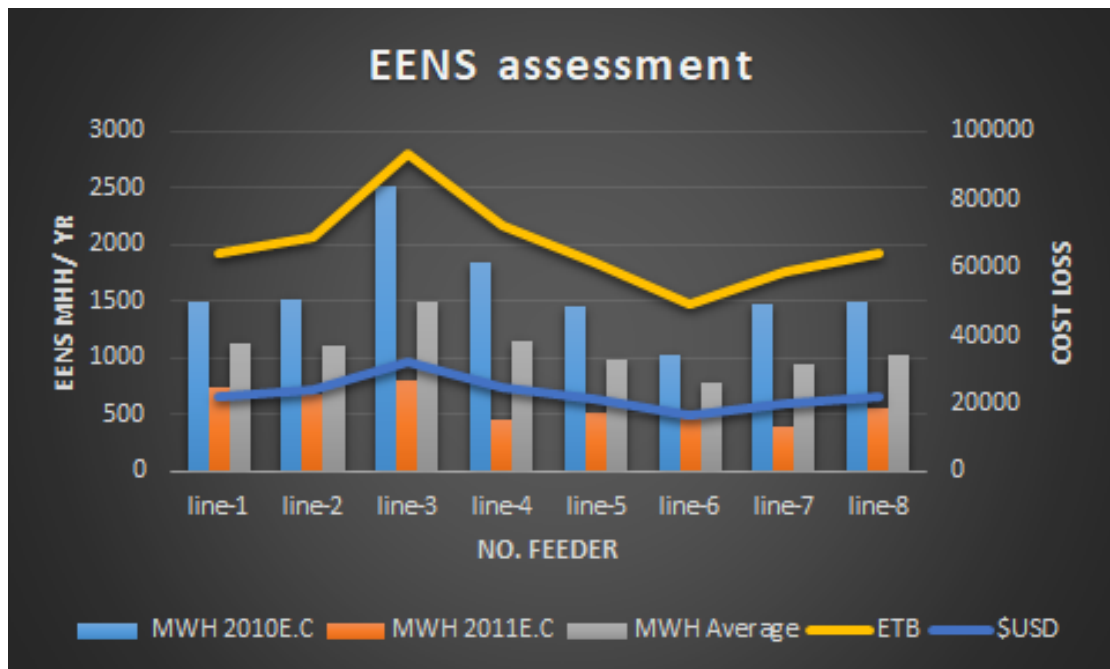


Figure 4.6: Cost assessment of Kombolcha distribution network based on two years data.

The figure 4.6 shows the total cost assessment of Kombolcha distribution substation, the utility is loss in millions ETB each year from power interruption loss without considering generation, transmission and distribution power losses. Based on collected data of two years, averagely 8956

MWH of energy losses from interruption and 5318417.5 ETB of cost losses the substation. From these easy to conclude all Ethiopia electric utility have high interruptions and power losses, which leads to low system reliable and customer dissatisfaction.

Based on the above results of reliability indexes, it covers more than 40% of the town and it contain very critical loads (health station, commercial, government and NGO offices), the thesis has been done on feeder 3 to improve reliability and power loss reduction of the network.

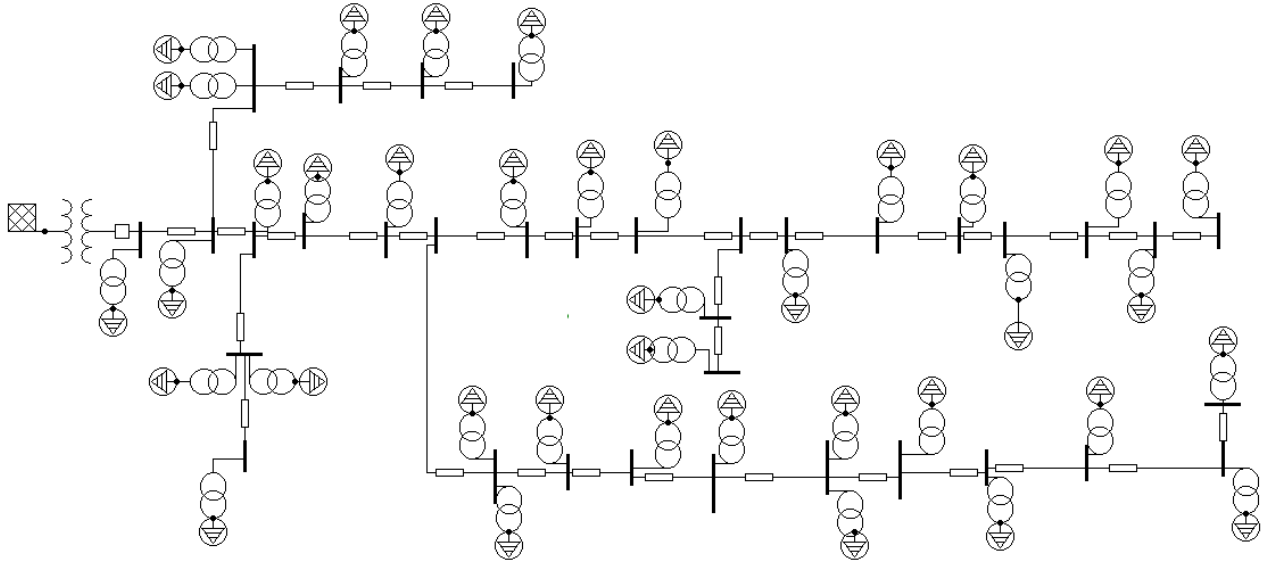


Figure 4.7: Kombolcha distribution system feeder-3 single line diagram.

4.5 Cause of Faults

In Ethiopia each interruption, interruption duration and loads of each feeder per hour is recorded but the causes of interruptions are not in detail. So, to put an appropriate mitigation technique for the reliability problem Kombolcha area it is critical knowing the causes of interruptions. There are different causes in power interruptions at Kombolcha distribution network. These are failing of trees, lighting, car accident, animals, maintenance and failures of equipment. These and other causes are the root of distribution reliability and understanding them allows abstract topics like reliability modeling and computer optimization to be viewed from a practical perspective. Also, identifying and addressing physical root causes is often the most cost effective way to address reliability problems. Component failure is one of the major reasons for electric power interruption in the distribution system like, transformers, circuit breakers, overhead lines, switches and insu-

lators are electrical materials installed in the distribution system. Each component has its own probability of failure. The failure of transformers in a substation because of different faults can cause interruption of service to most of customers. For each interruption, any healthy transformer is called upon to supply this load, which dangerous to the transformer being overloaded. Due to this, the system might lead to failures of transformers due to overloading, which leading to power interruption to thousands of customers of Kombolcha distribution system. So that, fast decision should be taken to determine whether system transformers are over loaded or not. Due to overloading it is cause of heating in transformers which decreases its thermal age.

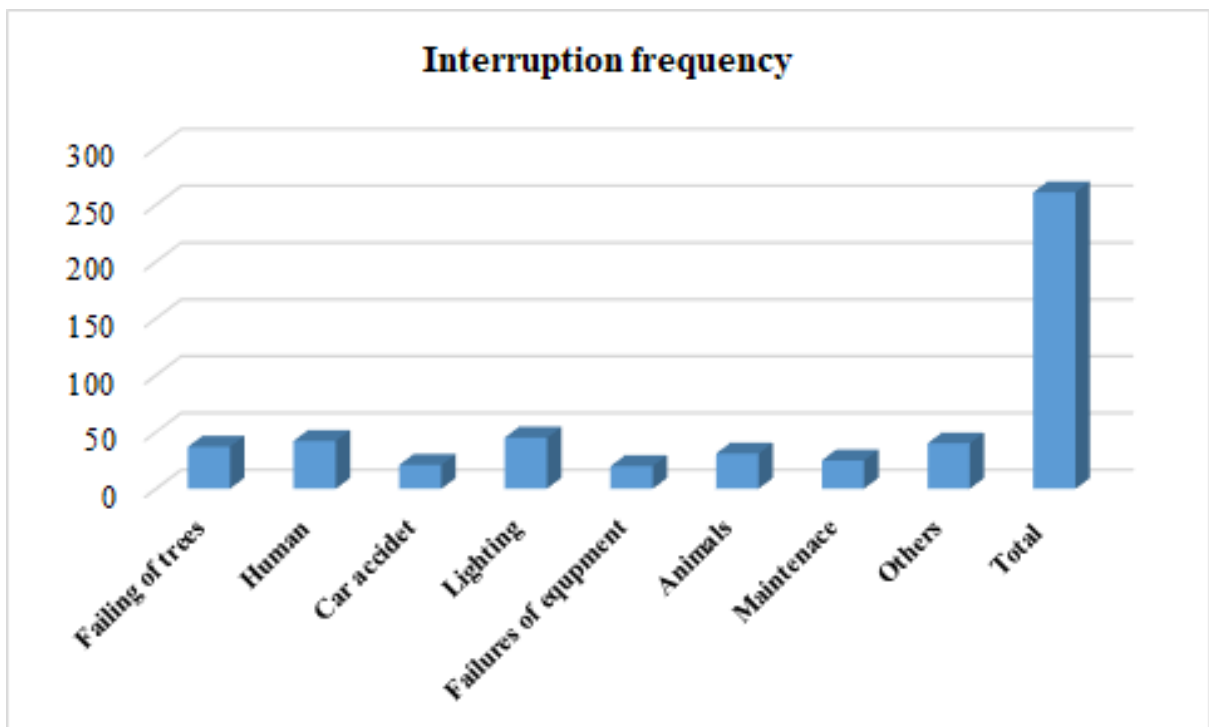


Figure 4.8: Causes of faults at Kombolcha distribution with their frequency.

4.6 System Modeling

The Electrical Transient Analysis Program (ETAP) is totally graphical enterprise package that operates on different Microsoft windows operating systems. It is the most comprehensive analysis tool for the design & enhancement of power systems available. Using its standard of line simulation modules, ETAP can utilize real time operating data for advanced monitoring, real time simulation, optimization, energy management systems and high speed intelligent load shedding.

ETAP can be combining the electrical, logical, mechanical and physical attributes of system materials in the similar database.

ETAP is one of the foremost integrated database for electrical systems, allowing engineers to have multiple presentations of a system for different analysis or design purposes. ETAP software uses to analyze most electrical analysis, for example reliability, short circuit, load flow, arc flash, protection coordination and others. For this thesis, ETAP 12.6.0 is used for design and simulation of existing system reliability and power loss assessment analysis as a tool. The figure 4.9 shows the editor view, with the reliability page open. The parameters used in designing, assessment analysis and enhancement for reliability of any system are those shown on this page.

