OPTIMAL PLACEMENT OF AUTOMATED SWITCH IN DISTRIBUTION NETWORK WITH CUSTOMER INTERRUPTION COST (CASE STUDY: HAWASSA DISTRIBUTION SYSTEM)

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By

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A Thesis Submitted to Hawassa University, Institute of Technology, Department of Electrical and Computer Engineering, for the Partial Fulfillment of the Requirement for the Degree of Masters of Science in Power System and Energy Engineering.

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ADVISOR’S APPROVAL SHEET

This is to certify that the thesis entitled “OPTIMAL PLACEMENT OF AUTOMATED SWITCH IN DISTRIBUTION NETWORK WITH CUSTOMER INTERRUPTION COST (CASE STUDY: HAWASSA DISTRIBUTION)” submitted in partial fulfillment of the requirements for the degree of Masters of Science in Electrical Engineering with specialization in Power system and Energy Engineering, The Graduate Program of the Department of Electrical and Computer Engineering, and has been carried out by Aster Tsegaye ID No- PEGEngW/004/10 under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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Co-Advisor	signature	Date

DECLARATION

I declare that this thesis work entitled **optimal placement of automated switch in distribution network with customer interruption cost model "** is the result of my own work; it contains no materials previously published or written by another person except where due reference is made. This research has not been previously submitted for any degree to other higher academic or other institutions.

Aster Tsegaye ______________________ __________________

This thesis is submitted for examination with my approval as university advisor

Dr. Baseem Khan ______________

May 2022

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ABSTRACT

Power system is to provide an adequate and secure electrical supply to its customers as economically as possible with reasonable level of reliability. In distribution system, reliability and cost of Energy not supply (power loss) are the major issues for the consumers and utility. Hawassa distribution feeder has repeated power interruption difficulties. The main causes of interruptions are earth fault (EF) and short circuit (SC). The intended outage such as operation and maintenance purpose of the distribution system is another causes of distribution planned outage. The feeder's System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Energy not supply (ENS) and power loss are 123.9 interruptions per customer per year, 136.8 hours per customer per year, 1843.2 MWhr/yr. and 409.2 Kw, respectively. The feeder is not reliable by the standard of Ethiopian Electric Agency (EEA) which has set SAIFI as equal to 20 interruptions per customer per year and SAIDI which is around 25 hours per customer per year. Optimal placement of automated switches (auto recloser) can significantly improve reliability of the system, reduce Energy not supply (power losses) and decrease Expected Interruption Cost (ECOST) of the system. Therefore, the main aim of the study is to improve the reliability of the distribution system by optimal placement of automated switch (auto recloser). The economic impact of power interruption in both the utility and customers is significant, thus makes placement of auto recloser on selected feeder, improve distribution system reliability and reduce cost of energy not supply (power loss). Optimal placement of auto recloser is determined by the Grasshopper optimization Algorithm (GOA) technique using MATLAB code and the reliability indices evaluated by using etap 16.0.0 and compared with PSO (particle swarm optimization).The reliability of distribution system has improved by employing optimal placement of auto recloser. Therefore, the overall reliability of Hawassa city distribution feeder 12 indices SAIFI by 88.9 %,SAIDI by 76.3% , EENS by 76.5 % , power loss by 70.5 % and ECOST by 55%; had improved as compared with the base case system.

Key words: Reliability improvement, optimal placement, cost of energy not supplied reduction and GOA

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ABBREVIATIONS

AC	Alternating current
ACCI	Average Customer Curtailment Index
AENSI	Average energy not supplied index
ASAI	Average service availability index
ASUI	Average service Unavailability index
CAIDI	Customer average interruption duration index
CAIFI	Customer Average Interruption Frequency Index
CIC	Customer interruption cost
CTAIDI	Customer Total Average Interruption Duration Index
DA	Distribution Automation
DE	Differential evolution algorithm
DG	Distributed generations
DPEF	Distribution permanent Earth Fault
DPSC	Distribution Permanent Short circuit
DTEF	Distribution Transient Earth fault
DTSC	Distribution Transient Short circuit
ECOST	Expected interruption cost
EEA	Ethiopian Electric Agency
EEP	Ethiopian Electric Power
EEU	Ethiopian electricity utility
ETAP	Electric transient analysis program
ENSI	Energy Not Supplied Index
EENSI	Excepted energy not supplied index
GOA	Grasshopper optimization algorithm
GWO	Golf Wolf Optimization
IEEE	International Electrical and Electronics Engineering
Kv	Kilo Volt

Kva	Kilo volt Ampere
Kw	Kilo watt
Kwh	Kilo watt hour
MOF	Multi objective function
MATLAB	Matrix laboratory
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
MW	Mega watt
PSO	Particle swarm optimization
RCS	Remote control switch
SAIDI	System average interruption duration index
SAIFI	System average interruption frequency index
SC	Switch cost
SS	Sectionalizing switches
TCC	Time-Current Characteristics
TCR	Total cost of reliability
TDS	Time dial setting
UCR	utilities cost of reliability

CHAPTER ONE

INTRODUCTION

The fault management procedures are returned the network to the usual utilization condition, when faults are happened in the distribution network. Generally, a generic fault management procedure includes of three sections: (1) locating the fault, (2) separating the fault, (3) Restoring the power supply. Fault indicators supply data to speed up the fault location procedure and the power supply recovery procedure. Automated switches are able to separate the fault part and decrease the number and customer's interruption period that have the interruption. Hence, the assignment of automated switches and fault indicator in the distribution networks are able to remarkably decrease cost of interruption and amend reliability.

The automated switches are able to progress the distribution network automation level and cause significant advantages to power supply companies. The switches separate sound zones from the faulted zones, when a fault is occurred in the system. The client upstream to the faulted zone is remade by the main route, and the client downstream to the faulty zone is remade through the alternate route coupled via the tie switch. In addition, the customer interruption period in the faulty zone is the sum of repair and fault location times. There are two kinds of sectionalizing switches: (1) manual switch, (2) remote controlled switch. Manual switch is implemented the separation manually and the remote-controlled switch is performed the separation remotely. The manual switch status is varied manually through the maintenance operators, and the remote-controlled switch state is alternated remotely through the central control unit of distribution network. So, the switching time of remote-controlled switch is shorter than manual switch, which is able to decrease more period and cost of interruption. Although the remote-controlled switch executes better in the fault management procedure, it is so expensive which it is not chosen and located preferentially through power supply companies. Manual switches are considered by the power supply companies firstly. The remote-controlled switches are selected when the manual switch located could not satisfy the related reliability requirements. In brief, reliability requirements and device price have a remarkable impact on the switches located.

Reliability means the probability that a system or components perform their assigned task for a given period of time under the operating conditions stumbled upon during its anticipated lifetime. 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, 2]. 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 utility (EEU) constitutes relatively a very poor distribution system as compare to the 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.

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 Optimization

System optimization has always been a favorite topic in academia, but until recently has 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.

1.2 Statement of the Problem

Power system reliability is the main problem that disturbs power system operation and security throughout Ethiopia. Hawassa distribution system carries so much load like industry parks and other small factories it is prone to power outage and interruption. In distribution system, reliability and cost of Energy not supply (power loss) are the major issues for the consumers and utility. Since system reliability indexes in Hawassa distribution selected feeder are (SAIFI, SAIDI and ENS) are 123.9 int/cust/yr., 136.8 hr./cust/yr. and 1843.2 MWhr/yr., respectively that is very far from the standard of Ethiopian Electric Agency (EEA) and different international settings (which is SAIFI as equal to 20 interruptions per customer per year and SAIDI which is around 25 hours per customer per year). The 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. To evaluate the power outage costs or energy not supply cost, to analysis the main cause of failures and identify relevant techniques reliability assessment is the first concern. Optimization and placement of automated switch (recloser) in the distribution feeders has significant impact in reliability and minimization of cost, this will be further evaluated along with the outage minimization techniques for the distribution system in Hawassa. Therefore, in this thesis, focus on the distribution system of Hawassa has been considered, particularly targeting on selected feeder based on more interruption occurred and by identify critical loads like hospitals and other sensitive types of loads at Hawassa district’s distribution system.

1.3 Objectives

1.3.1 General objective

The main objective of this thesis is optimal placement of automated switch in distribution network with customer interruption cost with a case study of Hawassa distribution system.

1.3.2 Specific objectives

- Collect and analyze the necessary data from different sources
- Identifying and locating auto recloser using GOA
- Compare existing system with proposed GOA based system.
- A detailed comparative analysis of GOA and PSO
- Improve overall distribution system reliability by optimally placing automated switch
- Detailed cost analysis of system components

1.4 Significant of the Thesis

This thesis out put a significant importance of measuring the existing network performance of reliability and energy not supply (power loss) which provide reliability improvement and cost of energy not supply (power loss) reduction solutions for Hawassa electrical distribution network.

In general it has the following advantages:

- Indicate the influence of power interruption on the economy of customers and utility.
- Assess average duration and frequency of power interruption per year in the system.
- Improve reliability and reduce energy not supply (power loss) using optimal placement of automated switch (auto recloser) by Grasshopper optimization algorithm.

1.5 Scope of the Thesis

The thesis, focus on optimal placement of automated switch in distribution with customer interruption cost model at Hawassa distribution network. The parameter used to determine the reliability indices are SAIFI, SAIDI, ECOST, ENS and power loss reduction of distribution network of Hawassa on selected feeder by optimal placement of auto recloser by using Grasshopper optimization algorithm (GOA).

Generally, the scopes of this thesis are:

- Assess and by analytical and simulation (ETAP) methods for the existing distribution network of Hawassa.
- Analysis of SAIDI and SAIFI for distribution of Hawassa and Compare both method and further evaluate to obtain optimum reliability indices
- Grasshopper optimization algorithm (GOA) technique is used to get optimal number and optimal location of auto recloser
- A detailed comparative analysis of GOA with PSO is performed

1.6 Thesis Organization

The following activities are performed in this thesis:

Literature review: A number of journals, article and papers on optimal placement of automated switches on power distribution system.

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

Data collection: two years (2012-2013) interruption data has been collected from Hawassa. 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 and analysis: The distribution system is represented using single line diagram and optimal placement of auto recloser has been performed.

Reliability indices have been calculated for the existing selected feeder and the modified systems.

Based on the result of this analysis ,optimal placement of recloser have been evaluated for reliability improvement and cost of energy not supply(power loss) reduction, using GOA(Grasshopper optimization algorithm) for determine the optimal number and place.

The system has been designed and simulated using latest Electrical software, ETAP 16.0.0 and mat lab.

The objectives are to minimize SAIFI, minimize SAIDI, minimize ECOST and minimize cost of energy not supply (power loss) of Hawassa distribution network.

Several methods have been developed to determine the best topology for a distribution system. These include heuristic methods, linear programming, neural networks, expert systems, simulated annealing and genetic algorithms. For this thesis Grasshopper optimization algorithm is the most commonly used since it can produce fast results with good accuracy.

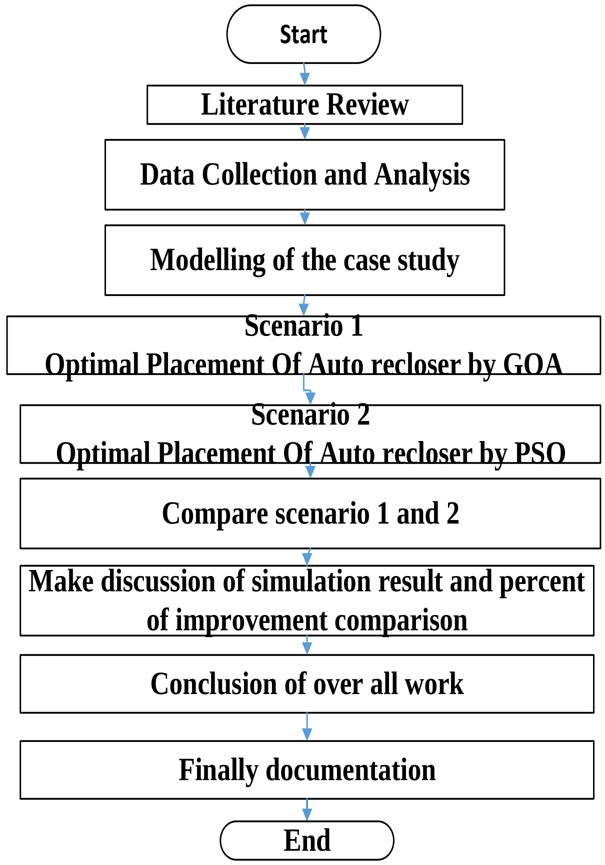

Figure 1.1: Methodology

1.7 Thesis out line

The content of this thesis is briefly explained as follow: Chapter one provides a brief description about back ground, statement of problem, objectives, research methodologies, scope and significant of the thesis. Chapter two discussed about distribution literature review of system reliability. In chapter three deals about methodology are clearly discussed. Chapter four described about result and discussions of the results are presented. Finally, conclusion recommendation and future work were presented in Chapter five. The reference and appendices include, two year substation monthly power interruption reports, load distribution of selected feeders.

CHAPTER TWO

REVIEW OF LITERATURE AND THEORETICAL BACKGROUND

2.1 Literature Review

The research publications which are related to power distribution system reliability improvements are discussed in this section. Power interruption becomes a serious problem in Ethiopia. Optimal placement of automated switch is a must-do work by utilities to improve their system reliability and to satisfy their customers. The distribution systems need automated switches to improve their reliability, efficiency, and service quality.