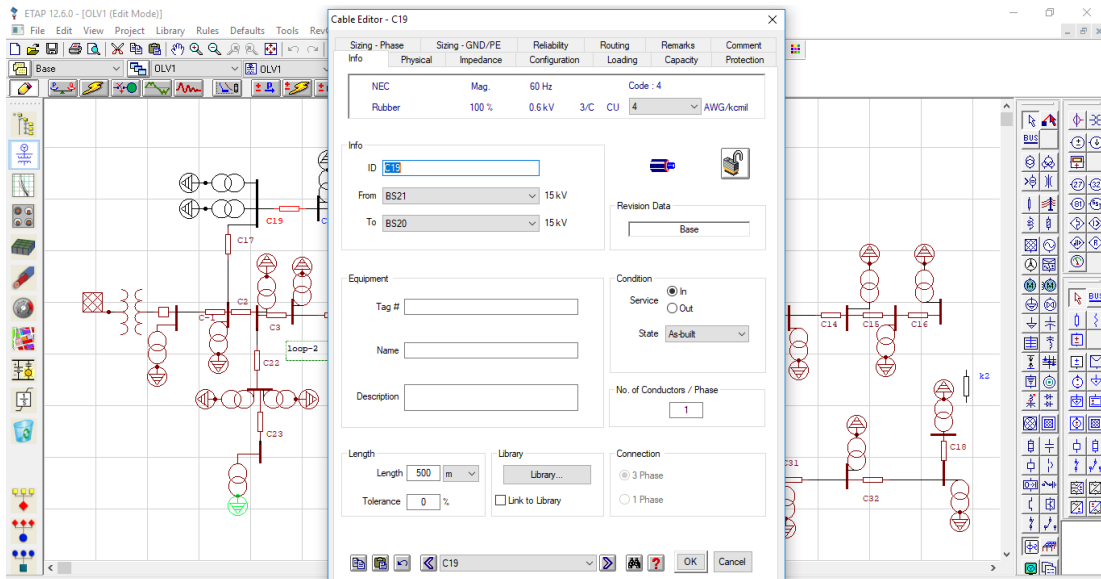


Figure 4.9: The feeder editor view with the reliability page open.

4.7 Existing System Reliability Output

The existing system reliability assessment of Kombolcha distribution network using ETAP is shown below figure 4.10 and the result summary of reliability indexes are shown in table 4.3. The result shows the system is very low reliable, due to these the customers are daily complain on utility.

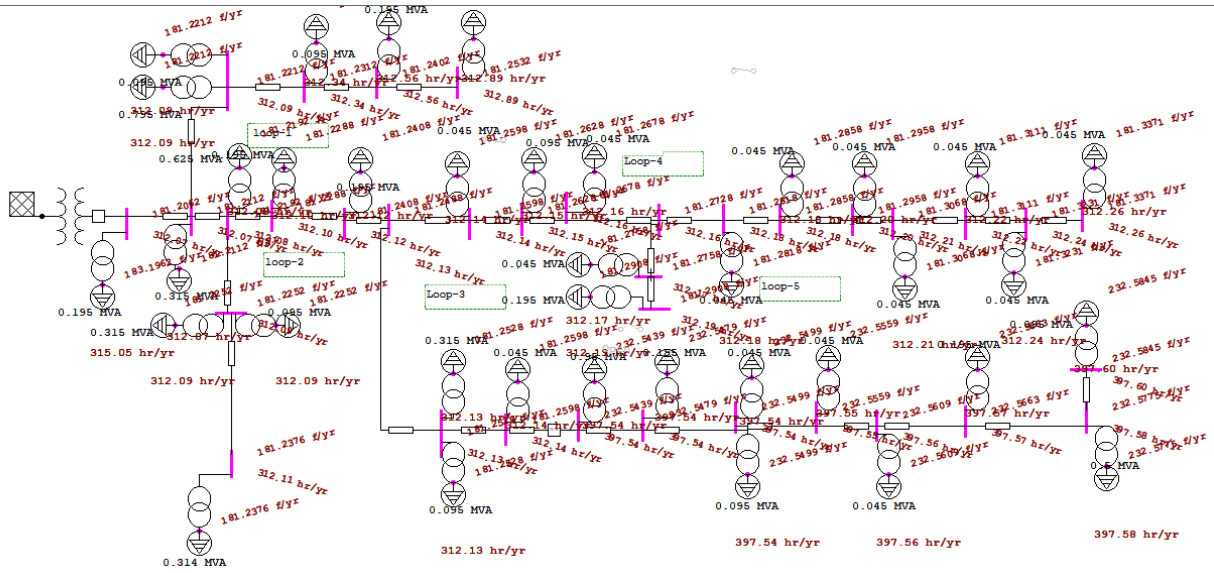


Figure 4.10: Reliability result of existing system by using ETAP.

Table 4.3: Reliability index result of existing network Line-3

Reliability indexes	Output
SAIFI	261 f/cust. yr
SAIDI	423 Hr/cust.yr
CAIDI	1.6 Hr/cust.inter
ASAI	0.9517 pu
ASUI	0.04833 pu
EENS	2.5 GWHr/yr
AENS	67.49 MWHr/ cust.yr

4.8 Power Loss of Existing System

The power loss can be categorized active and reactive power loss. The resistance of the cables, which are causes of active power loss of the network. While the reactive components, which are produce reactive power loss. Normally, the active power loss draws high attention for utility, because it reduce the efficiency of energy to be transmitting the customer. But, the reactive power loss is obviously not less important due to the fact reactive power flow in the system need to be maintained at a certain amount for sufficient voltage level. Kombolcha distribution system

of line-3 power losses at initial condition were 430 KW and 149 KVA_r, active and reactive losses respectively. The existing power loss of Kombolcha distribution system by using ETAP is as shown figure 4.11.

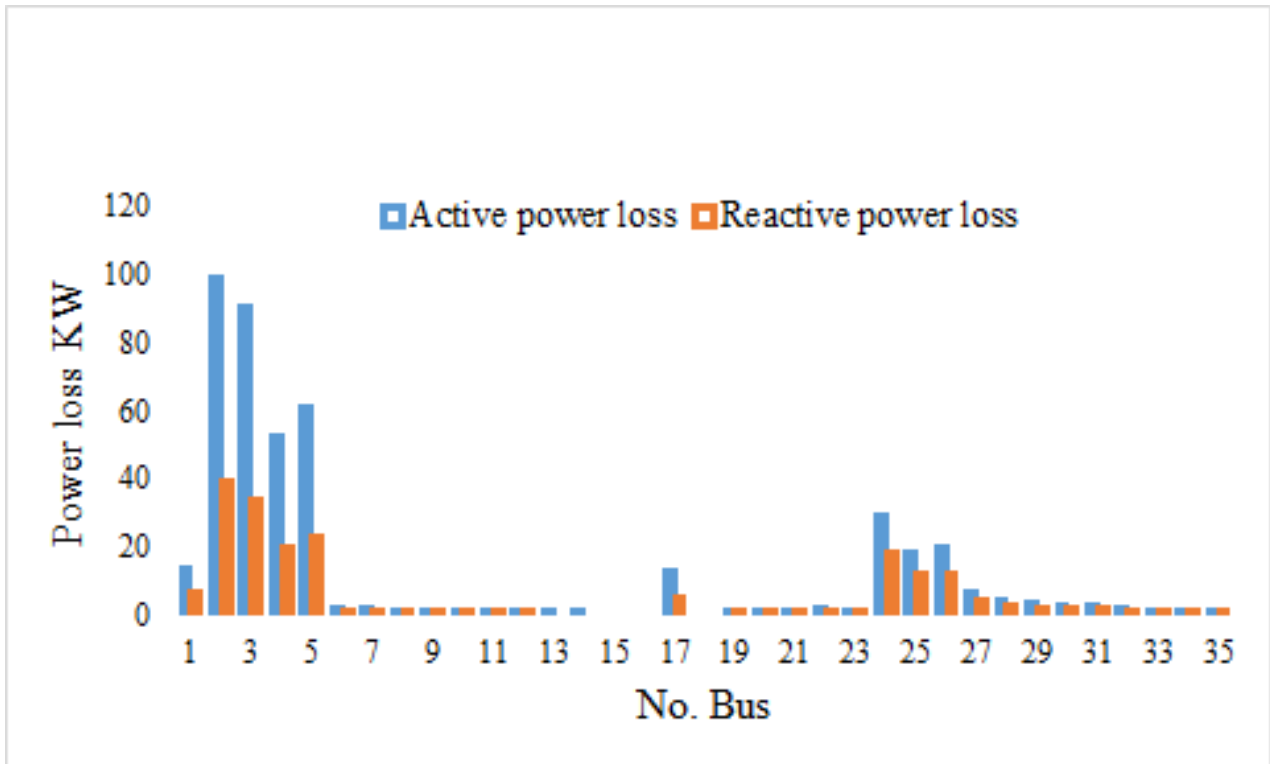


Figure 4.11: Active and reactive power losses of existing network.

To finalize the assessment of Kombolcha, based on two years data collected and the analysis of its results, the following points can be observed:

1. The reliability of the utility in Kombolcha does not meet the requirements set by the regulatory body that is Ethiopian Electric Utility (EEU), and the line loss of the system also high, which leads system unreliable,
2. The reliability of Kombolcha city is not good enough as compared the reliability indices of Ethiopia and developed countries like Austria, USA and England,
3. There is high unavailability of electric power in the network,
4. There is also much loss of unsupplied energy due to sustained interruptions in the present power grid of Kombolcha city,
5. Due to these high ETB losses each year, which can be affect both the utility and customers.

Chapter 5

Result and Discussion

5.1 Introduction

The mitigation of reliability and power losses for different simulation scenarios conducted on Kombolcha radial distribution system are recorded in this chapter. The first case analyzed the initial total power losses and voltage profile of the base load flow of the system at 100% of the total power load demand.

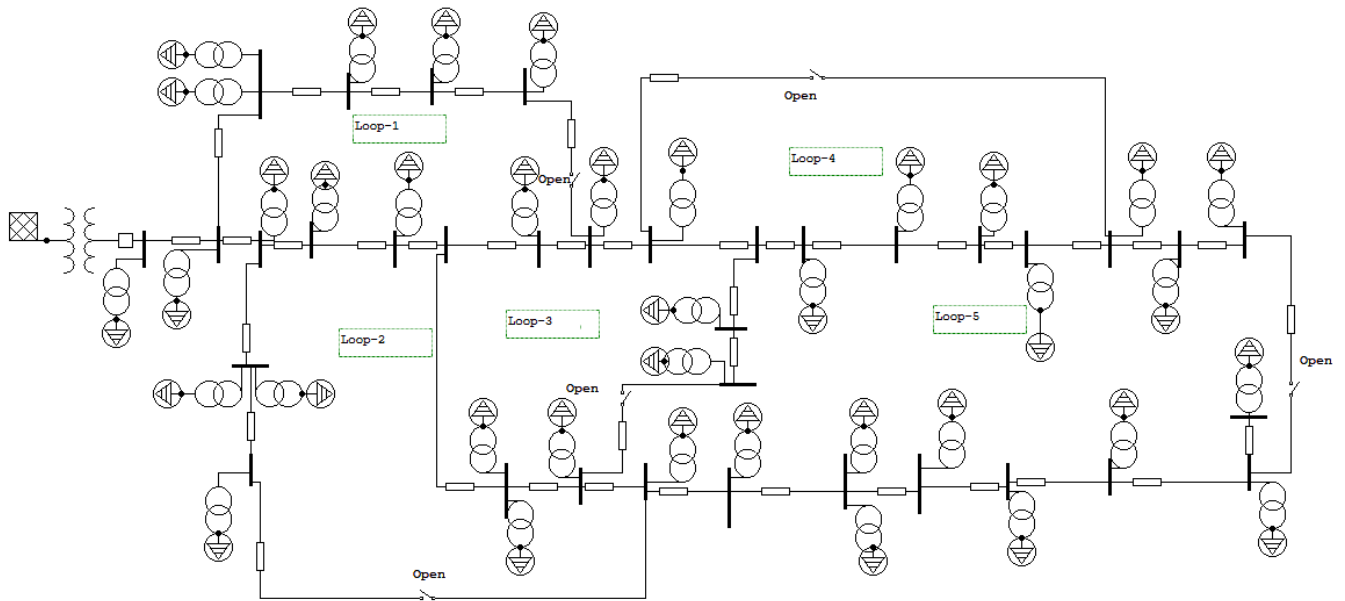


Figure 5.1: Random reconfiguration of Kombolcha distribution network.