The optimal placement of devices in the distribution network has been investigated by many researches. Many researches have been done with the purpose of addressing SSs placement problem, with the aim of determining their locations and number. The procedures have been applied for SSs optimal placement have been mostly classified into heuristic and mathematical optimization procedure. The researches applying heuristic procedures use various algorithms that have been discussed in short in this part. A differential evolution algorithm (DE) with the aim of determining optimal number and location of the switches are applied [1]. In that case of study, an index was presented in the role of restoration index afterwards that was applied in the role of objective function, while the economic problems and network limitations were not considered. The Tabu search algorithm was applied with the aim of determining the location of SSs and protective equipment [2]. However, technical limitations were taken into account in the research, economic problems like costs of repair were not considered. In that research, there were restricted candidate places with the aim of installing switches on the basis of engineering experience. The switch locations are defined with the aim of minimizing the distribution interruption costs incurred through customers as well as the switch cost [3]. Sectionalizers were applied with the aim of dividing the network into smaller parts that were taken into account algorithm is applied for SS placement issue as well as taking into account in the circuit-breaker switches [4]. Although, the research did not consider the indices of network load points. The placement of SSs has been applied a graph-based procedure where manual switches were not taken into account [5]. The ant colony algorithm for SSs placement issue is expressed [6, 7]. Although, economic problems were not taken into account [6]. Ref [8] solved the issue through applying the reliability index. However, the research covered plenty of prior studies debilities, MS placement was not considered. A multi-objective model is applied with the aim of solving the issue of switch positioning [9, 10]. Extra to these mentioned sources which have applied innovative procedures with the aim of solving the issues, a linear procedure studied optimal placement of RCS that makes sure optimal solution during a many short times [11]. However, this paper just takes into account RCS installation on the main feeder. Practically, the procedure is not efficient in real networks in which the main feeder is not be able to be recognized simply.

Paper [12] discussed that network reconfiguration of distribution systems is done to improve system operating conditions and reduce system cost. It is a procedure that alters feeder topological construction, shifting the open/close status of sectionalizing switches and tie switches in system. Approximately 80% of the customer interruptions occur due to the problems in distribution networks.

Paper [13] presented a sectionalizing switch separates a faulted section of the system. So that the healthy part can still be electrically supplied, however a tie switch recovers loads that have been disconnected by transferring some of loads to other supporting distribution feeders.

A Paper entitled [14], "Reconfiguration of Actual Distribution Network with Optimum Power Flow for Loss Reduction" described that radial operation constraint makes it compulsory to open the distribution feeders connected to multiple sources or to a single source from a suitable switching location. According to his description, meshed networks offer many other configuration choices and it is possible to reconfigure the network by exchanging the switching locations. Exact choice of switching positions would decrease losses, increase the lifetime of equipment and enhance power reliability by balancing the system loading.

A Paper [15], discussed that a distribution recloser is designed to interrupt fault current. It is designed to "reclose" on the fault repeatedly in a predefined sequence in an attempt to clear the fault. One of the philosophies for the use of reclosers is to increase reliability.

Paper [16] has presented the potential use of reclosers for power reliability improvements. In their discussion, if a fault is of a momentary nature, the recloser helps to restore the service quickly; and hence enables the reduction of the outage time.

Table 2.1: Summary of literature review

Reference	Method	Advantage	Disadvantage	Application
Ref (10)	Particle swarm optimization(OSO)	minimization of total installation and operational cost and maximization of network reliability	It converge for large number of iteration	Increasing reliability
Ref (12)	Convention method	Improve the reliability	Didn't use any optimization technique	Increase reliability
Ref (13)	Conventional method	reducing the impacts that a fault can have in terms of customer outages, and the time needed for fault location and system restoration	Didn't use any optimization technique to get the optimal place of auto recloser	Increase reliability
Ref (14)	Conventional method	Approximating the reliability indexes to standard	Didn't use optimization method	Increase reliability
Ref (15)	Conventional method	Improve the overall reliability	Didn't use optimization technique	Increasing reliability
Ref (16)	Genetic optimization algorithm	minimizes the system power loss	Didn't minimize as fast as mine	Increase reliability

Ref (35)	Conventional method	Study of Reliability of Power Distribution System and Improvement Options at Awash7 kilo Substation	Use trial and error method to select the total number of recloser and there sizing	Increase reliability
The Proposed GOA based system	Use metaheuristic techniques	Optimally size and place auto recloser	Cost	Effectively Improve reliability

2.1.1 Summary of literature review and Work contribution

Mandefro Teshome on ref [15] and Jemal Mohammed on ref [35] are used conventional method or they used trial and error method to improve the reliability but the proposed thesis uses metaheuristic technique to optimally place auto recloser to get optimal size and place. Jemal and Mandefro improve the customer oriented reliability indexes more than 70% but not approach to the standard one, but the proposed thesis improve the customer oriented reliability indexes to IEEE standard. GOA is superior to other algorithms in that GOA has good sizing capability and has exact location of auto recloser. In this thesis GOA is compared with PSO and it is selected due to its robustness.

2.2 Theoretical background

Electric power is a basic element in any modern society because the life of human being directly or indirectly depends on electric power. The availability of a reliable electric power deliver 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 [21]. 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 [22] 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.

2.2.1 Distribution System

Electric power system transfers electricity from the generation station (plant) to the end consumer loads. The power can be transmit in to the customers through different stages from generation, transmission, distribution and finally to the loads. 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 380V for the three-phase consumers or 220 V for the single phase consumers [23].

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 consumer's 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.

Induction motor loads constitute a major portion of industrial loads while commercial and residential loads consist largely of lighting, compressors, cooling and heating [24]. 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. 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.

2.3 Reliability

There are many terms and definitions used in Reliability Engineering. Some terms and definitions are presented below.

Reliability R (t): refers to the probability that a component practices no failure during a time period.

Failure: is the inability of an item to function as the originally defined guideline. **Downtime**: is the time period during which the item is not in a situation to carry out its stated mission working.

Maintainability: is the probability that a failed item will be repaired to its satisfactory conditions.

Availability: is the probability that an item is available for application or use when needed.

Failure Frequency (f): refers to the number of failures that may happen to a time period. In this study, the unit of the failure rate frequency is failure per year.

$$f = \frac{number\ of\ failure}{studied\ period * circuit\ length\ of\ transmission\ lines\ or\ cables} \quad (2.1)$$

Mean Time to Failure (MTTF): The average time it takes to the occurrence of the component or system failure measured from t = 0.

Mean Time to Repair (MTTR): The average time it takes to identify the location of the failure and to repair that failure.

The relationship between the failure frequency and the mean time to failure is given by;

$$\boldsymbol{f = \frac{1}{MTTF+MTTR}} \quad (2.2)$$

Failure Probability Q (t): is the probability that under stated conditions, the system or components fail in a specified time period. It is identical to unreliability.

$$Q\ (t) = 1\text{-}R\ (t) \quad (2.3)$$

Availability (A): is the probability that the component is normal at an arbitrary time t, given that it was good at a time zero.

$$\boldsymbol{A = \frac{MTTR}{MTTR+MTTF}} \quad (2.4)$$

Unavailability (U): It is the probability that the component is down at any arbitrary time t and unable to operate.

$$U = \frac{f*MTTR}{8760} \tag{2.5}$$

In the above equation (2.5), 8760 in the right part are the total hours of one year, because MTTR is measured in hours. According to the definition availability and unavailability are related as given below equation:

$$U = 1 - A \tag{2.6}$$

2.3.1 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 / or 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 [25]. These standards distribution and transmission reliability indices and factors that affect their calculation are collected and presented. The indices are intended to apply to power distribution and transmission systems, substations, circuits, and defined regions.

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==Total number of interruption/total number of customer served *(2.7)*

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.

$$SAIDI = \frac{Total\ duration\ of\ all\ interruptions\ in\ customers}{Total\ number\ of customer\ served} \quad (2.8)$$

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. CAIDI 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=sum of customer interruption duration/Total number of customer interruption (2.9)

Average service availability index (ASAI): It is the fraction of time the customer has power during the reporting time. A higher ASAI value indicts higher levels of reliability.

ASAI=customer hour service available/(customer hour service demand)pu (2.10)

Some less commonly used reliability indices are not based on the total number of customers served. The Customer Average Interruption Frequency Index (CAIFI) and the Customer Total Average Interruption Duration Index (CTAIDI)

Customer average interruption index (CAIFI): Shows the trends in customers interrupted and used to determine the number of customers affected out of whole customer base.

CAIFI= Total number of customer interruption/ Number of customer affected (2.11)

Average service Unavailability index (ASUI):

ASUI=SAIDI/ (8760 hours/yr.) (2.12)

Excepted energy not supplied index (EENS):

EENS=∑ (Li*Ui) (2.13)

Where Li is the average connected load at load point I Ui is average annual outage time at load point i.

Average energy not supplied index (AENS):

AENS=∑ (Li*Ui)/∑ (Ni) (2.14)

Where Ni 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 tells not only to assess the past performance of a distribution system but also to predict the future system performance.

2.3.2 Expected Customer Interruption Cost

The contingency based analytical method, which is employed to calculate the ECOST in distribution networks for a typical feeder, is well described in (40) the index can be utilized to associate the reliability with the customers' cost. The contingency based analytical method, which is employed to calculate the ECOST in distribution networks for a typical feeder, is well described in (2.15).

$$ECOST = \sum_{i=1}^{Nq} \sum_{j=1}^{Nlp} \sum_{k=1}^{Nct} \boldsymbol{\lambda}\mathbf{i} * \mathbf{CDF_{ijk}}(\mathbf{r_{ij}}) * \mathbf{L_{jk}} \qquad (2.15)$$

Where λi is the average failure rate of the distribution network equipment i**,** $\mathrm{CDF_{ijk}}(\mathrm{r_{ij}})$is the customer's damage function that depends on r_{ij}, r_{ij} being the failure duration of $\boldsymbol{J^{th}}$ load point, and J_{LK} is the average load of K^{th} type customer located at the $\boldsymbol{J^{th}}$load point.

2.4 Electrical fault

Most of the time faults are caused by breakdown of insulation systems and can be classified as self-clearing, temporary and permanent. A self-clearing fault will extinguish itself without any external intervention (e.g., a fault occurring on a secondary network that persists until it burns clear). A temporary fault is a short circuit that will clear if de energized and then re-energized. A permanent fault is a short circuit that will continue until repaired by human intervention. Some types of faults are discussed as follows.

2.4.1. Outage

An outage occurs when a part of equipment is de-energized. Outages can be either programmed or un programmed. Programmed outages are known in advance (e.g., outages for periodic maintenance). Un programmed outages result from contingencies [13].

2.4.2. Transient Faults

A transient fault is a fault that disappears either by itself or by de energization of the faulted circuit and it does not require any immediate repair work. Transient faults occur mainly on outdoor equipment or overhead feeders where air is the main insulating medium. Common causes of Transient faults are momentary tree contacts with conductor and flashovers initiated either by lighting or by conductors temporarily swinging together. In this thesis it is assumed that in the event of a transient fault, reclosing of the associated circuit breaker or reclosing is always successful, though it might not be successful on the first or second attempt [26, 27].

2.5. Power Interruption

Customer power interruptions are caused by a wide range of phenomena including equipment failure, animals, trees, severe weather and human error. These causes are at the root of distribution reliability, and understanding them allows abstract topics like reliability modeling and computer optimization to be viewed from a practical perspective. In addition, identifying and addressing physical root causes is often the most cost effective way to address reliability problems.

There are different types of power interruption and are discussed below.

2.5.1. Momentary Interruption

A momentary interruption occurs when a customer is de-energized for less than a few minutes. Most of momentary interruptions result from reclosing or automated switching. Multiple reclosing operations result in multiple momentary interruptions (e.g., two recloser operations equals" two momentary interruptions for downstream customers).

2.5.2. Sustained Interruption

A sustained interruption happens when a customer is de-energized for more than a few minutes. Most sustained interruptions result from open circuits and faults [26].

2.5.3. Temporary Interruption

This is usually categorized as interruptions that last a few hours. It is usually less in duration than a sustained interruption and higher than a momentary interruption. Temporary interruption usually requires an operator to put the system back on by manual operation. Hence, the duration is usually as determined by the unavailability of an operator to perform the switching operation immediately. This interruption is expected to last for less than two hours. Both momentary and temporary interruptions can be as a result of faults due to lightning, two conductors in contact when there is wind etc. [28].

2.5.4. Planned Interruption

Planned interruption is a loss of electric power that results when a component is purposely taken out of service at a selected time. This is usually done for the purposes of construction preventative maintenance, or repair [29].

CHAPTER THREE
METHODOLOGY

3.1 Introduction

Distribution is the procedure of transferring the electricity from generating station to the consumer premises. The transfer of power from generating plant to the consumer is carried through a transmission system and distribution system. In general, the distribution station is the part of the electric power system, which delivers the power to the customers for consumption. The electrical distribution is performed at a constant voltage level.

Transmission network supplying power to Ethiopian utility grid consists of 400kV, 230kV, 132kV, 66kV and 45kV. Distribution network consists of 33 kV and15kV middle voltage distribution line by step down transformer rated at 132/33kV, 132/15kV, and 45/15kV and like. Electricity of low voltage customers are supplied by 400V or 220V with frequency of 50 Hz using 3-phase and 1-phase distribution line respectively.

In this study Improving the reliability and minimize power loss in a distribution system will be an important consideration. For this purpose, the automated switch (auto recloser) will used in this work.

This auto recloser is mainly used to improve reliability of distribution network.

The auto recloser is optimally placed in the 15kV Hawassa distribution network and the location is decided by the best fitness value for the cost of energy not supply (power loss**)** reduction through optimization technique.

3.2. Description of study area

This study is conducted in the Hawassa substation in Sidaama region, Ethiopia. The substation

is located at 273 km (170 mi) southern of Addis Ababa via Bishofitu. There are two substation, new and old. The selected feeder is from the old substation.

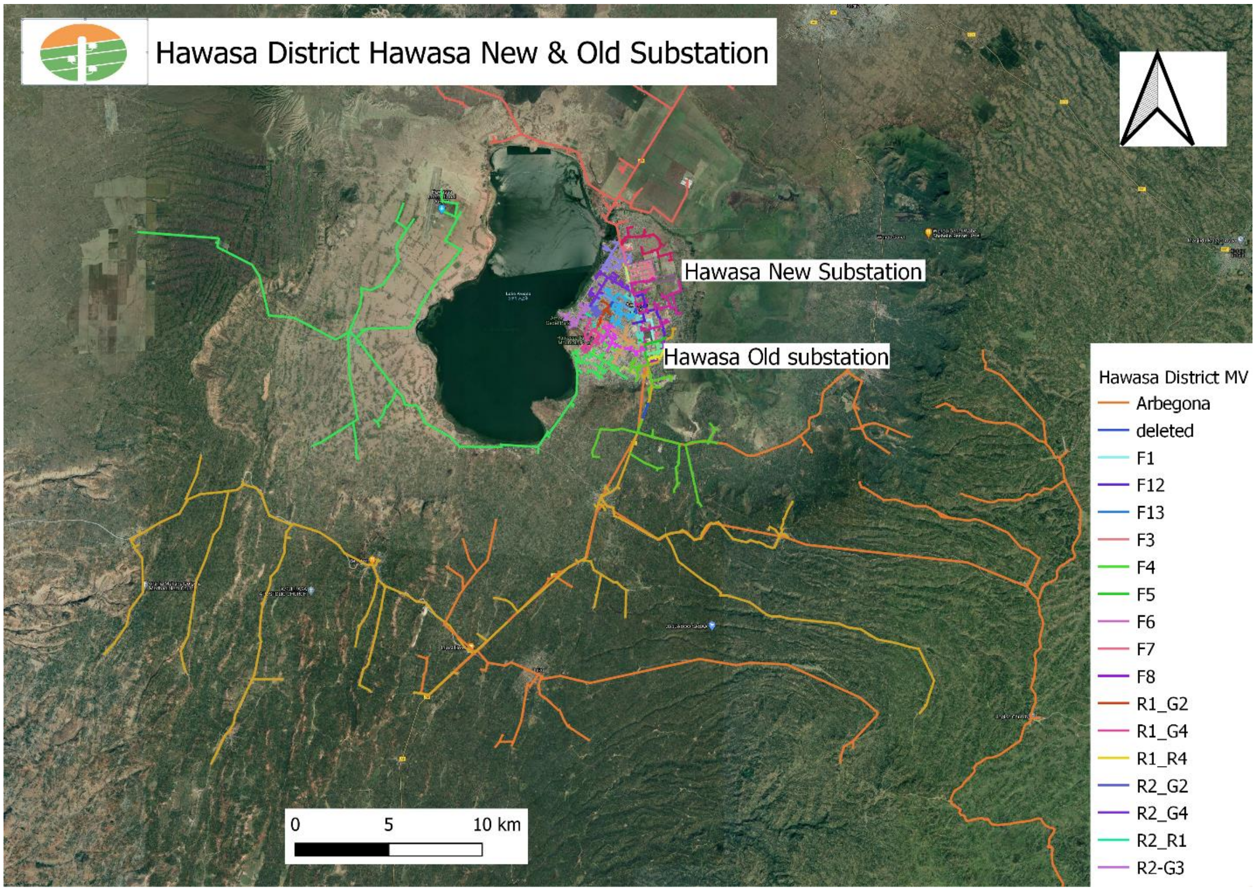

Figure 3.1: Location of Hawassa substation

Distribution substation consists of 33 kV and15kV middle voltage distribution line by step down transformer rated at 132/33kV and132/15kV, low voltage customers are supplied by 400V or 220V with frequency of 50 Hz using 3-phase and 1-phase distribution line respectively. It incorporated many residential, industrial and commercial sectors.

3.3. Data Collection

For this thesis work primary data and secondary data's will be collect from EEU, EEP and Hawassa substation. The data will be gather through conducting interviews with the respective personnel of the substations, Physical observation in the substations, past recorded feeders loading (peak load and each hour load) data of the substation and distribution feeder roots, from Ethiopian Electric Utility (EEU) and Ethiopian Electric Power (EEP) engineering office. The collecting data will include interruption data with different types fault measured in frequency and duration, line length, Bus connected ID (From Bus to Bus), bus description, bus nominal voltage, reactive and active power flow, transformers data, actual voltage level of the line and peak load data of the distribution network of case study.

Table 3.1: Name and voltage levels of Hawassa substation I (old) outgoing feeders

Feeder code	Voltage level in kv	Circuit breaker type	CT Ratio
Feeder 1	15	Vacuum	100/1
Feeder 2	15	Vacuum	200/1
Feeder 3	15	Vacuum	200/1
Feeder 4	15	Vacuum	200/1
Feeder 5	15	Vacuum	100/1
Feeder 6	15	Vacuum	100/1
Feeder 12	15	Vacuum	200/1
Feeder 9	33	Vacuum	150/1
Feeder 11	33	Vacuum	150/1
Main feeder of 15 kv	15	Vacuum	500/1
Main feeder of 33 kv	33	Vacuum	300/1

Table 3.2: Annual average energy and Power consumption feeder 7(12) for 2020(21) G.C

Feeder name	Average power consumption		Average energy consumption	
	Average active power (KW)	Average reactive power(Kvar)	Average active energy (KWh)	Average reactive energy(Kvarh)
Feeder 7(12)	442.85	200	318,857.2	144,000

$$PF = \cos(tan^{-1}(\frac{Q}{P}) \quad (3.1)$$

$$PF = \cos(tan^{-1}(\frac{200}{442.85}) = 0.91$$

Where, PF = power factor, P = Active power, Q = Reactive power

The power factor obtained from equation 3.1 is 0.91, which is only for 15kV feeder 7(12). But, the power factor including the rest of feeders is 0.87 as per the information obtained from the technician of the institution.

Table 3.3: Average and Peak Load of the Substation feeder 7(12) in 2020(21) G.C

Feeder name	Minimum load(MW)	Peak load (MW)	Average load (MW)
Feeder 7(12)	0.37	1.58	0.975

Table 3.4: Hourly load (MW) each feeder of Hawassa distribution feeder 7(12), 2/4/2021

Feeder	Feeder 7(12)
Hours	
8	1.41
9	1.34
10	1.2
11	1.31
12	1.43
13	1.21
14	1.32
15	1.46
16	1.12
17	1.23
18	1.2
19	1.45
20	1.27
21	1.11
22	1.01
23	1.00
24	0.98
1	0.91
2	0.88
3	0.81
4	0.76
5	0.85
6	0.75
7	0.92

3.4. Major Interruption Causes of Hawassa Distribution (feeder 12)

In Hawassa substation distribution, the major faults occurring frequently are short circuit, earth fault, blackout, overload, and under frequency. And there are planned outages for operational
and maintenance purpose. The major faults occurring can either be of temporary and permanent type. Permanent or Sustained interruptions are long-duration interruptions which last longer than 5 minutes; whereas interruptions with duration of less than 5 minutes are termed momentary interruptions. Usually, only data on sustained interruptions is reported to the regulatory authority. The most common causes of interruptions are: trees, overload, windy rain, lightning, accidents, Animals, scheduled interruptions, human error, generation outage, equipment malfunction, unknown causes of interruptions and others [12].

Tree: Per the discussion with line technicians' trees are recognized as cause of power interruption. Tree trimming, periodically cutting vegetation adjacent to power lines to guarantee safe and reliable clearances, is a critical utility action. Many customers have extremely negative responses to tree trimming.

Over Load: Based on the questionnaire and the discussion with line technicians overload is ranked first as a cause of power interruption. Transformers, lines and equipment's are overloaded above their capacity, as more and more customers are connected to already existing distribution system.

3.4.1 Scheduled Interruptions

It is sometimes necessary to interrupt customer service when performing work on radial distribution systems. Since this work is scheduled in advance, customers can be notified as to the time and expected duration of the interruption. Advance knowledge greatly reduces the economic impact and negative perception that interruptions have on customers.

3.4.2 Substation Interruption Data from 2019(2020) G.C to 2020(2021) G.C

Among the different types of power system faults, frequently occurring faults at Hawassa substation I(old) feeder 7(12) include permanent and transient earth fault, permanent and transient short circuit, and interruptions due to operation/maintenance. Table 3.5 and 3.6 shows the duration and frequency of these different types of faults such as distribution permanent Earth Fault (DPEF), distribution Permanent Short circuit (DPSC), distribution Transient Earth fault (DTEF) and distribution Transient Short circuit (DTSC) [14].

Table 3.5: Distribution Substation frequency of interruption 2019(20) G.C to 2020/21 G.C

Types of fault	2019(2020) G.C	2020(2021) G.C
DPEF	233	285
DPSC	320	345
DTEF	56	121
DTSC	130	108
Total	739	859

Table 3.6: Distribution substation Duration of interruption 2019(20) G.C to 2020/21 G.C

Types of fault	2019(2020) G.C	2020(2021) G.C
DPEF	1321.77	1485.85
DPSC	1758.41	1844.35
DTEF	8.17	10.14
DTSC	21.87	29.88
Total	3110.22	3370.22

Table 3.7: Percentage average frequency interruption of each type of fault

Causes	DPEF	DPSC	DTEF	DTSC
% frequency (int/yr.)	33.2	40.2	14.1	12.5

Table 3.8: Percentage average duration interruption of each type of fault

Causes	DPEF	DPSC	DTEF	DTSC
% duration (hr.)	43.3	55.65	0.3	1.2

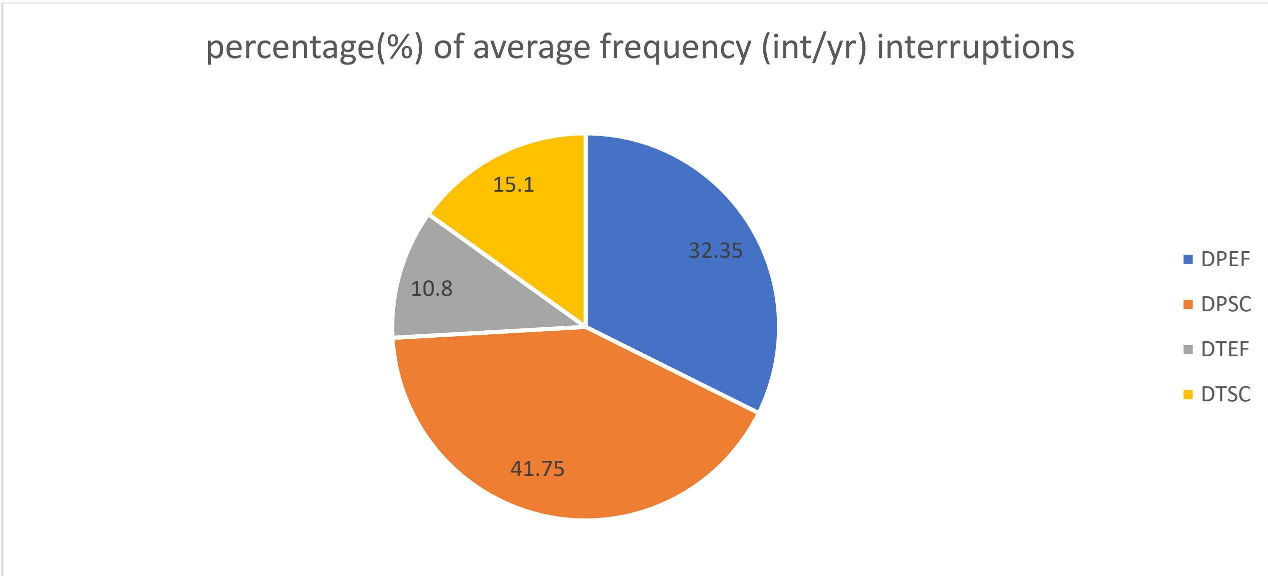

Figure 3.2: Percentage of 2019/20 G.C and 2020/21 G.C frequency interruptions of Hawassa distribution feeder 7(12).

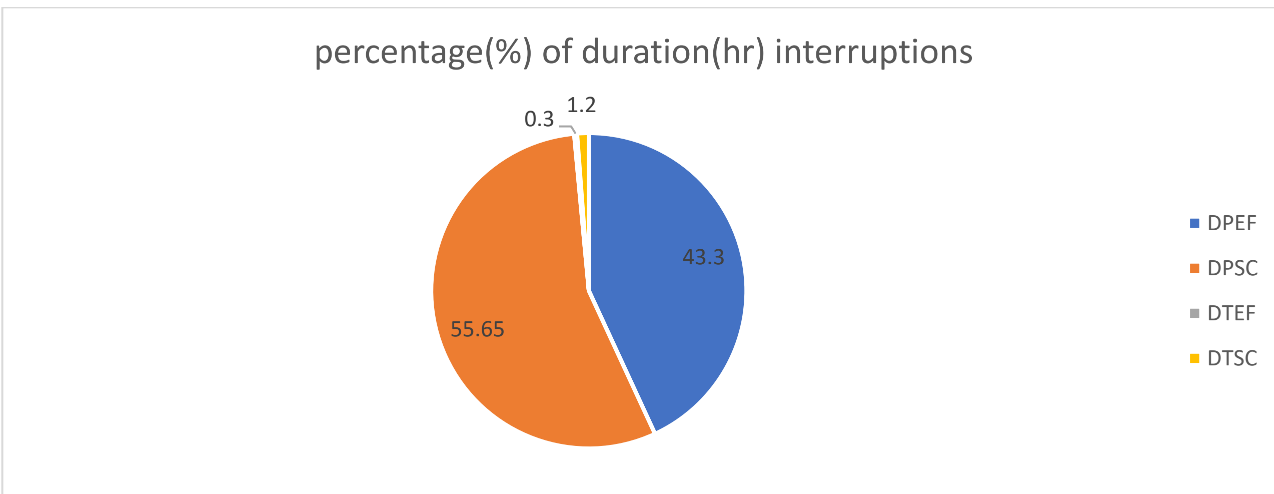

Figure 3.3: Percentage of 2019(2020) G.C and 2020(2021) G.C duration interruptions of Hawassa distribution feeder 12.