The position of the tie switches are selected randomly, since the proposed MSSO algorithm is

stochastic in nature, it will perform a random search, thus the initial value setting of variables does not affect the search for an optimal solution. From the above randomly selected the position of tie switches it forms five loops. Based on these loops collecting each branch with the appropriate loop then table below is formed.

Table 5.1: The branches of distribution system at initial reconfiguration

No. loops	Branches
Loop-1	2 3 4 5 6 7 17 19 20 33
Loop-2	3 4 5 22 23 24 25 26 27 37
Loop-3	6 7 8 9 24 25 26 38 39 36
Loop-4	9 10 11 12 13 14 34
Loop-5	10 11 12 13 14 15 16 27 28 29 30 31 32 33 35 38 39

The maximum reduction of the overall power losses and voltage profile improvement in the KDS were analyzed in two cases. The proposed MSSO algorithm and the load flow analysis were developed and simulated in MATLAB software R2018a on a PC with 2.20 GHz, core i5-2500U, 4 GB RAM. The proposed MSSO algorithm used in network reconfiguration problem was applied in two cases and compared with the existing methods in the literature to validate the performance.

5.2 Simulation Result of Kombolcha Distribution System

The load flow analysis was performed using the Fast Decoupled method to obtain the parameters used in determining the performance of the network. Table 5.2 shows the summary of the load flow results of the two cases.

Table 5.2: Simulation result of Kombolcha distribution network

Activities	Existing Configuration	After Reconfiguration
Tie switches	-	6 11 24 28 36
Power loss	430 kW	170.2877 kW
Power loss reduction	-	60.5%
Minimum voltage	0.85 pu	0.96697pu

5.3 Voltage Profile Improvement Simulation Result

The figure 5.2 shows the comparison of the voltage profile of before and after network reconfiguration for case 1 and case 2, respectively. The network a base reconfiguration is represented by case 1. The minimum voltage in case 1 was 0.92 pu at node 18. With the MSSO algorithm for optimum switching, the configuration in case 1 was converted into case 2. The result of voltage improvement became 0.96697 p.u at node 14 as shown in case 2 of figure 5.2. The slight drop in voltage at buses 20, 21, 22, 23 and 24 in case 2 was caused by the changes made to the network topology after network reconfiguration.

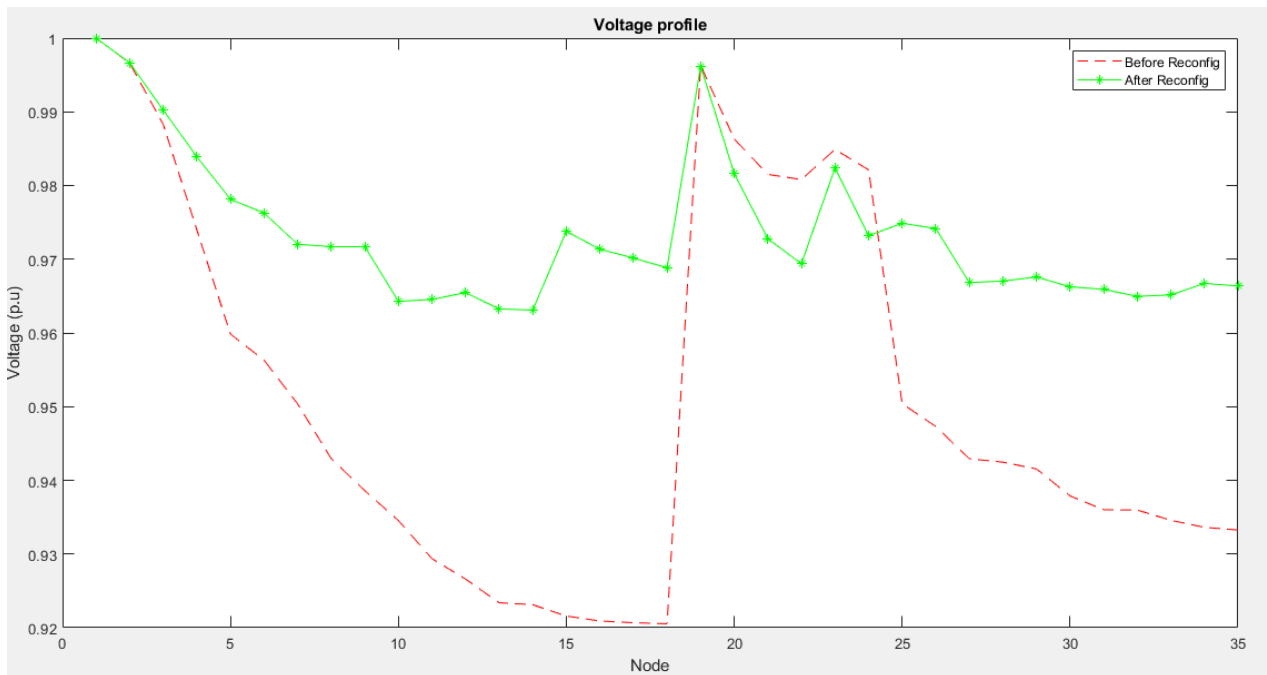


Figure 5.2: Voltage profile of Kombolcha distribution before and after reconfiguration.

The figure 5.3 shows the iteration of load flow by using Fast Decouple to obtain optimal solution. The result reported in this figure is the best solution (the best location of tie switches) obtained after 31 times running of simulation. MSSO algorithm have different advantages from these fast to converge for large system.

The MSSO for each iteration records the power loss and voltage profile of the network before updating the next iteration, from these recorded data it selects the global best position of tie switches, which mean less power loss and best voltage profile. Therefore, for now the global best position of tie switches are 6,11,24,28 and 36.

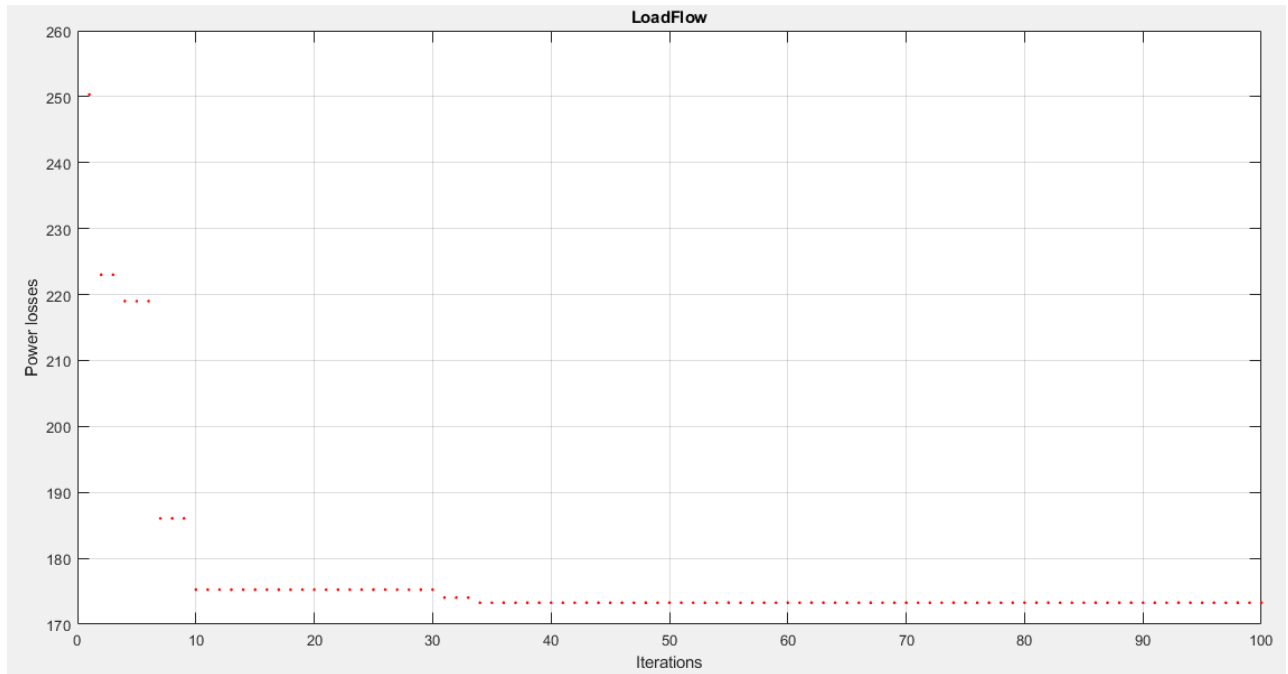


Figure 5.3: Power flow iteration of Kombolcha distribution system.

5.4 Power Loss Simulation Result

The network reconfiguration problem for power loss reduction is solved by MSSO algorithm. The objective is to minimize utility power loss cost with the constraints that all load points have to be electrically supplied and radially connected. The comparison for the real power losses in the branches is shown in figure 5.4 for the initial network before and after reconfiguration, case 1 and case 2 respectively. The power losses in almost every branch in case 2 reduced, except at 14, 18,19, 20, 22, 23, 33, 34 and 37 where there was a small increase in losses due to load shifting of the feeders altered by the switching. The power losses in the feeder lines in case of existing system decreased as moved further from the substation, as a result, there was less strain on power lines and a smooth flow of power. In case 2, the real power losses in the second branch decreased to 18 KW due to network reconfiguration. The optimal tie switches had affected the power flow through the branches of the network, reducing the power lost in most of the branches.