As collected data shows in Hawassa substation I (old) of feeder 12, interruption is classified into two that is planned and unplanned. Planned interruption is voluntary interruption for the purpose of maintenance; unplanned interruption is involuntary interruption which is classified into distribution temporary short circuit (DTSC), distribution permanent short circuit (DPSC), and distribution temporary earth fault (DTEF) and distribution permanent earth fault (DPEF). As shown in the above tables and pie charts DPSC takes the highest percent than the other fault types.

3.5 Power reliability improvement techniques

There are many types of techniques used to improve power reliability. Recloser is one of them.

3.5.1 Recloser

The electrical recloser is a modern automatic switchgear, integrated with intelligent sensors and technology to protect power lines, grid systems as well as electrical equipment. Recloser (or Automatic Circuit Reclosers) is electrical equipment, precision automatic switchgear device with high reliability. The control unit is installed in an outdoor pole mounted cabinet under tropical conditions, using an electronic chip, includes functions for measuring, protecting and saving events, and capable of allowing monitoring, control locally and remotely, and connect to the system. Basically, the Recloser consists of a conventional circuit breaker with a controller that allows programming of the number of repetitive closings according to predetermined requirements.

To further reduce the number of customers taken out of service in a fault condition, reclosers are "coordinated" with downstream fused cutouts and upstream substation circuit breakers. Reclosers are predominantly located on the distribution feeder, though as the continuous and interrupting current ratings increase, they are seen in substations, where traditionally a circuit breaker would be located. Reclosers have two basic functions on the distribution system: reliability and overcurrent protection. A re-closer is a device which sense short circuit and earthling fault overcurrent conditions, to interrupt the circuit if the overcurrent continues after a preset time, and then to automatically reclose to re-energize the line.

3.5.2 Modeling of Auto-recloser

Figure 3.4 shows the control circuit of auto recloser which islocated inside the subsystem.

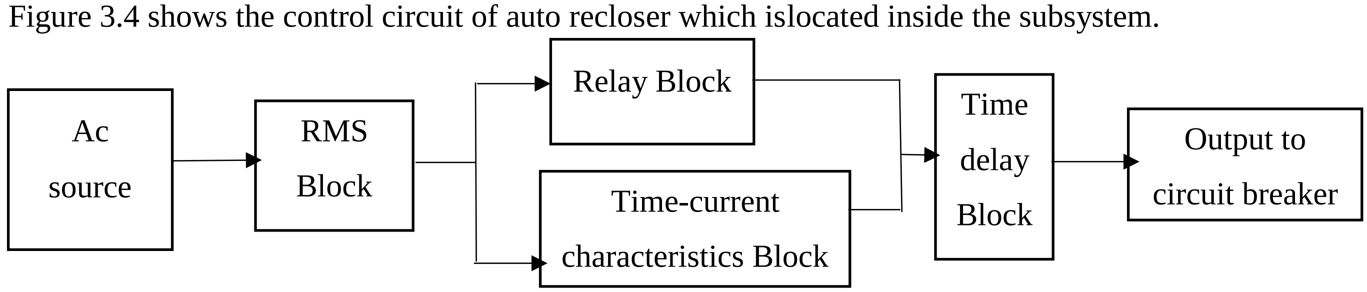

Figure 3.4 Recloser control circuit

- **Sine wave**: The sine wave block is the representation of AC source that is considered as supply source. For recloser AC (230V) or DC (110V) source can be considered as supply source.
- RMS (Root Mean Square): The RMS block is used to measure the root mean square value of the Instantaneous current passing through the recloser.
- **Gain:** The gain block is used to obtain peak value of the instantaneous current passing through the recloser.
- **Time-Current Characteristics:** The peak value will pass to two blocks; the first is a Function Block parameter which contains the fast curve of the recloser (TCC). This fast curve is based upon the IEEE STANDARD INVERSE-TIME characteristic equations.

The equation for Time Current Characteristics [3] is given as:

$$tt=\left(\frac{\frac{k_d}{\tau_s}}{\left(\left(\frac{I}{I_p}\right)p-1\right)}\right)TDS \qquad (3.1)$$

Where, tt: trip time, kd: drag magnet damping factor, τs: initial spring torque, I: normal current, P: constant exponent, TDS: time dial setting and Ip: relay pickup

The equation can be further modified as,

$$tt=\frac{A}{M^p-1}TDS \qquad (3.2)$$

$$A=\frac{K_d}{\tau_s} \qquad (3.3)$$

$$M=\frac{I}{I_p} \qquad (3.4)$$

The output of this block is a time corresponding to the passing current

- **Relay:** The next block is a Relay Block which allows its output to switch between two specified values (0, 1). If the current is less than a specific value (reclosers setting) the relay output will stay at zero value, if the current value is greater than that specific value and more the output of the relay will be stick with 1.
- **Variable time delay:** Variable Time Delay block receives the output of the previous two blocks as an input. The output of that block will be either 0 or 1 after a delayed time. If a fault current is passed through the relay; its output signal is 0, and this signal will be delayed (by the variable time delay block) for a short time inversely

proportional to the fault current value. The output of the last block is a signal that opens the breaker switch. If the fault is a temporary one, the relay output will be 1, so that the breaker switch closes.

3.5.3 Rating of recloser

This model aims to reduce the cost and increase the system reliability with recloser' optimization model given by Equation (2). This equation describes amount of power transferred during a blackout in a distribution network.

$$E_h = \sum_0^N KVA_I * t_r = P * t \qquad (3.5)$$

In which, $\boldsymbol{t_r}$ is operation time of the recloser, P is transferred power and $\boldsymbol{E_h}$**,** kW sec of the lost supply. $\boldsymbol{KVA * t_r}$ is the thermal energy required to melt a specific fuse element; taken as recloser dead-time.

$$ENS = KVA * t_1 + 0.01 * KVA * t_2 + 0.06 * KVA * t_3 \qquad (3.6)$$

Where ENS is Energy not served during reclosing operation. KVA = Transformer rating or size, t_1, t_2 , and t_3 time interval for reclosing period.

3.6 Reliability Indices

The reliability indices of the existing system (distribution feeder 12) have been got by using Etap 16.0.0 software.

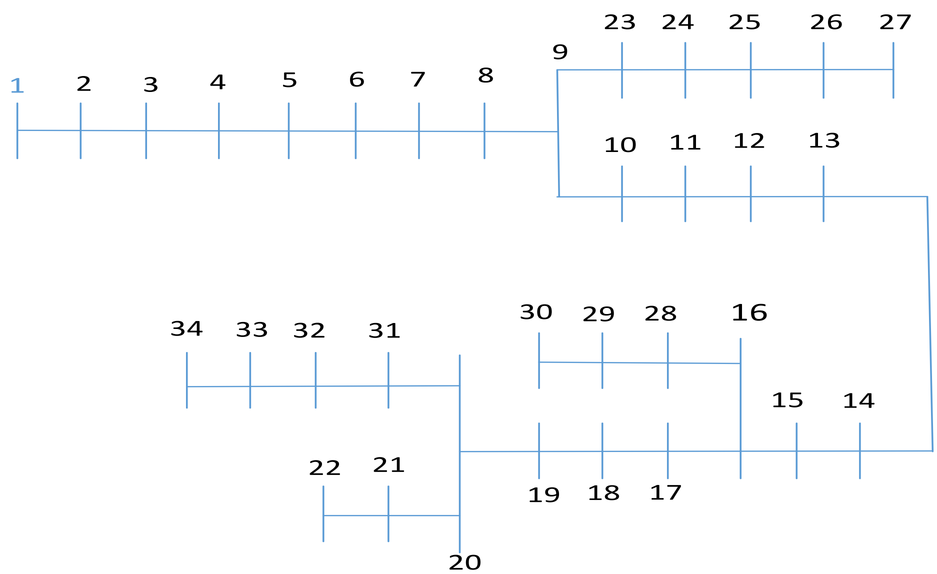

Figure 3.5: the existing system Single Line Diagram

Table 3.9: etap result for reliability indices of existing system

Feeder	SAIFI Int/cust/yr.	SAIDI Hr/cust/yr.	ECOST $/yr.	EENS MWhr/yr.
Feeder 7(12)	123.9	136.8	4,865,430.00	1843.2

3.6.1 Comparison of the existing system Reliability Indices with benchmarks

In the Table 3.10 bellow, shows the calculated Reliability indices values of Hawassa city feeder line L12 compared with Ethiopia Electric Agency standard and other country benchmark values most commonly used reliability indices. This thesis also focuses on the customer oriented reliability indices and energy oriented indices.

Table 3.10: Comparisons of SAIFI and SAIDI values with different countries

Countries	SAIFI (int/./yr./customer)	SAIDI(Hr./yr./customer)
United states of America	1.5	4
Italy	2.2	0.967
France	1.0	1.03
Denmark	0.5	0.4
Australia	0.9	1.2
Spain	2.2	1.73
Canada	3.4	6.9
United kingdom	0.8	1.5
Germany	0.5	0.383
Netherland	0.3	0.55
Ethiopia	20	25
Hawassa city feeder 7(old f12)	123.9	136.8

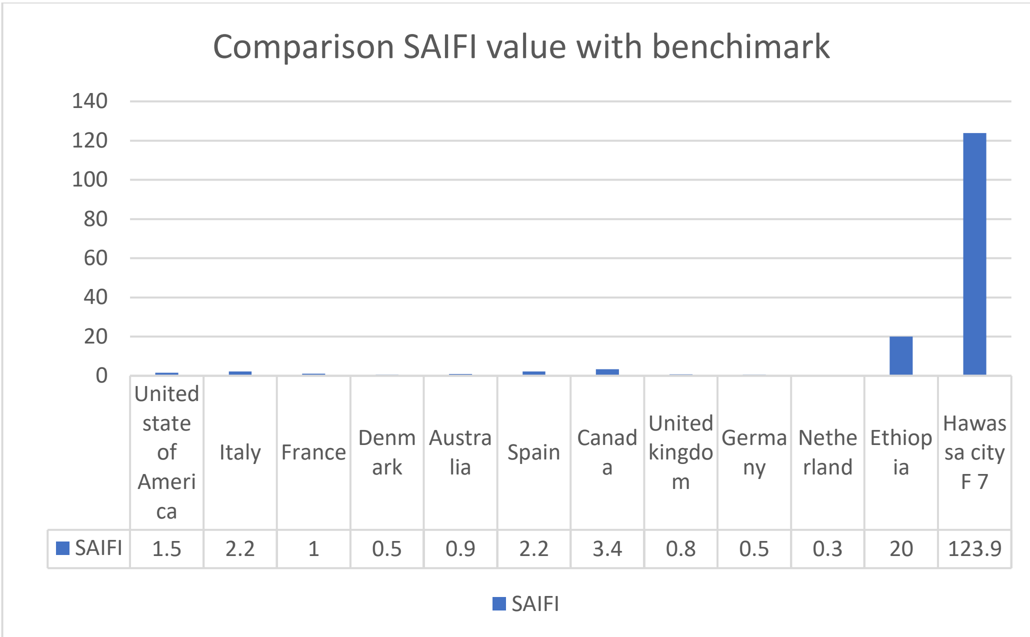

Figure 3. 6: Comparison of SAIFI value with different countries standards

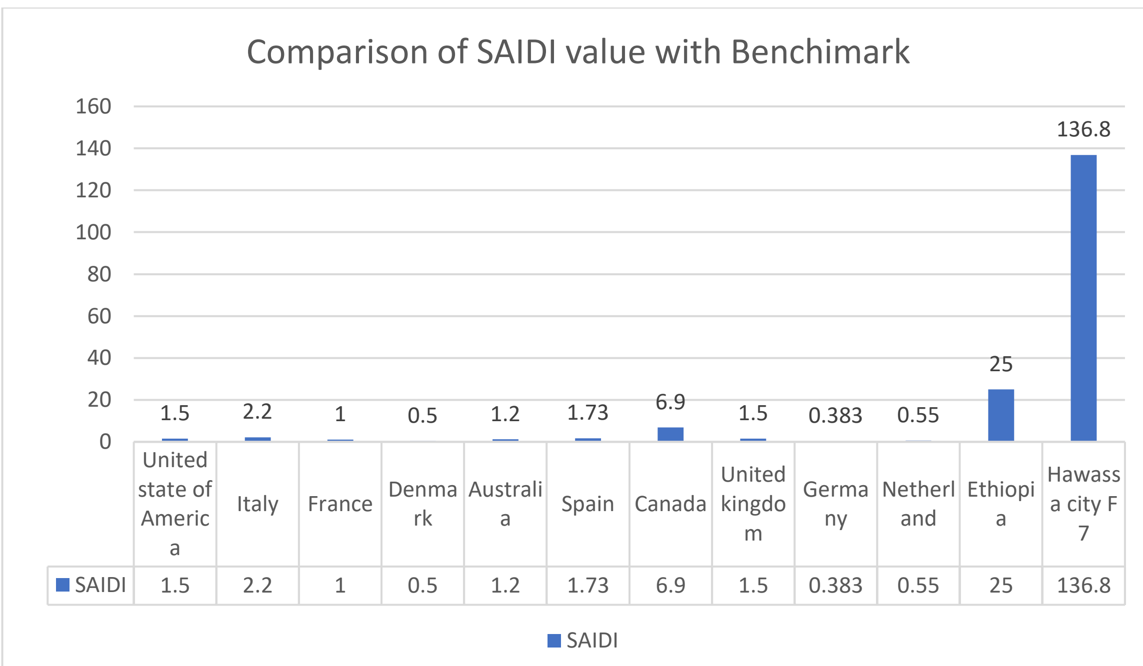

Figure 3.7: Comparison of SAIDI value with different countries standards

3.7 Outage Cost Evaluation of Hawassa City Feeder Line 12

Power interruption cost is both the utility and the customer sides. The size of the economic losses due to interruption depends largely on the composition of the customers that experience interruptions. Customers in the Hawassa city are roughly divided into three categories: residential, commercial, and small industrial customers. On the utility side power interruption cost is estimated based on customer data, interruption data, and cost per outage data.

Cost of Energy not supplied=Energy not supply (in KWhr) *cost of electricity tariff (3.7)

Where, the cost of electricity tariff when energy is greater than 500kwh is 2.0343 which is the latest tariff taken from Ethiopian electric utility that are used until December 8, 2021 G.C. Energy not supply which is get from etap 16.0.0 for existing system is 1843.2MWhr/yr. (1,843,200 KWhr)

Cost = 1,843,200KWhr * 2.0343 ETB /KWh = 3,749,621.76 ETB / yr.

Expected interruption cost which is 4,865,430.00$/yr. (243,271,500 ETB/ yr.)

ECOST = 243,271,500 ETB/ yr.

The power loss of the feeder is around 18.6% of the total load (2.2MW) which is obtained by forward backward sweeping algorithm on load flow analysis.

$P_{loss=}409.2kw$

The MATLAB script code has been presented on appendix D at the end of this thesis.

3.8 Optimization Techniques used to improve Reliability and Power loss

Most methods have been developed for optimal placement of auto recloser. However, not many take into account the optimal sizing and number of recloser. Reported works can be categorized into sequential and simultaneous techniques.

3.8.1 Grasshopper optimization algorithm (GOA)

The GOA algorithm was proposed by Saremi *et al.* in [36], which is a recent and interesting swarm intelligence algorithm that mimics grasshoppers' natural foraging and swarming behaviors. Grasshoppers are insects well-known as a dangerous pests that affect and damage crop production and agriculture [36], [37]. Their life cycle includes two phases called nymph and adulthood. The nymph phase is characterized by small steps and slow movements, while the adulthood phase is characterized by long-range and abrupt movements [36]. The movements of nymph and adulthood constitute the intensification and diversification phases of GOA. The swarming behavior of grasshoppers is mathematically modeled as follows [36]:

$$P_i = S_i + G_i + A_i \quad (3.9)$$

Where Pi indicates the i^{th} grasshopper' position, Si is the social interaction between grasshoppers, Gi denotes the gravity force on the i^{th}grasshopper, and Ai is the wind advection. To produce a random behavior of grasshoppers, Equation **(**3.10) can be rewritten as follows***:***

$$Pi = r1*Si + r2*Gi + r3*Ai \quad (3.10)$$

Where r1, r2, and r3 are random numbers in the range [0, 1]

The social interaction Si is defined as follows:

$$S_{i=\sum_{j=1, j\neq i}^{N} s(d_{ij})\ \hat{d}_{ij}} \quad (3.11)$$

Where N denotes the number of grasshoppers, dij=|pj-pi| defines the Euclidean distance between the $i^{th} grasshopper$ and grasshopper, dij =Pj-Pi/dij is a unit vector from the $i^{th}\ grasshopper$ to the j^{th} grasshopper, and **s** represents the social forces designed by the following equation**:**

$$S(r) = f exp^{-\frac{r}{l}} - exp^{-r} \quad (3.12)$$

Where f and l are the attraction intensity and attraction length scale, respectively. The social interaction between grasshoppers can be defined as attraction and repulsion. The distance is considered in the range [0, 15]. The attraction increases in the interval of [2.079, 4] and then decreases gradually. The repulsion occurs in the range [0, 2.079]. When the distance between two grasshoppers is exactly 2***:***079, there is neither repulsion nor attraction (no force). This area is called comfort zone. Figure shows 5 the interaction between grasshoppers with respect to comfort area.

The gravity force Gi is given by the following equation*:*

$$G_i = -g\hat{e}_g \quad (3.13)$$

Where g denotes the gravitational constant and eg^ represents a unit vector toward the center of earth. The wind advection Ai is given by the following equation***:***

$$A_{i=} u\hat{e}_w \quad (3.14)$$

Where u represents the drift constant and e_w is a unit vector in the wind direction. After replacing the values of S; G; and A**,** the following equation can be obtained***:***

$$P_i = \sum_{j=1, j\neq i}^{N} s(|p_j - p_i|)\frac{p_j = p_i}{d_{ij}} - g\hat{e}_g + u\hat{e}_w \quad (3.15)$$

Equation (3.14) cannot be used directly to solve optimization problems, as the grasshoppers reach quickly the comfort zone and the swarm system does not converge to a target location**.** An enhanced version of this equation is given as**:**

$$P_i^d = c(\sum_{\substack{j=1 \\ i \neq i}}^{N} c\ \frac{ub_d - lb_d}{2}\ s(|p_j^d - p_i^d|)\frac{p_j - p_{i)}}{d_{ij}} + \hat{T_d} \tag{3.16}$$

Where ubd and lbd represent the upper and lower bounds in the d^{th} dimension, respectively. $\hat{T_d}$ Denotes the best solution found so far in the d^{th} dimension space. Note that S is similar to S component in equation (3.12) G is equal to zero and A is always toward the best solution $\hat{T_d}$**.** The parameter **c**1 is similar to inertia weight! In PSO, loudness A0 in BA, or $\boldsymbol{\alpha}$ in GWO. It is used to reduce the grasshopper's movements around the target (food). Thus, it provides a good balance between intensification and diversification. The parameter **c**2 is used to reduce the repulsion zone, attraction zone, and comfort zone between grasshoppers correspondingly to the number of iterations. **C1** and **c**2 are considered as a single parameter and it is expressed using the following equation [3.17]:

$$c = c_{max} - t\,\frac{c_{max} - c_{min}}{t_{max}} \tag{3.17}$$

Where cmax and cmin represent the maximum and minimum values of **c**, respectively, **t** is the current iteration and tmax is the maximum number of iterations. The position of a grasshopper is updated based on its current position, global best position, and the positions of other grasshoppers within the swarm. This helps GOA to avoid getting trapped in local optima.

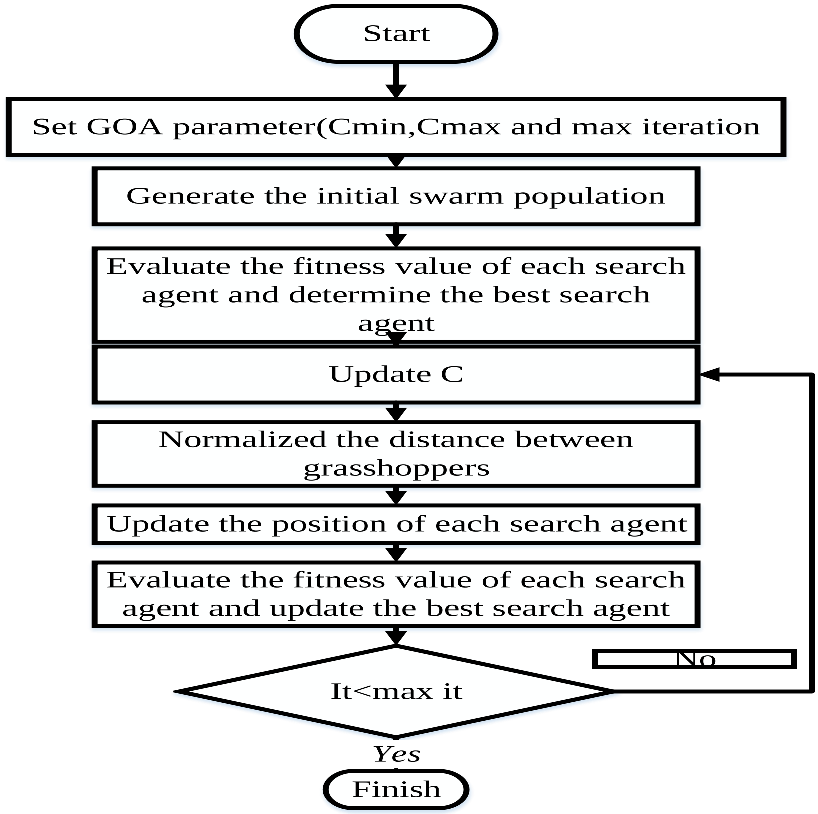

Figure 3.8. Flowchart of the Grasshopper Optimization Algorithm.

3.8.2 Particle Swarm Optimization

The Particle Swarm Optimization (PSO) is inspired by the social behavior 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 behavior 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. 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.

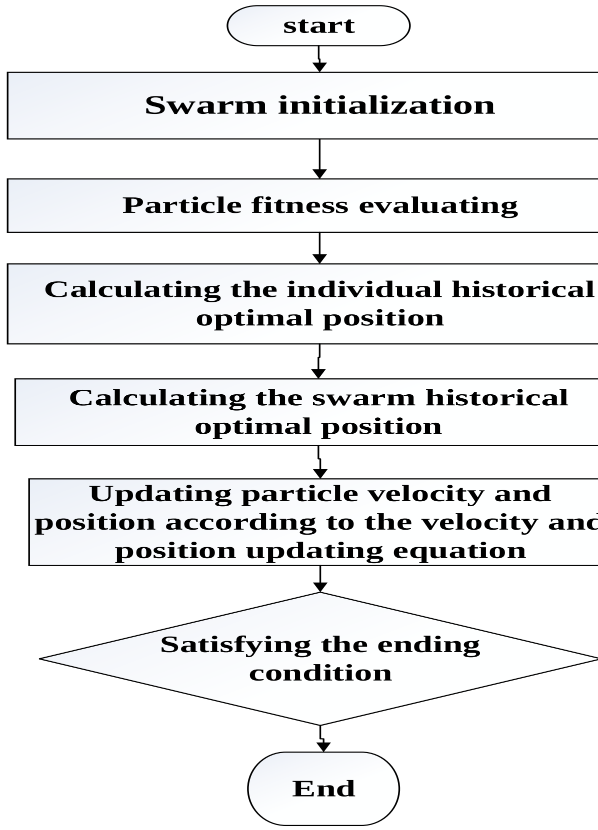

Figure 3.9. Flowchart of the particle swarm optimization (PSO).

3. 9 Objective Function Formulation

The main purpose of this paper is to minimize the yearly energy not supplied cost (ENSC) for each load point in the distribution system

$$\text{Min,}F_1 = \sum_{i=1}^{N_b} ENSi * Ci \quad (3.18)$$

Where Ci is the cost of the outage of load point i and ENSi is the energy not supply of load point i

The second main objective of this work is minimization of the power loss and given by

$$min, F_2 = \sum_{i=1}^{N_b} ENSi/t \quad (3.19)$$

The third objective of this work is minimization of the expected interruption cost and given by $ECOST = \sum_{i=1}^{Nq} \sum_{j=1}^{Nlp} \sum_{k=1}^{Nct} \mathbf{\lambda i} * \mathbf{CDF_{ijk}}(\mathbf{r_{ij}}) * \mathbf{L_{jk}}$ (3.20)

min, F_3=ECOST (3.21)

Where λi is the average failure rate of the distribution network equipment i**,** $\text{CDF}_{\text{ijk}}(\text{r}_{\text{ij}})$is the customer's damage function that depends on r_{ij}, r_{ij} being the failure duration of $\boldsymbol{J^{th}}$ load point, and J_{LK} is the average load of K^{th} type customer located at the $\boldsymbol{J^{th}}$load point.

3. 9.1 Multi Objective Formulation

The separate objective functions listed above combined together to form the multi-objective function of the distribution networks using the weighting factor. That is

$$\text{MOF}=\min(W_1F_1 + W_2F_2 + W_3F_3) \tag{3.22}$$

Where F1 is Energy not supply cost, F2 is power loss and F3 is Expected interruption cost. The weight of each index is assigned according to its importance. And sum of all weight is equal to 1.

$$W_1 + W_2 + W_3 = 1 \tag{3.23}$$

$$\text{MOF} = \min\,(40\%F1 + 40\%\,F2 + 20\%F3) \tag{3.24}$$

3.9.2 Constraints formulations

Auto recloser position constraint

$$1 \le bus \le N_{bus}$$

Inequality constraint formulation

The recloser voltage constraint is given by

$$\text{Vbus} \le Vrec$$

Where: Vbus is the bus voltage, Vrec is the recloser voltage, it is for tolerance.