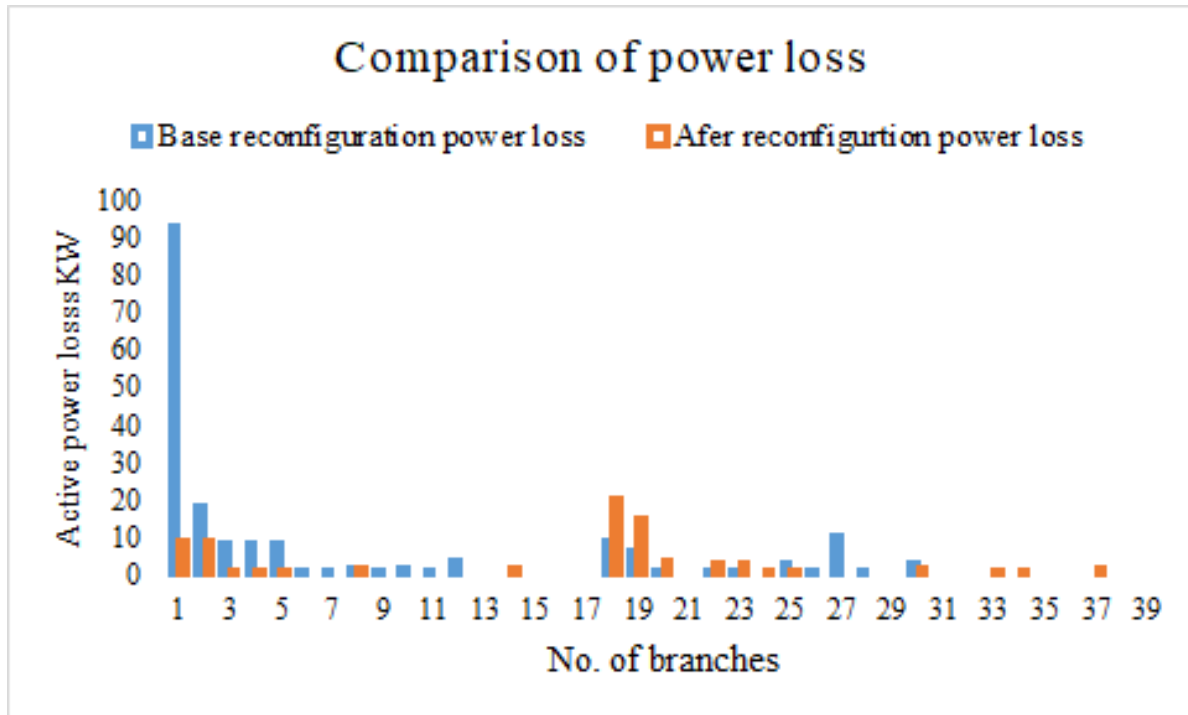


Figure 5.4: The active power loss of the system base and after reconfiguration.

5.5 Reliability Enhancement Simulation Result

From the beginning of existing system of Kombolcha distribution design and calculating of the reliability indices in two years. The simulation output of reliability analysis is obtained by performing the following steps in ETAP12.6.0 software.

- Single line diagram of the existing system (Kombolcha distribution at Line-3) has been designed on the working plane of the software.
- Then run the reliability assessment of existing network.
- Inserting with in optimal location of tie switches based on MSSO output. All switches have been specified based on type and operation.
- Run again of ETAP, which is after reconfiguration

The figure 5.5 shows a single line diagram of Kombolcha distribution after reconfiguration by optimal placement of tie switches, depending on the matlab output. The topology of the network

different from the existing (initial) with similar supply (source), loads, transformer and others but, the change is system reliability and power losses.

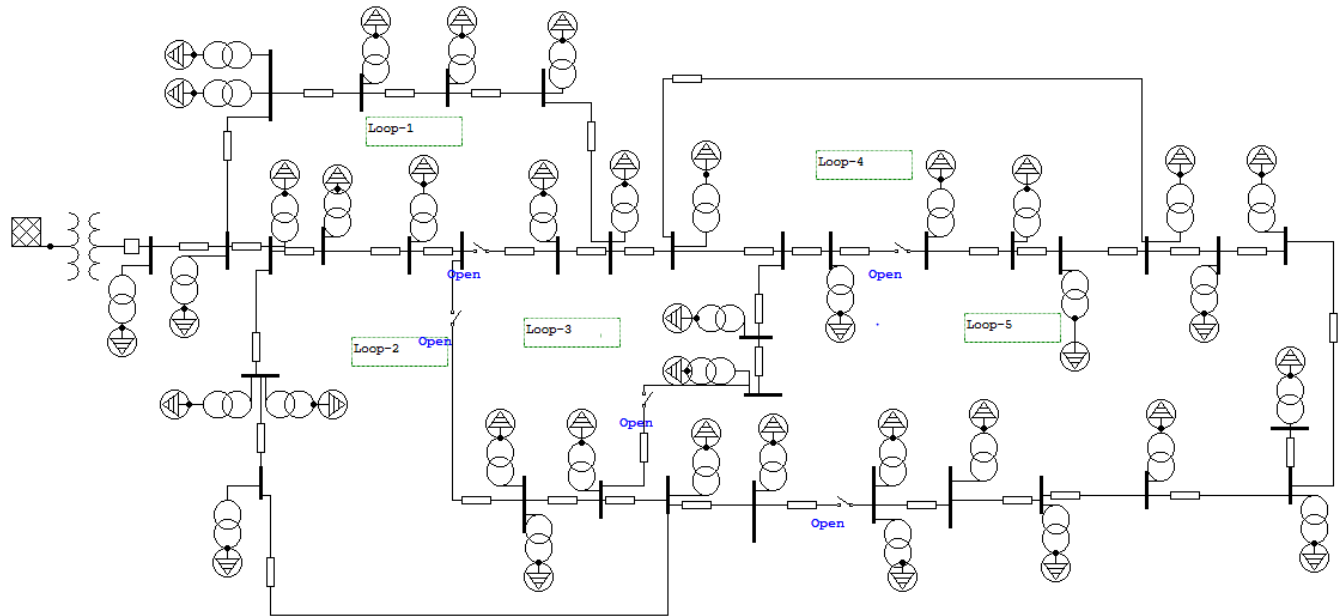


Figure 5.5: Kombolcha distribution system feeder-3 after reconfiguration single line diagram.

The best location of tie switches design by MSSO, considering of system less power loss and best voltage profile. The system is converted from radial system to loop configuration, which gives good result i.e system reliability, power loss and voltage profile of the line are improved. The table 5.3 shows reliability indexes of the system after optimal placement of tie switches, the output tells the reliability of the system is enhanced as shown the table.

Table 5.3: Reliability index result after reconfiguration network

Reliability indexes	Output
SAIFI	91 f/cust. yr
SAIDI	150 Hr/cust.yr
CAIDI	1.652 Hr/cust.inter
ASAI	0.9829 pu
ASUI	0.01712 pu
EENS	743 MWHr/yr
AENS	20.088 MWHr/ cust.yr

Table 5.4: The output comparison between existing and after reconfiguration

Measurement	Existing Configuration	After reconfiguration	% improvement
SAIFI	261 f/ cust.yr	91 f/cust.yr	85
SAIDI	423.4 Hr/cust.yr	150 Hr/cust.yr	86
EENS	2497.1 MWhr/yr	743 MWhr/yr	70
Ploss	430 KW	170 KW	60

Table 5.4 shows the reliability indexes and power loss of Kombolcha distribution network existing and after reconfiguration, the result shows the reliability of the system is enhanced by 70% and power loss of a line reduced by 60% than the existing system.

5.5.1 Sensitivity analysis

The sensitivity analysis, which includes the load point of EENS, ECOST and component ranking. The figure 5.6 and figure 5.7 are sensitivity analysis of EENS and ECOST respectively. The most contributed component for system EENS is C39 and list contributed C17. Similarly, the most and list contributed components of system ECOST are T6 and T38 respectively.

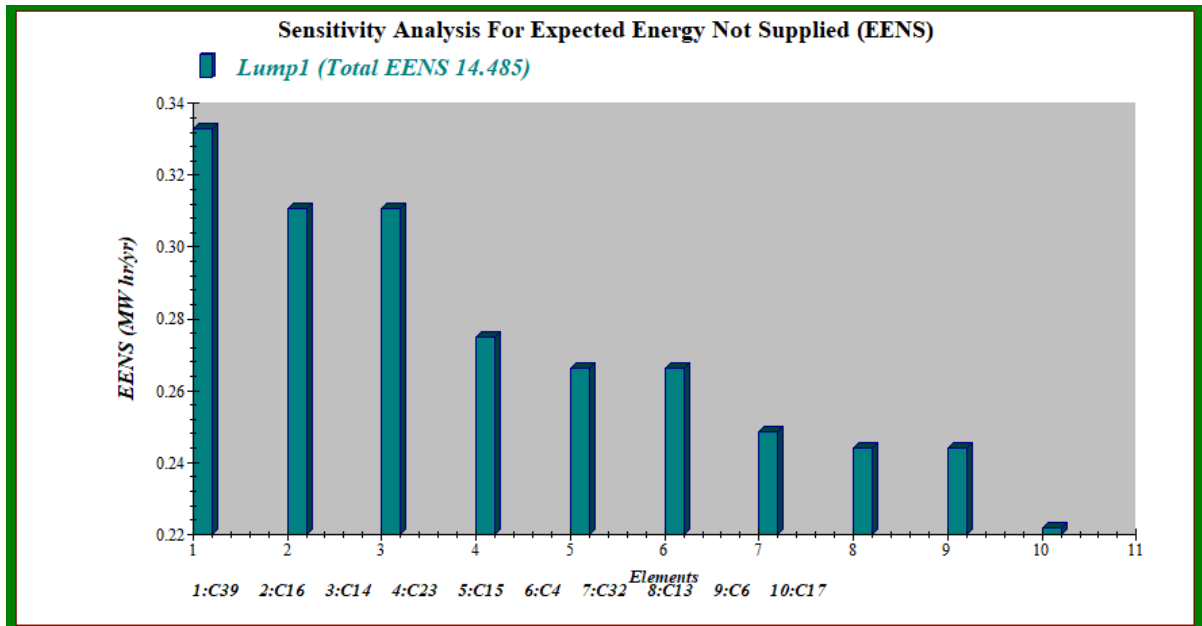


Figure 5.6: Sensitivity analysis for Expected Energy Not Supplied of Kombolcha distribution.

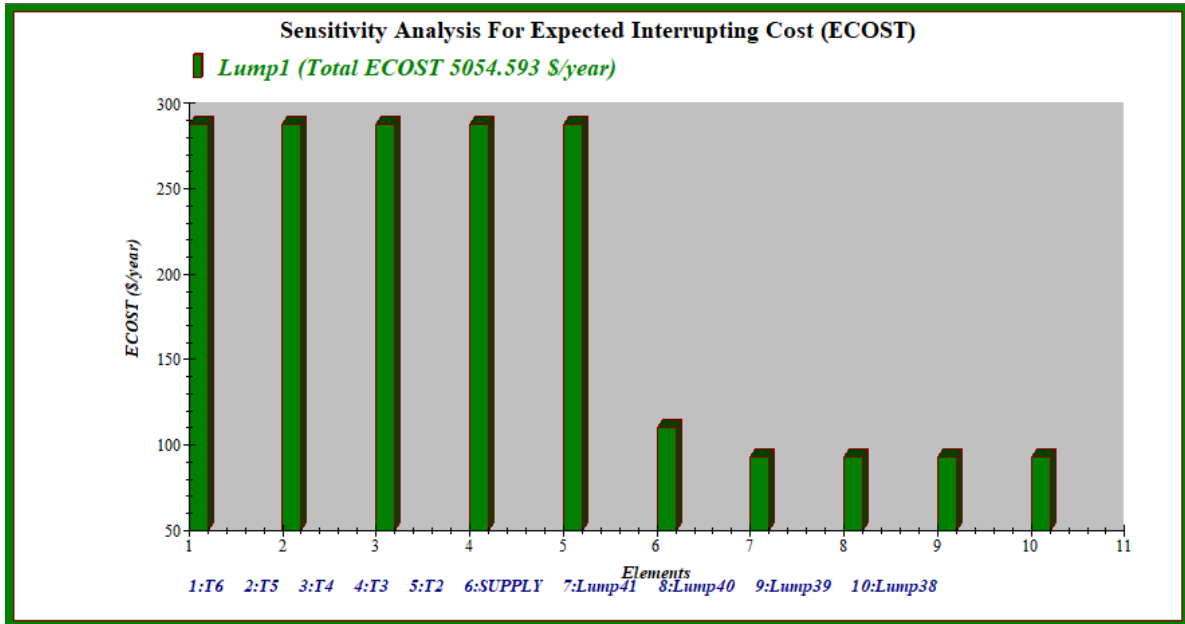


Figure 5.7: Sensitivity analysis for Expected Interruption Cost of Kombolcha distribution.