3.9.3 Customer Interruption cost model for Reliability assessment

The financial value incurred by an electricity consumer as a result of power supply interruption to its daily activities. Total cost of reliability (TCR) is formulated as explicit nonlinear function of decision variables indicating the installation of auto-recloser on the sections of a radial distribution network. The binary decision variable is defined as follows:

$$X_{sfr} = \begin{cases} 1 & if\ a\ recloser\ is\ installed\ on\ location\ s\ of\ feeder\ 12 \\ 0 & otherwise \end{cases}$$

A contingency simulation based technique is used to formulate the TCR as a mathematical function of basic reliability indices and the above mentioned binary variables as follows:

T CR = UCR + CIC (3.25)

Where UCR denotes the utilities cost of reliability including costs of auto-recloser and **CIC** represents the customer interruption cost.

UCR = SC (3.26)

Where *SC* (switch cost) represents the cost including the cost auto-reclosers of capital investment, installation and maintenance as follows.

$$SC=\sum_{f_r=1}^{N_{fr}}\sum_{s=1}^{N_s}(CC_s + IC_s) * X_{sfr} + \sum_{t=1}^{T}\sum_{f_r=1}^{N_{fr}}\sum_{s=1}^{N_s} MC_{s,t} * X_{sfr} \quad (3.27)$$

The CIC consists of ECOST and *the interruption cost due to temporary faults (ICT).*

$$CIC=\sum_{f_r=1}^{N_{fr}}\sum_{t=1}^{T}\sum_{i=1}^{N_q}\sum_{j=1}^{N_{LP}}\sum_{k=1}^{N_{CT}}(ECOST_{ijtkfr} + ICT_{ijtkfr})(1+\gamma)^{t-1} \quad (3.13)$$

Where ICT_{ijtkfr} is defined by:

$$ICT_{ijtkfr} = C_{temp}L_{jtkfr}\lambda_{ijtfr} \quad (3.28)$$

The objective of the proposed formulation is to accurately model the sequence of events after a contingency in the network. It is achieved by minimizing the total cost of reliability in terms of customer outage cost in conjunction with auto-reclose capital investment, installation, and annual operation and maintenance costs. Also, taking into consideration the load increase rate during a time horizon under study, the average load of load points is multiplied by **(1 + γ)^t-1 (38)**.

3.9.4 Constraints

This section presents economic and technical constraints which are incorporated to the proposed Grasshopper optimization algorithm. Auto-recloser is expensive device. Therefore, adding more auto-reclosers in distribution system can increase the UCR cost. The following economic constraints are defined to limit the number of auto-recloser which are available to be installed in the case of budget limitation:

$$\sum_{f_r=1}^{N_{fr}}\sum_{s=1}^{N_s} X_{sfr} \le N_{as} \quad (3.29)$$

$$\sum_{f_r=1}^{N_{fr}}\sum_{f=1}^{N_f} Y_{ffr} \le N_{af} \quad (3.30)$$

$$\sum_{f_r=1}^{N_{fr}}\sum_{c=1}^{N_c} Z_{c_{fr}} \le N_{ac} \quad (3.31)$$

The following constraints are defined to restrict the continuous decision variable $CDF_{ijktfr}(r_{ij})$ based on the location and number of auto-reclosers.

$$CDF_{ijktfr}(r_{ij}) \ge CDF_{ijktfr}^{switching} * (1 - Y_{ffr}) * Z_{cfr} \quad (3.32)$$

$$CDF_{ijktfr}(r_{ij}) \ge [CDF_{ijktfr}^{Repair} * (1 - \sum_{s=s_i}^{s_j} X_{sfr})] * (1 - Y_{ffr}) * Z_{cfr} \quad (3.33)$$

3.9.5 Optimal placement of auto recloser using the GOA

The application of the proposed GOA algorithm to the optima placement of automated switch problem is discussed here. The flow process of the proposed GOA algorithm is as follows:

Step1: Randomly generate initial values of grasshopper positions taking into account the upper and lower limits of control variables.

Where w is the number of grasshoppers (search agent) and j is the number of control variables (dimension).

Step2: The generated grasshopper positions represent the switches that can place the switches to optimal location of the system are formulated as shown:

Step3: calculate the objective of each grasshopper position.

Step4: Arrange the grasshopper position according to its fitness from best fitness to worst fitness value

Step5: update the position of each grasshopper.

Where, a is the current iteration, $a_{max:}$ is the maximum current iteration, $a_{max:}$is the maximum value of coefficient c and equal to 1, $c_{min:}$is the minimum value of coefficient c and equal to 0.00001,f: is the intensity of attraction, l: is the attractive length scale, dij: is the distance between i-th grasshopper and j-th grasshopper, Id: is the target position (best solution) that obtains so far, $Gs_i^d = (i = 1,2, \ldots., w)$:is the i-th grasshopper in the d-th dimension,S: is afunction that defines the social repulsion and attraction forces between grasshoppers in the swarm.

Step6: Repeat steps from step3 to step5 until the maximum number of current iteration is achieved.

Step7: Print the target position that is represent the best opening switches after placement and the target fitness that is represent the minimum system power loss.

3.10 Overall Single line Diagram of the System

The single line diagram of Hawassa distribution substation with specific feeder of Gorche (feeder 12) represented in etap 16.0.0 as shown figure 3.9 below.

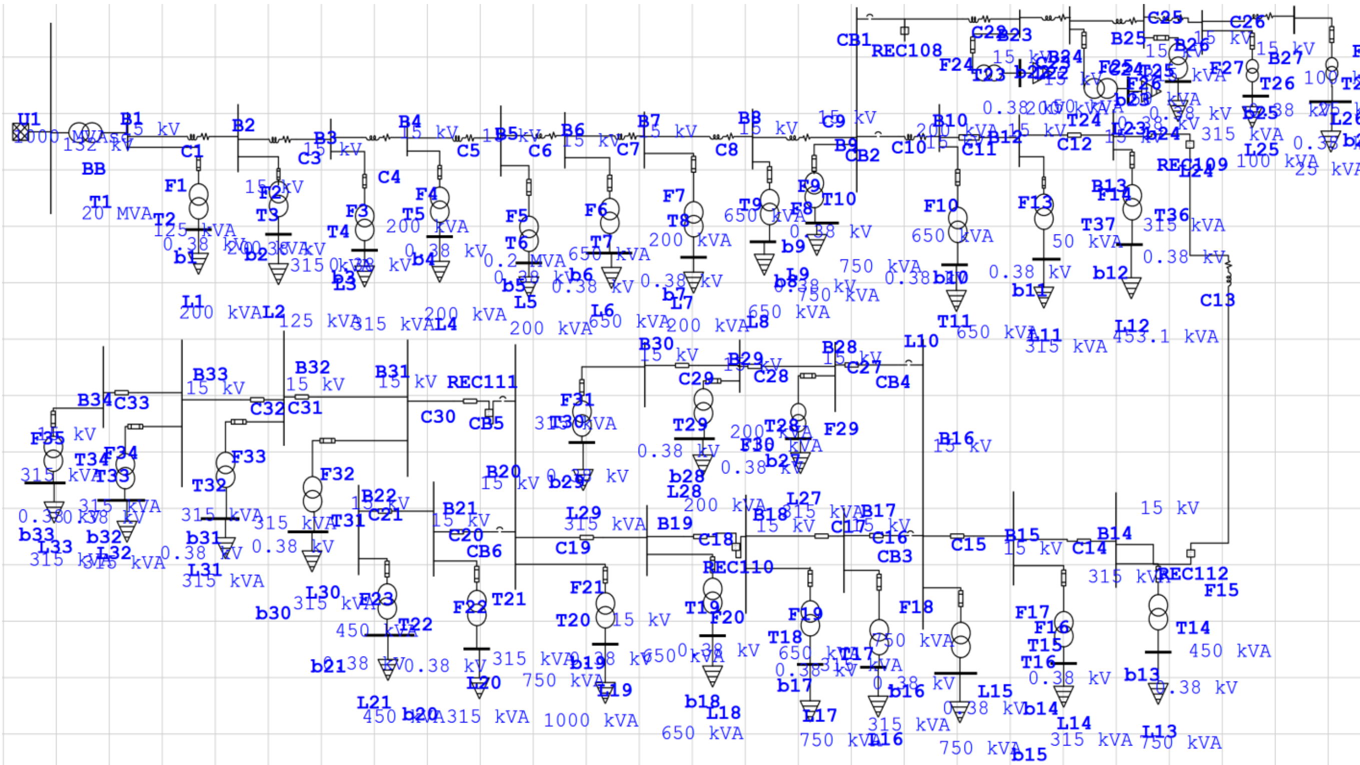

Figure 3.10: Single line diagram of Gorche feeder with auto recloser

The single line diagram of Gorche feeder has a total capacity of 2.2MW connected with different types of loads like residential loads, commercial loads and municipality loads. From 2.2MW of total power 409.2kw of power is lost due to different reasons. One of the main issue for those power loss problem is the unreliability of the system in which this thesis is proposed to address such kind of issue.

CHAPTER FOUR

SIMULATION RESULTS AND DISCUSSION

4.1 Introduction

The mitigation of Energy not supply, interruption cost (ECOST) for different simulation scenarios was conducted on radial distribution system (RDS) and recorded in this chapter. The first case analyzed the initial Total energy not supply (power loss) and Interruption cost (ECOST). The algorithm (The proposed GOA algorithm) outlined in the previous chapter was implemented and programmed in MATLAB software R2016a. The main codes programmed according to the implementation steps of the proposed algorithm are given in Appendix A. Different comparisons have also been done so as to show the reliability of this algorithm in reducing cost of energy not supply (power loss)real and Interruption cost (ECOST) in relation to other algorithms in open literature.

4.2. Description of Optimization Algorithm Parameters

The proposed algorithm is conducted for the energy not supply, power loss, and cost minimization function and enhancement of the voltage profile with the preferable objective functions. The optimization based algorithm is repeatedly executed with different optimal parameter settings and the parameters used to perform the simulation using this algorithm is shown in Table 4.1.

Table 4 1: Parameters for GOA algorithm

Population size	Max. number of iteration	decreasing coefficient	Design variable
100	100	$C = C_{max-i\frac{c_{max-c_{min}}}{L}}$	Vary

4.3. Simulation Results of Hawassa RDS

Based on the collected data that are given in Table 4.2 and 4.3 the reliability index analysis has been performed using etap 16.0.0 software. And using the line and energy not supply, SAIFI, SAIDI and ECOST index of the feeder was obtained. Many cases have been analyzed by computer simulation. The simulation focuses on evaluating the effects of using reclosers on reliability of Hawassa distribution system. The simulation output of reliability analysis is obtained by performing the following steps in ETAP16.0.0 software. Single line diagram of the existing system (Hawassa distribution at Line-12) has been designed on the working plane of the software. Hawassa distribution (Line-12 feeder) reliability calculations has been specified and entered. All switches has been specified based on type and operation. Then run the reliability assessment of exiting network. To obtain the optimal placement of auto recloser GOA algorithm was used. The simulation results for proposed system two different cases are considered for the implementation of the stated algorithm as illustrated below;

Case I: Network without reclosers (Base-case)

Case II: Network with recloser installed

4.4. Case I: Network without recloser (Base-case)

In Table 4.2 shows that the base case SAIFI, SAIDI, ENS, ECOST and power loss of Hawassa to Liku (gorche) feeder. The SAIFI, SAIDI, ENS, ECOST and power loss of the feeder are 123.9 int/cust/yr.,136.8hr/cust/yr.,1843.2MWhr/yr.,4,865,430.00$/yr. and 409.2kW/hr. respectively.

Table 4.2 Base case reliability indexes and power loss

Reliability index and pl	SAIFI (int/cust/yr.)	SAIDI (hr./cust/yr.)	ENS (MWhr/yr.)	ECOST ($/yr.)	PLOSS(KW)
Value	123.9	136.8	1843.2	4,865,430	409.2

From the above table 4.2 the data is obtained by simulating the single line diagram of the distribution substation of Hawassa city which is existing system or base case data but the power loss is obtained by calculating the total loss of the feeder from energy not supplied data.

4.5. Case II: Network with recloser installed

In this section, the simulation results are presented to show the impact of the allocations of auto recloser in the network in minimizing the power loss and improving reliability. After the base case analysis, the conventional GOA presented in sub-section 3.9.1 were comprehensively employed in the search for optimal size and location of recloser in the real network. The optimal size of recloser were determined as 15.5 kV while the optimal sites were found to be branch 5, 11, 18, 23, and 27. (It is found in appendix B).

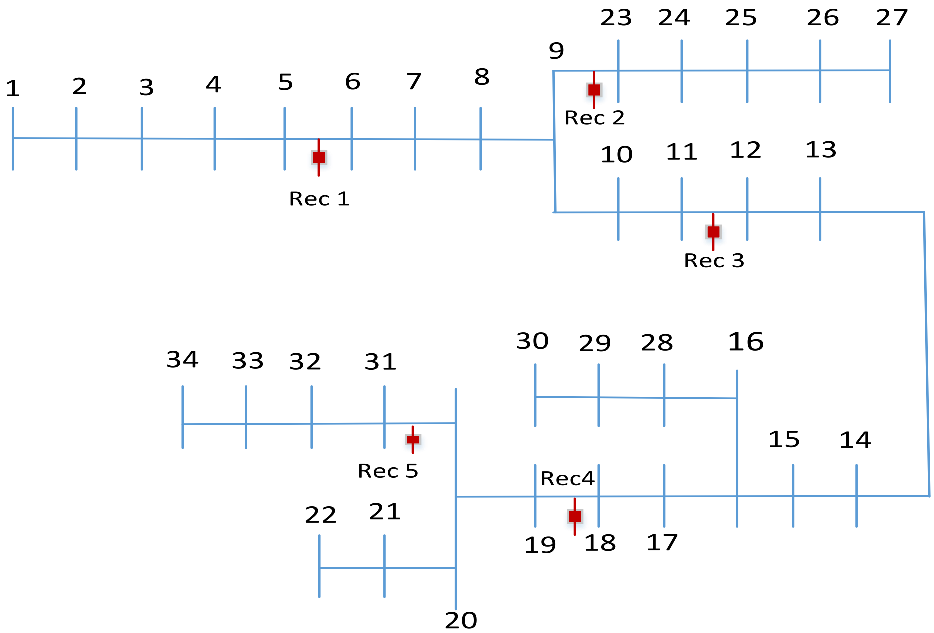

Figure 4.1: the proposed Single Line Diagram

SUMMARY

System Indexes

ACCI	kVA / customer
AENS	13.0801 MW hr / customer.yr
ALII	kVA pu
ASAI	0.9963 pu
ASUI	0.00371 pu
CAIDI	2.355 hr / customer interruption
CTAIDI	hr / customer
ECOST	2,655,882.00 $ / yr
EENS	431.644 MW hr / yr
IEAR	6.153 $ / kW hr
SAIDI	32.4801 hr / customer.yr
SAIFI	13.7917 f / customer.yr

Table 4.3 proposed system reliability indexes and power loss

Reliability index and pl	SAIFI (int/cust/yr.)	SAIDI (hr./cust/yr.)	ENS (MWhr/yr.)	ECOST ($/yr.)	PLOSS(KW)
Value	13.7	32.4	431.6	2,655,882	274.2

Table 4.4 Comparison of base case with new proposed system

Reliability index	SAIFI (int/cust/yr.)	SAIDI (hr./cust/yr.)	ENS (MWhr/yr.)
Base case	123.9	136.8	1843.2
Proposed	13.7	32.4	431.6

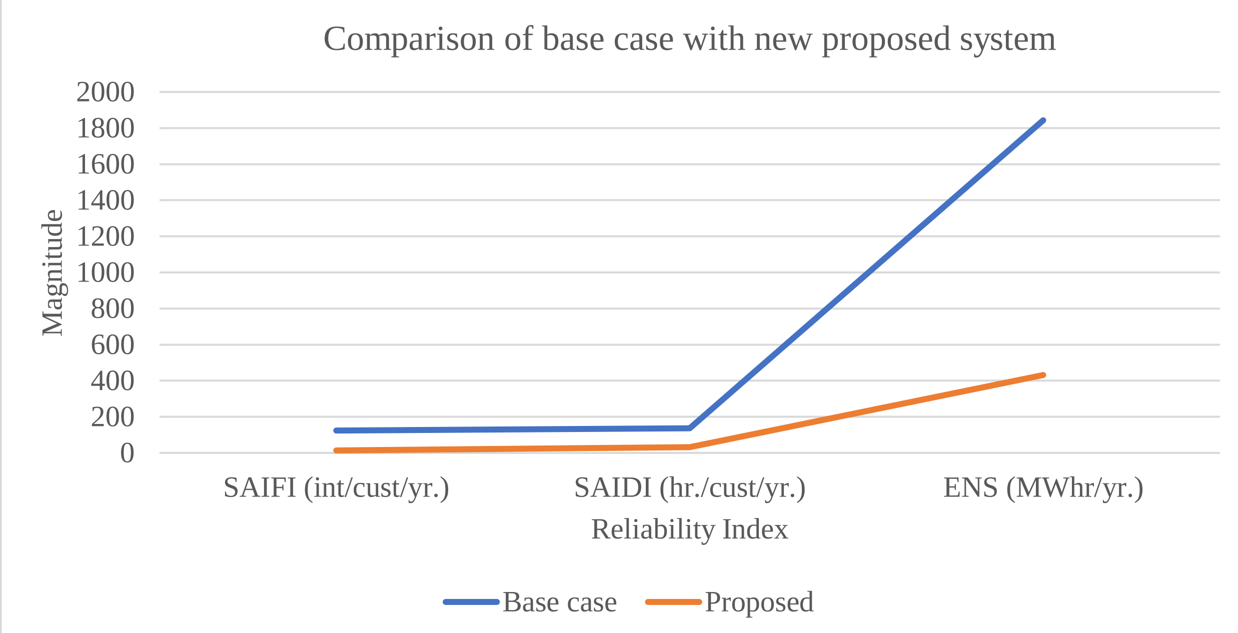

Figure 4.2: Comparison of base case with new proposed system

Table 4.5: Comparison of base case with new proposed system for interruption cost

Cases	ECOST ($/yr.)
Base case	4,865,430
proposed	2,655,882

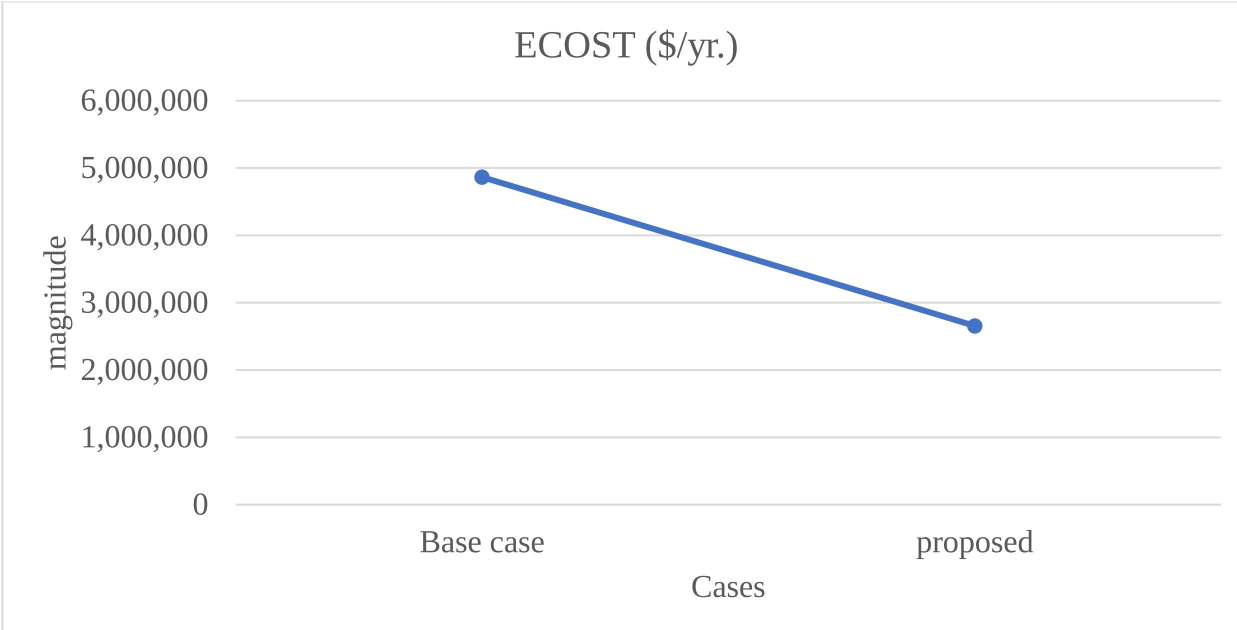

Figure 4.3: Comparison of base case with new proposed system for interruption cost

Table 4.6: Comparison of base case with new proposed system for power loss

Cases	PLOSS(KW)
Base case	409.2
Proposed	274.2

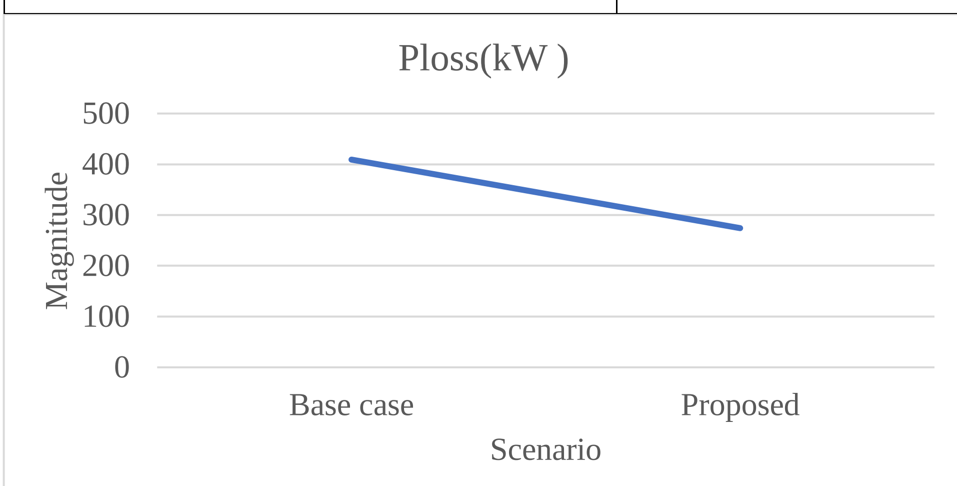

Figure 4.4: Comparison of base case with new proposed system for power loss

4.6 Comparison Result between GOA with PSO

Table 4.7: The reliability index output comparison between base case and proposed

Method	Auto recloser	SAIDI (hr./cust/yr.)	SAIFI (int/cust/yr.)	ECOST (ETB/yr.)	ENSC (ETB/yr.)	PL(Kw)
Base case	_	136.8	123.9	243,271,500	3,749,621.76	409.2
GOA	5,11,18,23,27	32.4	13.9	132,794,100	878,003.8	274.2
PSO	4,11,18,23,29	32.54	28.6	133,784,300	879,834.75	288.5