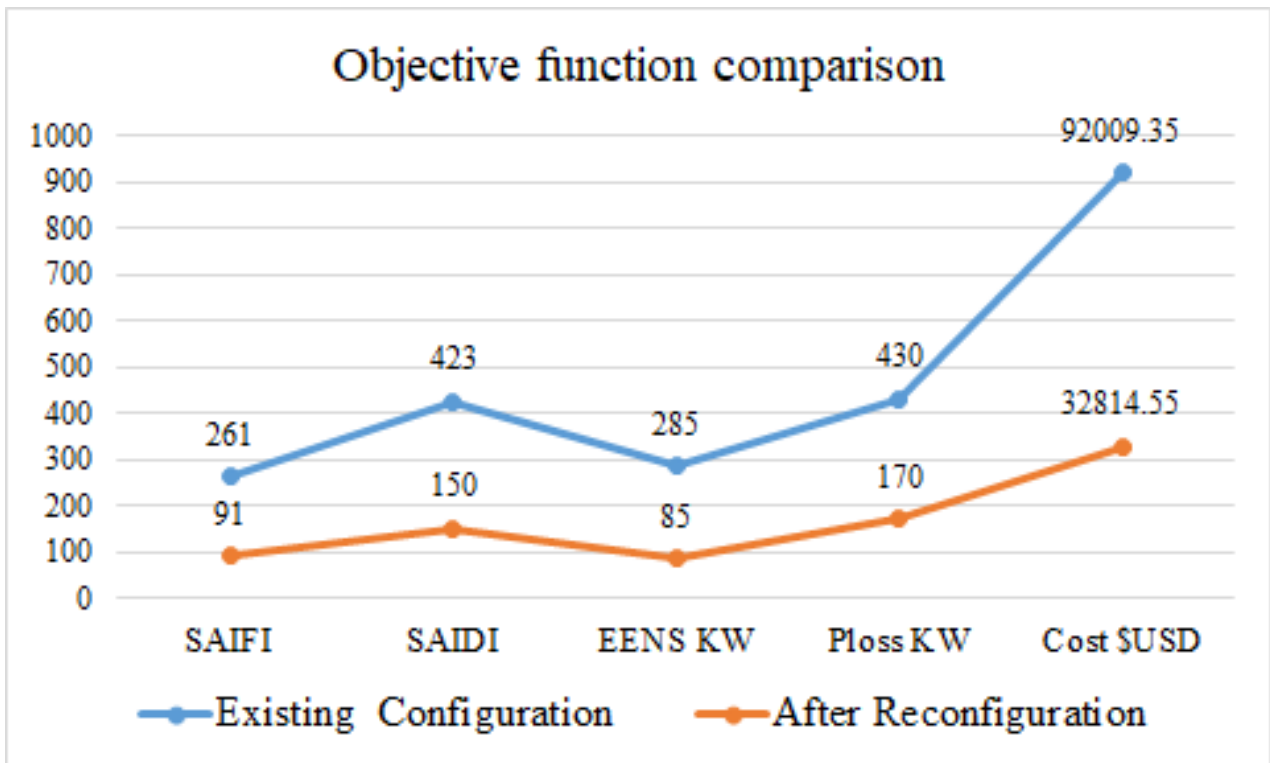


Figure 5.8: Objective function result comparison of existing and after reconfiguration KDS.

The figure 5.8 shows the objective function of the thesis, the result tells high EENS and power loss, which affects the costs of utility and customers too. Totally, Kombolcha distribution high

cost loss each year without considering customer side costs, complains and dissatisfaction. After optimal reconfiguration of the system the objective functions are improved more than 60%, due to this both utility and customers are beneficial in cost, satisfaction and production.

5.6 Comparison of MSSO with BPSO

The comparisons were based on power loss reduction, voltage profile, reliability enhancement, computational burden and cost saving analysis. The results in table 5.5 shows the comparison of the selected MSSO with Binary Particle Swarm Optimization (BPSO) algorithms. The computational time for the proposed MSSO and BPSO algorithms were 80s and 120s respectively. Therefore, MSSO was a short time consuming process to converge an optimum fitness function, better voltages profile and power loss improvement than BPSO. The figure 5.9 shows the voltage profile of KDS both cases i.e case-1 and case-2, which is before and after reconfiguration. So, the result shows the voltage profile increase from 0.918 to 0.945 pu and power loss of the system improved by 55.81% after reconfiguration of the distribution system but, result is less improved as compared to MSSO, that why the thesis is selected MSSO optimization.

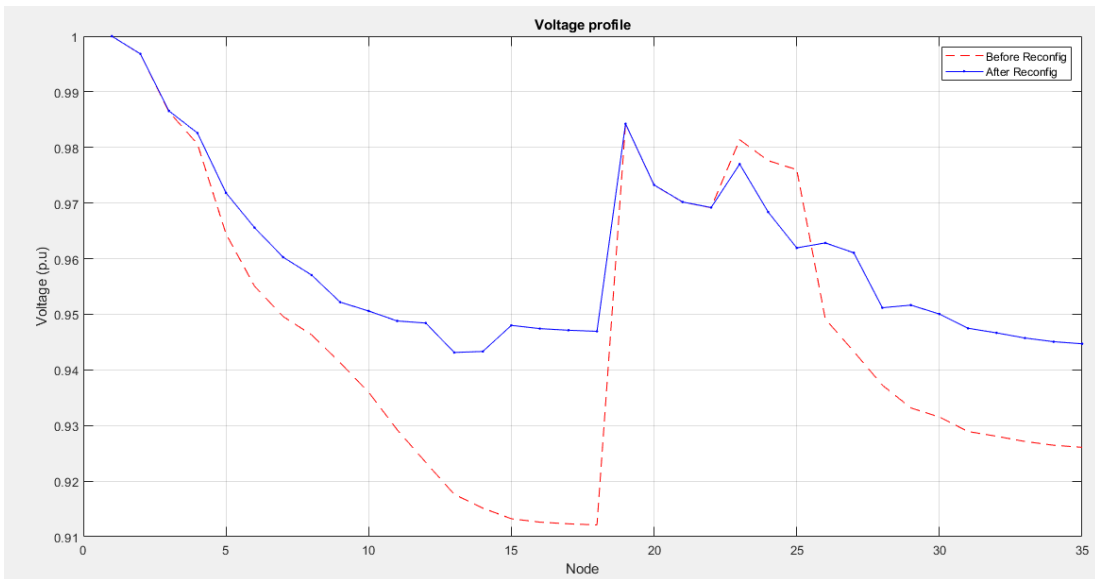


Figure 5.9: BPSO voltage output of Kombolcha distribution.

A cost reduction can be noticed in both algorithms applied in line-3 of Kombolcha distribution system from power loss reduction. It can be evidently seen from figure 5.10 that the proposed

MSSO algorithm serves better in reducing the power losses and cost saving as compared to the BPSO.

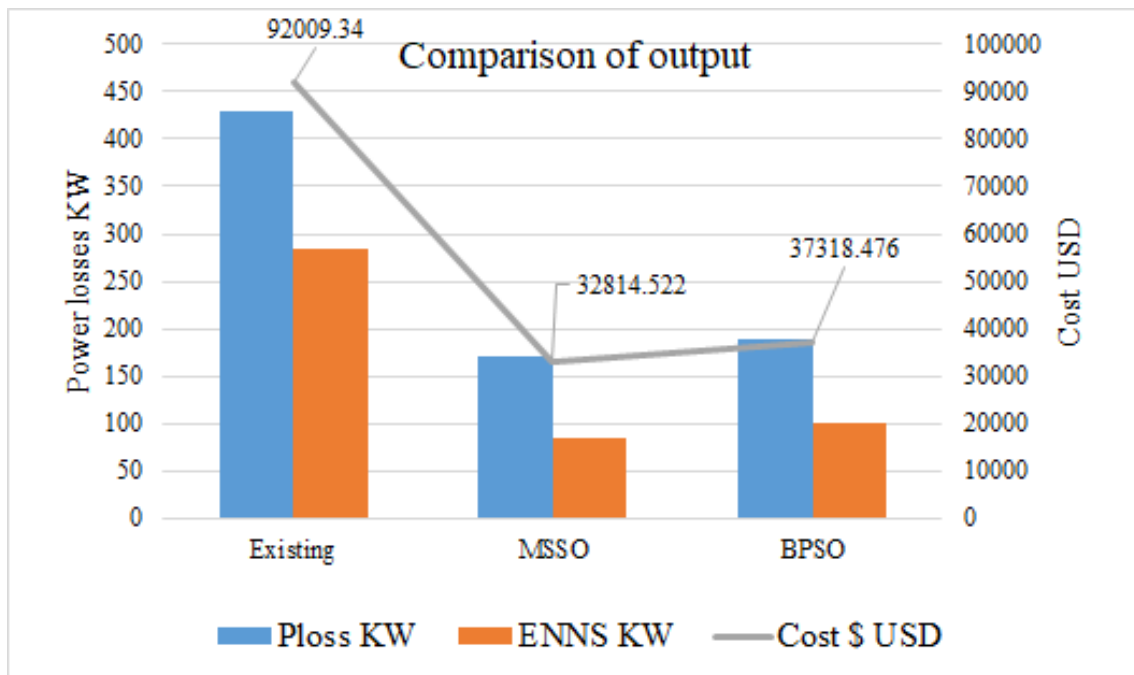


Figure 5.10: Power loss & cost comparison of existing, MSSO & BPSO of Kombolcha distribution.

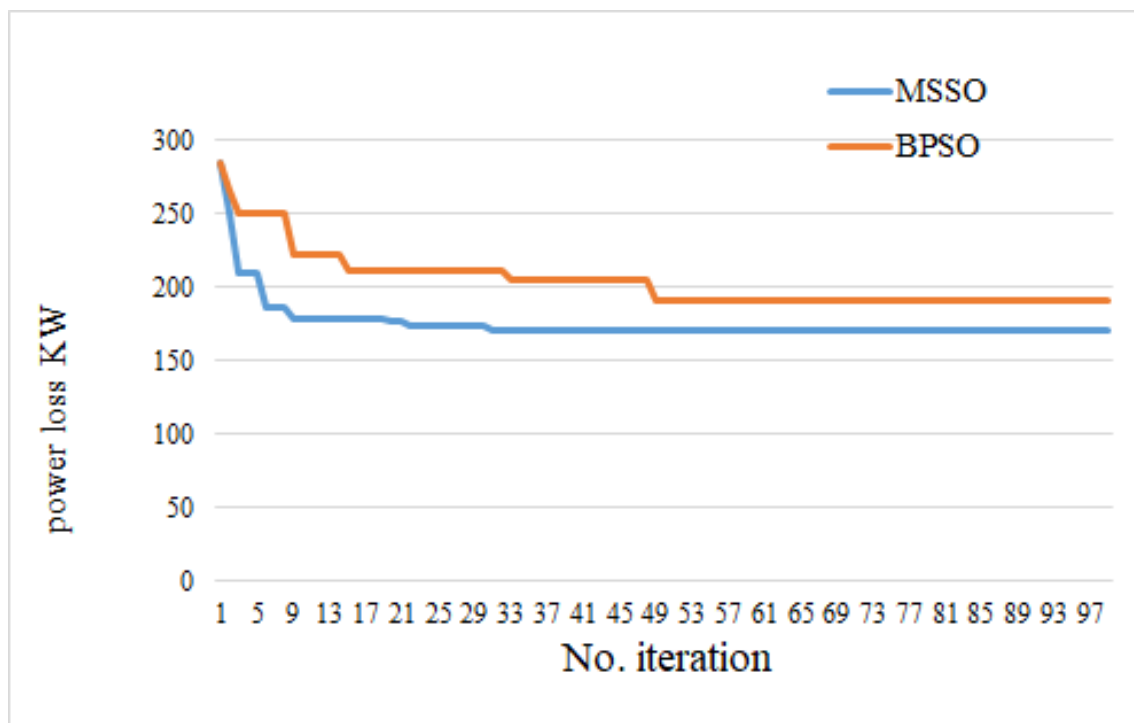


Figure 5.11: Convergence characteristics of MSSO and BPSO algorithm.

The convergence rate of the proposed MSSO algorithm and BPSO algorithm are shown in figure 5.11. The algorithm searches for a switching sequence which gives an optimum fitness function in a network for each load flow carried out in each iteration. The current least power losses in the system's switching sequence population will be maintained in each iteration until the shark smells a better solution with strong odor particles than the previous fitness function. Simulations were carried out for 100 iterations and the optimum solution was obtained after 31 iterations for the proposed MSSO algorithm and 50 iterations for BPSO algorithm. It had a faster convergence rate as compared to the BPSO algorithm. It also required shorter simulation time and a smaller number of iterations to reach an optimum solution.

Table 5.5: Output comparison of MSSO and BPSO with existing network

Parameters	Existing configuration	proposed MSSO	BPSO
Tie switch position	-	6 11 24 28 36	4 14 24 30 33
P_{loss} KW	430	170	190
Voltage profile pu	0.85	0.96	0.946
SAIFI f/ cust.yr	261	91	116
SAIDI hr/cust.yr	423	150	190
EENS MWhr/year	2497.086	740	875
Total Ploss improve	-	65%	60%
Reliability improve	-	85.5%	78%

5.7 Cost Saving Analysis

The size of the economic losses due to interruption depends on the composition of the customers that experience interruptions. Customers in Kombolcha utility are roughly divided into three categories; residential, commercial, and small and high industrial customers. For small industries, electricity supply interruption costs are strongly related to production losses and costs involved in restoring production. In addition, interruptions also cause property damages and revenue losses for industries, commercial customers and for private individuals.

Generally, the cost of customer side is difficult to estimate the exact value of interruption costs and economical losses, since the properties of each customer are different and difficult to found

important data. But it is easy to understand that the cost loss of customer is greater than utility. In this thesis interruption cost only related to the utility side has been analyzed by using Expected Energy Not Supplied (EENS) and the power loss of the system.

Existing configuration of Kombolcha distribution system the power loss is 430 KW and after reconfiguration by using MSSO optimization the power loss is reduced to 170 KW.

$$\Delta P_{loss} = P_{loss} \text{ existing configuration} - P_{loss} \text{ after reconfiguration}$$

$$430 \text{ KW} - 170 \text{ KW} = 260 \text{ KW}$$

This indicates the utility each day 260 KW power can be saving from loss. The loss due to reliability (EENS) is

$$\Delta EENS = EENS \text{ existing configuration} - EENS \text{ after reconfiguration}$$

$$2497.086 \text{ MWH/yr} - 743 \text{ MWH/yr} = 1754.086 \text{ MWH/yr} = 200 \text{ KW}$$

So that, the total power save is the sum of power loss ($I^2 * R$) and the power loss due to reliability i.e EENS.

Total power losses = 260 KW + 200 KW, which is 460 KW in each day can be save.

When the system analysis done the whole feeders of the substation, the utility benefit will be increase radically.

Table 5.6: The cost comparison between existing and after reconfiguration

Characteristics	Existing configuration	After reconfiguration
P_{loss}	430 KW	170 KW
EENS	2.5 GWH/yr	743 MWH/yr
Cost loss	\$92009.346 USD	\$32814.522 USD
Cost saving	- \$92009.346 USD	\$59194.824 USD

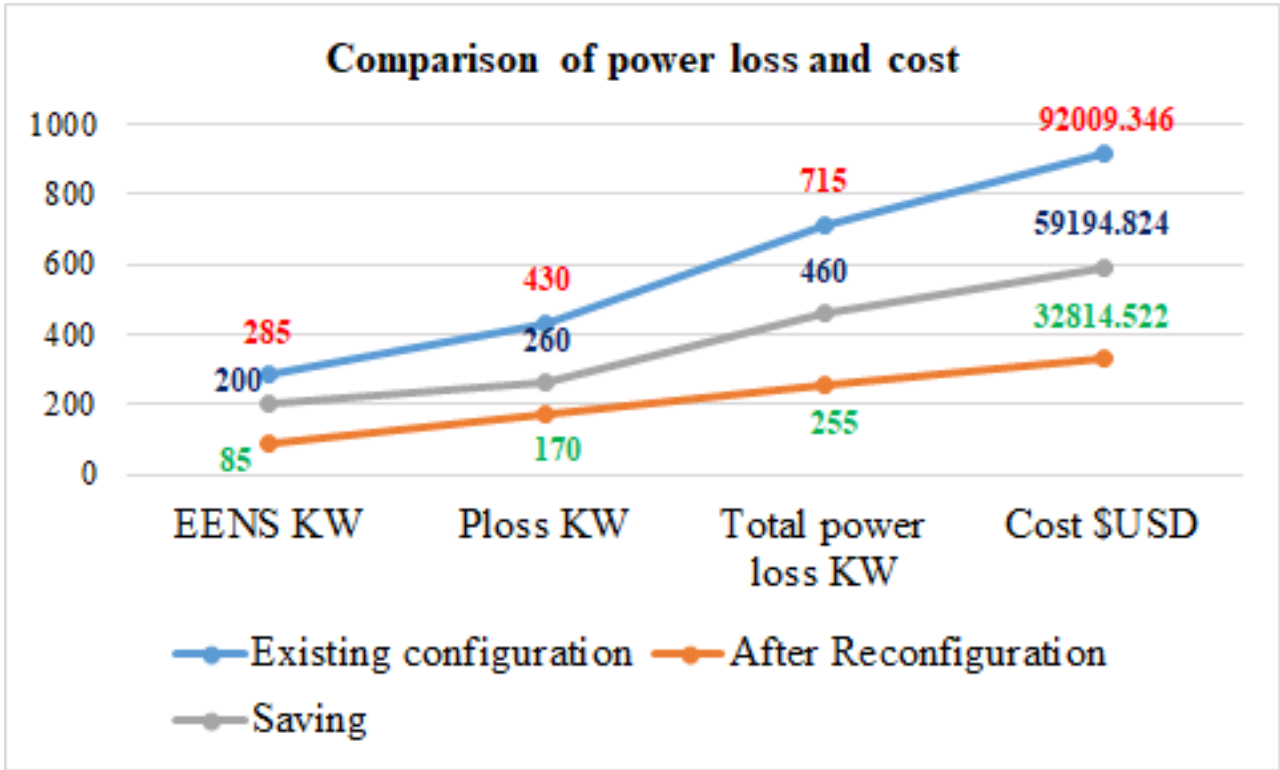


Figure 5.12: Comparison of existing and after reconfiguration in power & cost losses.

In the above analysis deals about the benefit of utility from power loss and EENS, now let see the investment cost of Kombolcha distribution network. The investment cost of Kombolcha distribution network can be calculated by using the cost of tie switches with current cost available in the market and other costs like labor, materials and including transportation. For this thesis, 23 KV and 600A rating of tie switches are selected. The selection of tie switch rating is based on:

- System voltage rating
- Load current rating
- Fault current rating

Table 5.7: Specification of protection device with their voltage and current ratings

Rated voltage (KV)	Rating current(A)	Max. symmetrical fault current rating(A)
15	50	1250
15.5	100	2000
15.5	280	4000
15.5	560	8000
27	100	2500
27	280	4000
38	560	8000

Both the load and fault current of Kombolcha distribution system collected from the data, which recorded at every interruption.

Table 5.8 shows the short circuit current values for a fault at different locations in the existing system. The table demonstrates that the short circuit current values are different for different fault types.

Table 5.8: The fault current result of Kombolcha distribution system

Bus	3 phase fault KA	LG fault KA	LL fault KA	LLG fault KA
B6	1.950	1.124	1.393	1.608
B13	1.146	0.769	0.885	1.021
B24	1.387	1.017	1.202	1.288
B28	0.730	0.521	0.605	0.698

Therefore, the rating of tie switch should be greater than or equal to the system voltage and current ratings. The maximum load current of the system is 200A, which is recorded to the system. Then, the design of tie switches are greater than the line current of 1.25-1.5 times.

Maximum load current in this line = 200A. Hence, continuous rating of tie switch is $200 * 1.5 = 300A$. From the table 5.8 let choose greater than or equal to 300A, which is a continuous rating of 560A. From the above two tables symmetrical interrupting capability of tie switch with 560A continuous rating is 8000A, and a maximum fault current of system is 1950A. Hence, this tie switch meets the requirements.

Currently, the average cost of tie switch with 23 KV and 600A rating is \$17,500 (USD). Based on investment and benefit cost of payback is calculated. Therefore, payback period is the period or length of time required to recoup the cost expended in an investment. It is the ratio of the cost of investment to the yearly saving at feeder line-3 by using that investment. The payback period of a given investment is an important determinant of whether to undertake the position, as longer payback periods are typically not desirable for investment positions.

$$\text{Payback period} = \frac{\text{Total investment cost}}{\text{Saving cost from power losses}}$$

Table 5.9: The materials used the new reconfiguration and cost summary

Types of material	Price of each	Quantity	Total Cost
N95 Insulator	175	100	17500
AAC conductor	127.34	1000	127340
Pole wood 12m	2623.4	33	86572.2
Labour and others	2000	10	20000
Sum	-	-	482824.4 ETB

Table 5.10: The total cost analysis summary of before and after reconfiguration

Case	$P_{loss}KW$	EENS KW	Interruption cost \$USD	Investment cost \$USD	Year
Before Reconfiguration	430	285	92009.346	-	-
After Reconfiguration	170	84.8	32814.522	103594.15	1.75

The table 5.10 shows a short summary of payback period, investment and interruption cost of Kombolcha distribution system. Its clearly show the investment cost will be covered with in less than two years, which is short time when it compared to system reliability and power losses, and the reconfiguration have 25 years warranty.

Chapter 6

Conclusion and Recommendation

The thesis was carried out on Kombolcha radial distribution network to optimize the overall distribution power loss and reliability enhancement by using a proposed MSSO algorithm and ETAP respectively. In the power flow analysis, the effectiveness of the proposed MSSO algorithm was conducted and compared in two cases, before reconfiguration and after reconfiguration of Kombolcha distribution at Line-3. The evaluation of selected algorithm MSSO was compared with other algorithms from the literature. The results of the power losses in each branch and reliability indexes output of the network were recorded and tabulated. A graphical presentation of the voltage profiles, power losses, reliability enhancement and evaluation of power losses cost of the Line-3 of Kombolcha distribution system were shown.

6.1 Conclusion

The city of Kombolcha is one of the oldest and industrial city of Ethiopia, which is poor electrical distribution system. The distribution network analysis using Matlab and ETAP simulation study is carried out on one of the 15KV distribution feeder Line-3, to assess the performance of the present network and also the future reliability and power loss analysis to be predict. Based on the two years interruption data of Kombolcha distribution causes of interruptions, it can be seen that Line-3 feeder experienced highest number of interruptions and the interruptions are mainly due to over load, tree, windy rain, distribution equipment failures, scheduled outages and others. After optimal reconfiguration of the network the reliability indices (SAIFI, SAIDI and EENS) and network power loss of Kombolcha Line-3 is improved. After optimal placement of the five tie

switches by using MSSO algorithm both the reliability and power loss of the system are improved by more than 60%. The tie switch and the high voltage circuit breakers are remotely controlled and have the ability of being operated in an automated scheme. This allows the automatic transfer of load from one branch to another during an outage. In order to achieve this objective, a computer program ETAP12.6.0 is used to model and run reliability analysis.

Finally, after optimal reconfiguration of the network SAIFI has been reduced by 85 % as compared with the average reliability indices value of the system in the base years. In the same case SAIDI and EENS have been reduced by 86 % and 70 % respectively and the power loss reduction 60%. Based on the above output results, the proposed (MSSO) presents better interruption and line power loss cost in comparison with that of the existing system \$92009.346/yr to \$32814.522 /yr (64.34 %) reduction along with enhancement in reliability indices and best power loss minimization.

6.2 Recommendation

The primary purpose of the system is to satisfy customer requirements and since the proper functioning and longevity of the system should found to be essential requisites for continued satisfaction. The interruption data recording have to be made systematic and rationalized meaning that all individual component failure data, localized fault data, have to be precisely recorded if future system analysis should represent true state of the system. As of now, the data have been recorded only when there is fault on the feeder, and all the hard copy data are not kept properly. As this thesis is conducted on one feeder, doing reliability assessment, analysis and power loss reductions in the whole part of the feeders is recommended. On practical implementation of the recommended alternative solution is also important to improve the reliability and power loss of the power distribution system. The reliability indexes of the system could be further improved by scheduled preventive maintenance, additional rehabilitation works which can reduce risk or vulnerability in the system and for power loss it is better to change the size of cables or conductors. Finally, highly recommended for Engineers to put their hands on solving such real time problems and utility better to consider the reliability rather than investment cost.

6.3 Future Work

Future work may lie in a deeper analysis of impact of reliability and power loss with different size and locations of DGs. Further, improvement of the system rather than using reconfiguration it is better to use also DG. When different types of DGs and reconfiguration are considered, the results will be better in reliability and power loss reduction. There is still more research to be conducted with network operations in radial distribution systems. The area recommended for future research include considering dynamic loads and DG operation modes, considering premature transformer failure cost, effects of unbalanced distribution systems, considering a combination of optimal capacitor placement and optimal feeder reconfiguration for further improvement and application of the proposed MSSO algorithm in a real-time system while considering transient effects of switching operations.

6.4 List of Publications

1. D. Anteneh (2019) Reliability Assessment of Distribution System Using Analytical Method: A Case Study of Debre Berhan Distribution Network. *Journal of Informatics Electrical and Electronics Engineering*, 1(1), 2, 1-9.
2. Degarege Anteneh, Baseem Khan. Reliability Enhancement of Distribution Substation by Using Network Reconfiguration a Case Study at Debre Berhan Distribution Substation. *International Journal of Economy, Energy and Environment*. Vol. 4, No. 2, 2019, pp. 33-40. doi: 10.11648/j.ijeee.20190402.12.
3. Degarege Anteneh, Book chapter, Reliability Enhancement of Smart Distribution Network Using Reconfiguration IGI Global 2020, DOI:10.4018/978-1-7998-1230-2.ch009
4. Degarege Anteneh, Birhanu Alene, Design and Optimized of Solar PV System a Case Study of KIOT Administration Offices, *American Journal of Electrical and Electronic Engineering*. Vol.8 No. 1,2020,pp.27-35.dio:10.11648/j.jeee.20200801.15
5. Reliability enhancement and power loss reduction in distribution network by optimal Reconfiguration A case study of Kombolcha distribution system, Ethiopia.
(submitted on **IET Generation, Transmission and Distribution**)

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Appendix

Appendix-A

Active and reactive power of each bus.

Bus	Active power	Reactive power	Bus	Active power	Reactive power
1	0.156	0.117	23	0.2512	0.1884
2	0.752	0.564	24	0.328	0.246
3	0.036	0.027	25	0.2512	0.1884
4	0.156	0.117	26	0.328	0.246
5	0.156	0.117	27	0.328	0.246
6	0	0	28	0.076	0.057
7	0.076	0.057	29	0.156	0.117
8	0.036	0.027	31	0.072	0.054
9	0.0000	0.000	32	0.036	0.027
10	0.036	0.027	30	0.112	0.084
11	0.156	0.117	33	0.156	0.117
12	0.036	0.027	34	0.036	0.027
13	0.036	0.027	35	0.076	0.057
14	0.328	0.246	22	0.156	0.117
15	0.036	0.027	21	0.712	0.534
16	0.036	0.027	20	0.712	0.534
17	0.036	0.027	0	0	0
18	0.036	0.027	0	0	0
19	0.156	0.117	0	0	0

Appendix-B

Power loss output of Kombolcha distribution system.

No. branches	From	To	P MW Before reconfiguration	Q MVA _r Before reconfiguration	P MW After reconfiguration	Q MVA _r After reconfiguration
1	1	2	0.093	0.01	0.090	0.01
2	2	3	0.018	0.01	0.009	0.00
3	3	4	0.008	0.00	0.001	0.00
4	4	5	0.008	0.00	0.001	0.00
5	5	6	0.098	0.01	0.010	0.01
6	6	7	0.001	0.00	0.000	0.00
7	7	8	0.001	0.00	0.000	0.00
8	8	9	0.002	0.00	0.002	0.01
9	9	10	0.001	0.00	0.000	0.00
10	10	11	0.002	0.00	0.000	0.00
11	11	12	0.001	0.00	0.000	0.00
12	12	13	0.004	0.00	0.00	0.00
13	13	14	0.000	0.00	0.00	0.03
14	14	15	0.000	0.00	0.002	0.00
15	15	16	0.000	0.00	0.00	0.00
16	16	17	0.000	0.00	0.00	0.00
17	17	18	0.000	0.00	0.00	0.00
18	18	19	0.009	0.00	0.020	0.01
19	19	20	0.006	0.00	0.015	0.00
20	20	21	0.001	0.00	0.004	0.00
21	21	22	0.000	0.00	0.00	0.00
22	22	3	0.001	0.00	0.003	0.00
23	23	24	0.001	0.03	0.000	0.00
24	24	25	0.000	0.00	0.001	0.02
25	25	6	0.003	0.00	0.001	0.00

No. branches	From	To	P MW Before reconfiguration	Q MVAr Before reconfiguration	P MW After reconfiguration	Q MVAr After reconfiguration
26	26	27	0.001	0.02	0.01	0.00
27	27	28	0.010	0.03	0.01	0.00
28	28	29	0.001	0.00	0.00	0.00
29	29	30	0.000	0.00	0.00	0.009
30	30	31	0.003	0.00	0.002	0.00
31	31	32	0.000	0.00	0.00	0.01
32	32	33	0.000	0.02	0.01	0.00
33	21	8	0.000	0.00	0.001	0.00
34	9	15	0.000	0.00	0.001	0.00
35	12	22	0.000	0.00	0.00	0.00
36	18	33	0.000	0.00	0.00	0.00
37	25	29	0.000	0.00	0.002	0.00
38	33	34	0.000	0.00	0.00	0.00
39	34	35	0.000	0.00	0.00	0.00
Total	-	-	0.274	0.13	0.170	0.109

Appendix-C

Interruption data of Line-3.

No.	Interruption Date dd/mm/yy	Interruption Time	Reconnection Time	Difference Hours
1	06/02/2010	9:24	16:27	7:03
2	07/02/2010	17:09	19:45	2:36
3	08/02/2010	9:09	12:03	2:54
4	09/02/2010	1:46	11:01	9:15
7	09/02/2010	11:48	12:41	0:53
8	10/02/2010	0:59	1:07	0:08
9	13/02/2010	6:37	8:07	1:30
10	13/02/2010	10:21	12:17	1:56
11	15/02/2010	17:58	18:06	0:08
12	16/02/2010	8:26	11:57	3:31
13	16/02/2010	17:37	17:48	0:11
14	17/02/2010	6:32	8:12	1:40
15	17/02/2010	9:33	12:09	2:36
16	18/02/2010	9:32	11:16	1:44
17	19/02/2010	14:57	15:00	0:03
18	19/02/2010	15:11	16:27	1:16
19	21/02/2010	6:38	7:36	0:58
20	21/02/2010	20:15	20:20	0:05
21	22/02/2010	15:33	10:04	18:31
22	23/02/2010	10:20	10:25	0:05
23	23/02/2010	17:39	19:45	2:06
24	25/02/2010	10:31	12:41	2:10
25	26/02/2010	8:06	14:38	6:32
26	27/02/2010	12:28	14:38	2:10
27	28/02/2010	10:59	11:00	0:01
28	29/02/2010	6:37	7:51	1:14

No.	Interruption Date dd/mm/yy	Interruption Time	Reconnection Time	Difference Hours
29	29/02/2010	9:26	12:51	3:25
30	29/02/2010	13:17	13:48	0:31
31	29/02/2010	15:32	16:01	0:29
32	29/02/2010	17:49	18:46	0:57
33	01/03/2010	16:10	16:26	0:16
34	03/03/2010	7:21	13:32	6:11
35	03/03/2010	13:32	14:05	0:33
36	05/03/2010	16:00	16:52	0:52
37	06/03/2010	0:08	12:22	12:14
38	06/03/2010	15:40	15:54	0:14
39	07/03/2010	6:43	14:31	7:48
40	09/03/2010	16:23	16:53	0:30
41	10/03/2010	11:10	12:00	0:50
42	11/03/2010	15:20	17:17	1:57
43	14/03/2010	6:47	6:52	0:05
44	19/03/2010	10:16	10:20	0:04
45	24/03/2010	9:31	10:00	0:29
46	24/03/2010	15:54	18:13	2:19
47	25/03/2010	16:30	16:35	0:05
48	30/03/2010	15:53	18:21	2:28
49	01/04/2010	9:16	12:05	2:49
50	03/04/2010	7:24	11:54	4:30
51	09/04/2010	9:31	10:04	0:33
52	11/04/2010	9:28	9:46	0:18
53	11/04/2010	15:19	15:25	0:06
54	19/04/2010	10:41	11:32	0:51
55	22/04/2010	10:05	11:06	1:01
56	22/04/2010	15:58	16:22	0:24
57	27/04/2010	15:52	17:28	1:36

Appendix-D

Code of MSSO.

```
% MODIFIED SHARK SMELL OPTIMIZATION (MSSO) ALGORITHM
% Done by Degarege Anteneh (2020)
% Department of Electrical and Computer Engineering (Electrical Power system and Energy)
% Hawassa University (IOT)

clear all

clear

clc

% INITIAL NETWORK CONFIGURATION

mpopt=mpoption ('pf.alg','FDXB'); % Fast-Decoupled method using Matpower
data1 = loadcase (Kocha); % Load kombolcha system data
for c = 1 : length (o)
data1.branch (o ( c ), 11 ) = 0;
end

loadflow = runpf (data1,mpopt); % Run Load Flow using Fast Decoupled method
Initial Ploss = sum (load flow.branch (:,14) + load flow.branch (:,16))*1e3; % System losses
Initial Voltage = load flow.bus (:,8); % Voltages at the buses
Vtagemin = min (Initial Voltage); % Minimum voltage tap

% INCIDENCE MATRIX

data = loadcase (Kocha); % Load Kombolcha distribution system data
doc = data.branch;

br = 39; % Branches
bs = 35; % Buses/nodes

matrix = zeros (br, bs); % Create a zero matrix

bs1 = doc (:,1);
bs2 = doc (:,2);

for d = 1 : br;
matrix (d, bs1(d)) = 1;
matrix (d, bs2(d)) = 1;
end
```

```

%% DEFINE MSSO PARAMETERS
dim = 5; % Dimension of searching space (switching sequences) Inertia / momentum rate [0-1]
b = 2.* rand (); % Velocity limiter ratio
n1 = 0.9.* rand (); % Value in the interval / element [0-1]
t1 = 5.* rand (); % Time interval for the stage n given as 1
M = 50; % No. of points in the local search of each stage n
R1 = -1 + (1 + 1).* rand (n, dim); % Random no. [0-1] for gradient term
R2 = -1 + (1 + 1).* rand (n, dim); % Random no. [0-1] for momentum term
maxiter = 100; % Maximum iteration
y1 = zeros (n, dim); % Creating a zero matrix of the position
vnew = rand (n, dim); % Creating an initial velocity
x1 = load ('popu.m'); % Creating a zero matrix of the x1 position
sigmoid = zeros (n, dim); % Creating a zero matrix sigmoid function
fitness = zeros (n,dim); % Creating a zero matrix fitness function
Lbest = load ('popu.m'); % Load the randomly created local best matrix
Gbest = [35 36 37 38 39]; % Introducing a global best
Xbest = load ('popu.m'); % Load the randomly created best position
flbest = zeros (n, dim); % Creating a zero matrix of local fitness function
for k = 1 : n
flbest(k) = 1000; % Calculating fitness function for local best(Ploss)
for iter = 1 : maxiter
y = Xbest';
data = loadcase(Kocha) ; % Load Kombolcha distribution system data
mat = matrix;
for m = 1 : dim
data.branch(y(m,k),11) = 0;
mat(Xbest(k,m),:) = 0;
end
% CHECKING RADIALITY CONSTRAINT OF THE SYSTEM
for cn = 1 :
length (matrix(1,:))

```

```

for r = 1 :
length (matrix(1,:))
if sum (mat(:,r)) == 1
row = find(mat(:,r));
mat(row,:) = 0;
end
end
if sum(sum(mat)) == 0
result = runpf(data, mpopt);
fitness(k) = sum(result.branch(:,14) + result.branch(:,16))* e3;
end
% UPDATING LOCAL BEST
if fitness(k) < flbest(k)
Lbest(k,:) = Xbest(k,:);
flbest (k) = fitness(k);
end
% CALCULATING FITNESS FUNCTION
u = Gbest';
data = loadcase ( Kocha ); % Load Kocha distribution system data
for jj = 1 : length ( u )
data.branch ( u ( jj ),11 ) = 0;
end
result = runpf ( data,mpopt );
fgbest = sum ( result.branch ( :,14 ) + result.branch ( :,16 ))* 1e3;
gbestvolt = result.bus ( :,8 );
minvolt = min ( gbest volt );
vnew ( i,j )= min ( abs ( n1.* R1( i,j )+ a.* R2 ( i,j ).* vnew ( i,j ))... ,abs ( b.* vnew ( i,j )));
% Velocity of Shark
% UPDATING PARTICLES' COORDINATE
y1 ( i,j ) = x ( i,j ) + vnew ( i,j ).* t1; % New Position due to forward movement
sigmoid (i,j)= length (non-zeros ( ta (:,j) )) / ( 1 + exp(-y1(i,j))); % sig function

```

```

x1(i,j) = ta ( ceil ( sigmoid ( i,j )),j);
% ROTATIONAL MOVEMENT OF THE SHARK
for ii = 1 : M
R3 = - 1 + ( 1 + 1 ).* rand( n, dim ); % Random no. in the range [-1 +1]
z ( i, j ) = abs ( x1 ( i, j ) + ceil ( R3 ( i, j ).* x1 ( i, j ))); % Local search
end
Xbest(i, j) = min( x1 ( i, j ) ,
z ( i,j )); % Best position
end
end
gbestvolt;
q = sort (Gbest);
ploss = (Initial Ploss - fgbest) * 100 / Initial Ploss;
figure (1)
plot (Initial Voltage,'- r')
hold on
plot (gbestvolt,'- g*')
disp(' SIMULATION RESULTS OF KOMBOLCHA 35 BUS DISTRIBUTION NETWORK')
disp('=====')
disp(' BEFORE RECONFIGURATION      AFTER RECONFIGURATION')
disp('-----')
disp(['Tie switches: ', num2 str (o), ' ', num2 str (q)] )
disp('-----')
disp(['Power loss:', num2 str' kW', ' ', num2 str (fgbest), 'kW'])
disp('-----')
disp('-----')
disp(['Minimum vol:', num2 str(Voltagemin), ", ", num2 str (minvolt), 'pu'])
disp('-----')

```

Appendix-E

Code of BPSO.

```
n=50;
dim=5; % dimension of searching space
x=load('popu.m'); % Creating a popu
vnew=rand(n,dim); % Creating a randomized initial velocity
sig=zeros(n,dim); % creating a sigmoid
vold=vnew;
fitness=zeros(1,n);
pbest=load('popu.m'); % Creating personal best matrice
gbest=[35 36 37 38 39]; % Introducing a randomized global best
wmax=0.8;
wmin=0.5;
r1 = rand(n,dim); % Creating a randomized matric
r2 = rand(n,dim); % Creating a randomized matric
iter= 0;
maxiter = 100; % Maximum iteration
tap = % Branches in the network (Switches)
ta = tap'; % Establish the incidence matrix
mpopt=mpoption('pf.alg','FDXB'); % for fast decoupled method
data=loadcase(Kocha);
doc=data.branch;
nhanh=39;
nut=35;
matrix = zeros (nhanh,nut);
nutcui = doc(:,2);
% Calculating fitness function for pbest
fpbest = zeros(1,n);
for i=1:n
fpbest(i) = 40000;
% Main loops
```

```

while iter < maxiter
iter = iter + 1;
w = wmax -( wmax-wmin) * iter / maxiter; % Specilize the weight coefficient
c1=2;
c2=c1;
% Updating velocity
vold=vnew;
for i=1:n
for j=1:dim
vnew (i,j)= w * vnew (i,j)+ c1 * r1 (i,j) * ( pbest(i,j)- x(i,j))+ c2 * r2 (i,j) * (gbest (j) - x (i,j));
if
abs(vnew(i,j))>= abs(vold(i,j)) vnew(i,j)=rand(1,1).*vnew(i,j);
end
end
end
% Updating particles' coordinate
for i=1:n
for k=1:dim
sig(i,k)=length(non-zeros ( ta (:,k ))) / ( 1 + exp (-vnew ( i,k )));
x (i,k)=ta ( ceil ( sig (i,k)),k );
end
end
% Updating pbest
for k=1:n
if
fitness(k) < fpbest(k)
pbest(k,:)=x (k,:);
fpbest(k)=fitness(k);
end
end
% Calculating fitness function for gbest

```

```

u=gbest';
hop=loadcase(Kocha);
for i=1:length(u)
hop.branch (u(i),11)=0;
end
result =runpf(hop,mpopt);
fgbest=sum(result.branch(:,14) + result.branch(:,16))* e3;
gbestvolt = result.bus(:,8);
minvolt=min(gbestvolt);
% Updating gbest
for k=1:n
if fpbest(k)< fgbest
gbest = pbest (k,:);
end
end
% Calculating initial configuration
Bandau = loadcase(Kocha);
o=[39 38 35 36 37];
for i=1:length(o)
bandau.branch(o(i),11)=0;
end
ketqua = runpf(bandau,mpopt);
tonthat = sum(ketqua.branch(:,14) + ketqua.branch( :,16 )) * e3;
dienapmin = min(dienap);
gbestvolt;
a=sort(gbest); ploss=( tonthat - fgbest) * 100;
figure ( 1 )
plot ( dienap,'-r' )
hold on
plot( gbestvolt,'-b. ')
ylabel('Voltage (p.u)')

```

```

xlabel('Node')
title('Voltage profile')
legend('Before Reconfig','After Reconfig')
grid on
hold off
pause(.1)
% plot the Power losses
figure(2);
plot(iter, fgbest,'-b.')
hold on
xlabel('Iterations')
ylabel('Power losses')
title('Loadflow')
grid on
end
disp(' ')
disp(' ')
disp(' SIMULATION RESULTS OF KOMBOLCHA 35 BUS DISTRIBUTION NETWORK ')
disp('=====')
disp('BEFORE RECONFIGURATION          AFTER RECONFIGURATION' )
disp('-----')
disp(['Tie switches: ', num2str(o), ' ', num2str(a)])
disp('-----')
disp(['Power loss: ', num2str(tonthat), ' kW, ', num2str(fgbest), ' kW'])
disp('-----')
disp('-----')
disp(['Mini volt:', num2str(dienapmin), ' pu, ', num2str(minvolt), ' pu'])
disp('-----')

```


No.	Cause of interruption	Highly agree	Agree	Neutral	disagree	Highly disagree	Total point	Rank
1	Lighting	..	..	..	..	..	..
2	Human	..	..	..	..	..	..
3	Failure of equipments	..	..	..	..	..	..
4	Car accident	..	..	..	..	..	..
5	Failing of trees	..	..	..	..	..	..
6	Animals	..	..	..	..	..	..
7	Maintenance	..	..	..	..	..	..
8	Natural phenomena	..	..	..	..	..	..
9	Unknown	..	..	..	..	..	..

3) If you have any other ideas regarding the causes of the power interruptions of Kombolcha distribution substation, please specify it here under

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4) If you have any reasons for prolongation of the power outage durations please mention it.

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5) If you have any suggestion about the solutions of the power interruption problems of Kombolcha distribution system please specify it.

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Thank you and I really appreciate for your willingness.