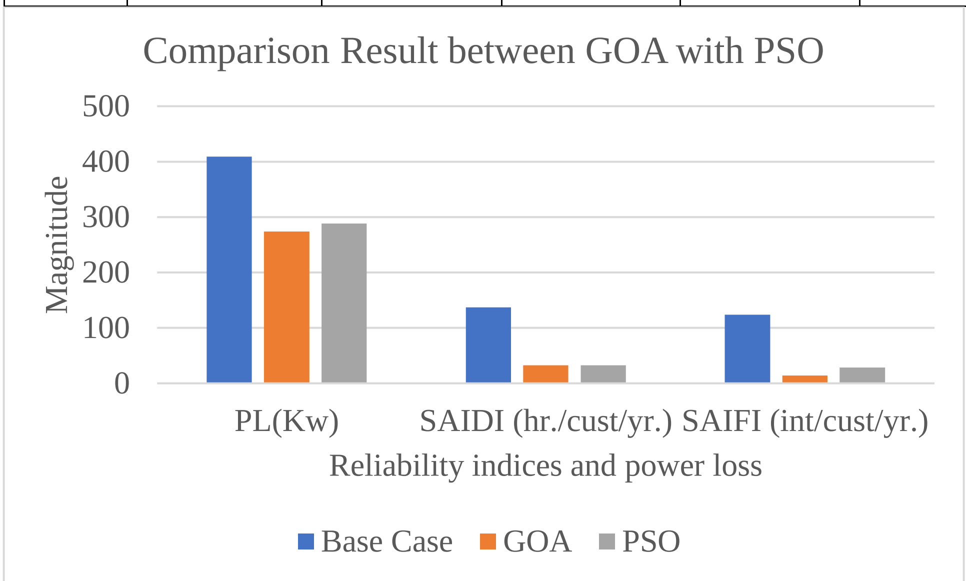

Figure 4.5: Comparison Result between GOA with PSO using reliability index

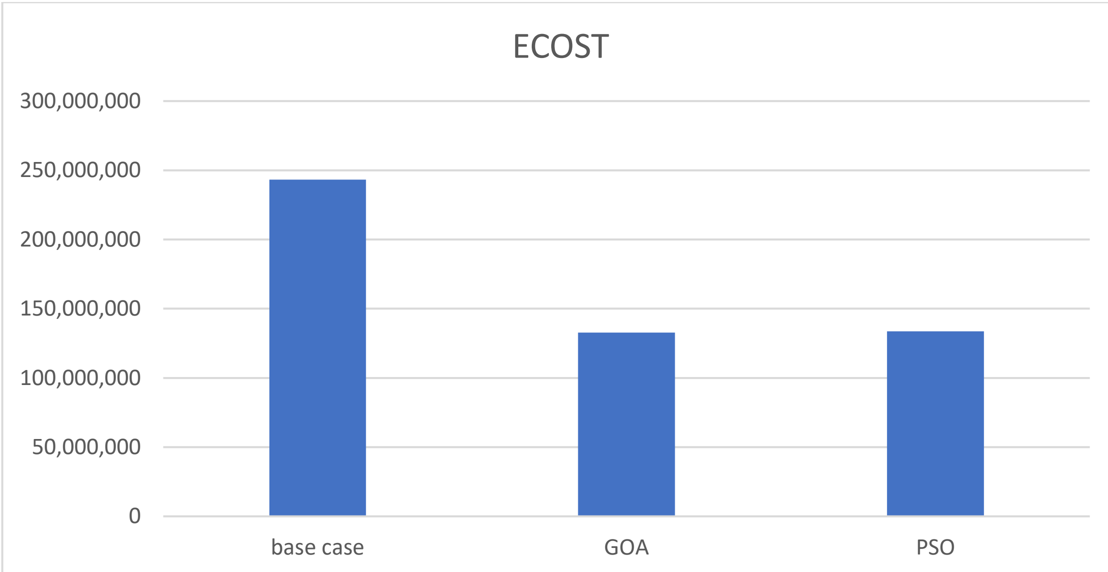

Figure 4.6: Comparison Result between GOA with PSO using ECOST

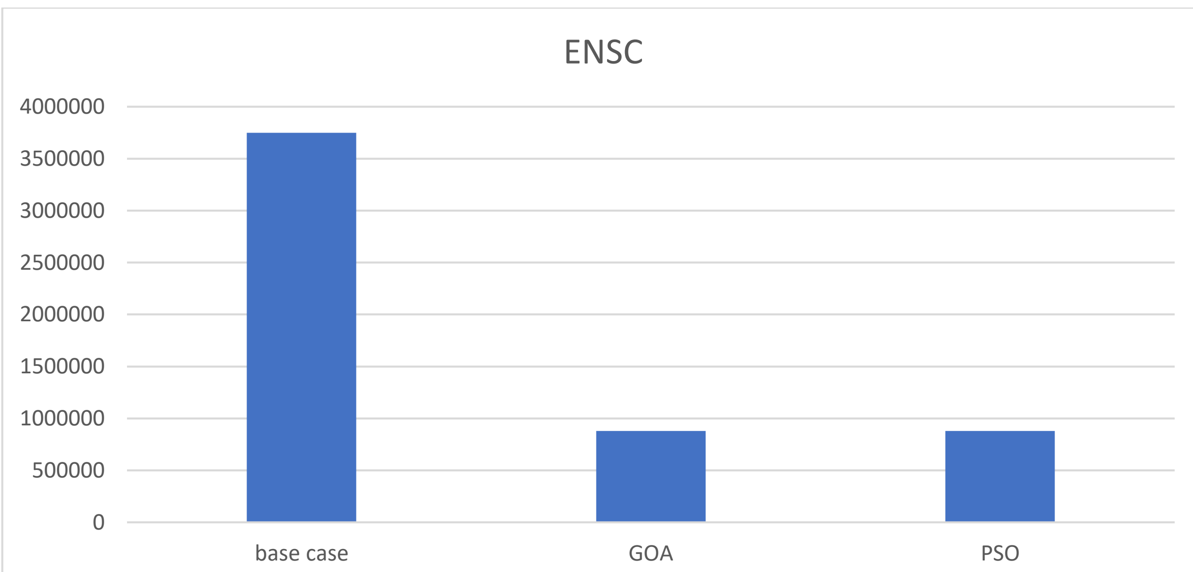

Figure 4.7: Comparison Result between GOA with PSO using ENSC

As shown in table 4.7 above, the Proposed GOA algorithm better reliability improvement and less Power loss than PSO that is why, for this thesis GOA algorithm was selected.

The state convergence of the two algorithm are:

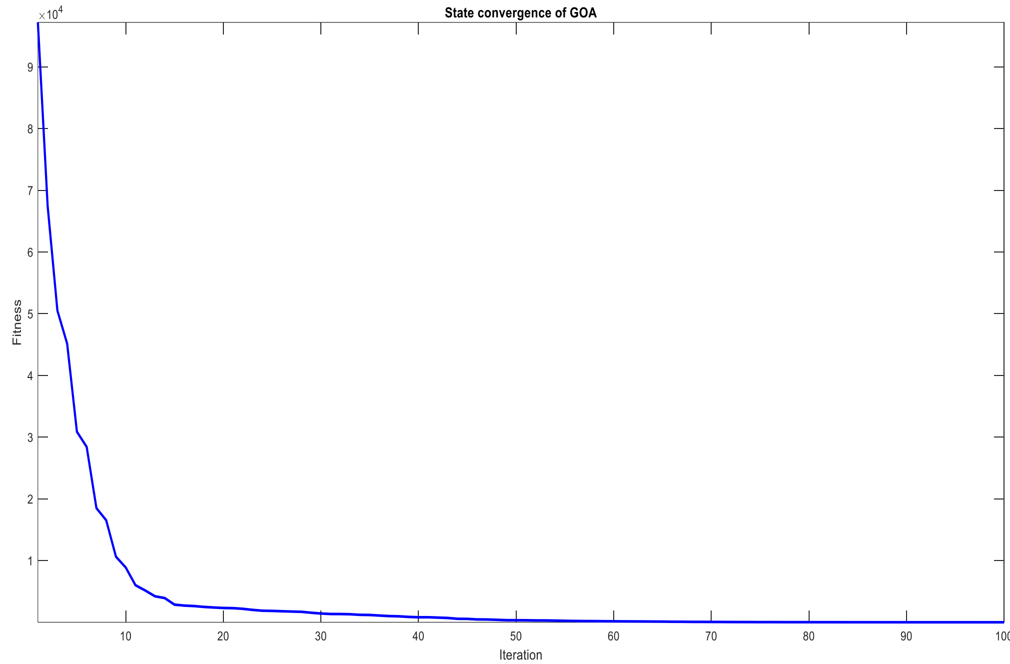

Figure 4.8: state convergence of GOA

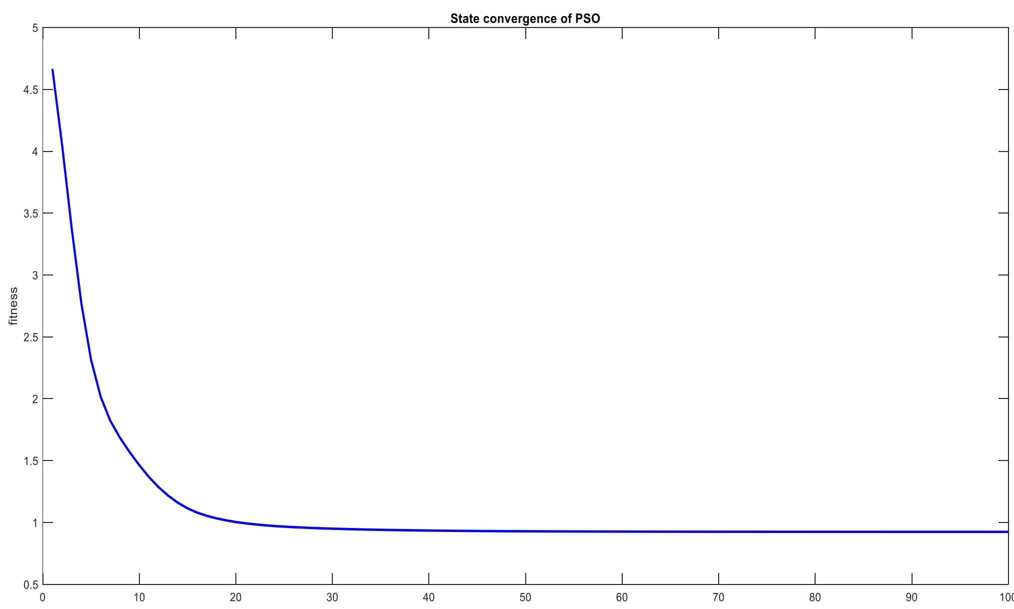

Figure 4.9: state convergence of PSO

As shown in figure 4.8 and 4.9, in the case of GOA with small iteration it convergence to optimal solution than PSO.

4.7 Result and Discussion Summary

The thesis were carried out on Hawassa radial distribution network on feeder 12 to optimize the overall distribution losses due to EENS, improve reliability and reduce by using a proposed GOA algorithm to identify an optimal place and number of automated switch. To evaluation, the selected algorithm GOA was compared with other algorithms from the literature. The results of the power losses due to EENS in the network were recorded and tabulated. A graphical presentation of interruption cost, power losses, convergence characteristics of GOA and PSO and evaluation of power loss cost of the feeder 12 of Hawassa distribution system were shown. A discussion was carried out in this chapter concluding with notable merits of the selected algorithm GOA over other algorithms from the literature on optimal placement of automated switch (recloser).

4.8 Cost Saving Analysis

Power interruption costs in both the utility and the customer sides. The size of the economic losses due to interruptions depends largely on the composition of the customers that experience interruptions. Customers in Hawassa utility are roughly divided into three categories: residential, commercial, and small industrial customers. For small industries, electricity supply interruption costs are strongly related to production losses and to costs involved in restoring production. In addition, interruptions also cause property damages and revenue loses for industries, commercial customers and for private individuals. It is difficult to estimate the exact value of interruption costs and economical loses, since the properties of each customer are different and difficult to found important data.

4.8.1 Energy Not Supplied

$ENS = \sum i \; Pi \times ri = \sum i \; Ei$ (4.4)

Where, Pi is the average load interrupted by each interruption i and Ei is the energy not supplied because of each interruption i.

CENS=ENS* cost of electricity tariff (4.5)

In this thesis interruption cost is only related to the utility side has been analyzed by using Expected Energy Not Supplied (EENS) of each cases and the power loss of the system.

4.8.2 Expected energy not supplied

The annual cost analysis by GOA technique can be calculated as follows:

Case 1: Financial losses of the system pre installation of auto recloser.

Before optimal placement of recloser in Hawassa distribution system the power loss is 409.2kw.

Financial loss =3,749,621.76 ETB.

Case 2: financial losses of the system after installation of auto recloser

Financial loss= 880,617.9 ETB.

By using GOA optimization the power loss is reduce to 274.2kW.

Saving =409.2Kw -274.2kW = 135kW

This indicates the utility saves 135kW of power each hour can be saving from loss.

Yearly saved energy =135*8760 =1,182600kWh.

Cost of saved energy=1,182600kWh * 2.0343 ETB/kWh = 2,405,763.18ETB

The total annual economic saving cost= cost of saving from EENS+ Cost saving from power loss

=2869003.86+2,405,763.18=5,274,767.04ETB

Table 4.8: The cost comparison between before and after placement

Scenario	Cost due to EENS	Annual economic saving cost(ETB)
Base case	3,749,621.76	-
With auto recloser	880,617.9	5,274,767.04

In the above analysis deals about the benefit of utility from loss and ENNS, now let us see the investment cost of Hawassa distribution network on feeder 12. The investment cost of Hawassa distribution network on feeder 12 can be calculated by using the cost of automated switch with current cost available in the market. For this thesis, outdoor poll mounted with 15.5 KV and 800A rating of recloser is selected. The selection of recloser rating of voltage and current is based on

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

Both the load and fault current of Hawassa distribution system on feeder 12 collected from the data, which recorded at every interruption. Therefore, the rating of recloser should be greater than or equal to both ratings. Currently, the Average cost of Recloser with 15.5 KV and 800A rating is 10,000 (USD).

The total number of recloser obtained by grasshopper optimization algorithm is five.

Total cost of recloser =5* 10,000$=50,000$ =2,500,000 birr

Investment cost = total cost of rec +installation cost + maintenance cost (4.2)

= total cost of rec + 10% total cost of rec +2% total cost of rec

= 50,000$ +5000 $ +1000$

= 56000$ = 2,800,000 birr

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 12 by using that investment. The payback period of a given investment or project is an important determinant of whether to undertake the position or project, as longer payback periods are typically not desirable for investment positions.

Table 4.9: investment cost and annual economic saving cost

Investment cost(ETB)	Annual economic saving cost(ETB)
2,800,000	5,274,767.04

$$payback\ period = \frac{investment\ cost}{economic\ saving\ cost} \quad (4.3)$$

$$payback\ period = \frac{2,800,000ETB}{5,274,767.04ETB/yr.}$$

= 0.53yr.

=7monthes

Therefore the payback period is almost seven months.

Generally, by optimal sizing and placing of automated switch with its optimal place, the number of interruption in distribution system (feeder 12) is reduced. Consequently, the energy is not supplied cost is also reduced which implies that the cost and power loss is reduced.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The thesis was conducted in one of the industrial cities of Ethiopia, Hawassa city has two substation, old and new. In the old substation, there are seven 15KV feeders and two 33 kV. The distribution network analysis and ETAP simulation study is carried out on feeder 12 based on the highest interruption data, to assess the performance of the present network and also the future reliability and power loss analysis to be predict. The interruption data of feeder 12 years 2012 & 2013 E.C has been considered as a base. Based on two years interruption data of Hawassa distribution about the causes of interruptions as mentioned in the appendix D, it can be seen that feeder 12 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 placement of automated switch not only the reliability indices; SAIFI, SAIDI and EENS but also the network power loss the feeder is improved. After optimal placement of recloser by using GOA algorithm both the reliability and power loss of the system improved by more than 50%. The switch is remotely controlled and have the ability of being operated in an automated scheme. In order to achieve this objective, a computer program ETAP16.0.0 is used to run reliability analysis, thus selecting the alternatives based on reliability indices and on cost benefit. Hence, the overall reliability problem of Hawassa city distribution feeder 12 reduces SAIFI by 88.9 %, SAIDI by 76.3%, EENS by 76.5%, ECOST by 55% and power loss by 70.5 %; as compared with the existing system. The economic analysis shows that the selected solution results in a cost saving of 5,274,767.04 ETB per year from the unsold energy of one feeder only with around 7 month payback period investment.

5.2 Recommendation

- Hawassa distribution network should use auto recloser to make the distribution system more sustainable and reliable.
- The way to reduce number of vegetation related failure is to replace bare 15kv overhead conductor with covered conductor, which can have significant effect both on SAIDI and SAIFI.

- Practical implementation of the recommended alternative solution is also important to improve the reliability and power loss of the power distribution system.
- Finally highly recommended for Engineers to put their hands on solving such real time problems and for utility better to first consider the reliability rather than cost.

5.3 Future Work

- As this thesis is conducted on one feeder, future researcher should do reliability improvement and power loss reductions in the whole part of the feeders including 33 kV.
- Future researcher should do reliability assessment and power loss minimization with different size of DGs at different locations.

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APPENDIX

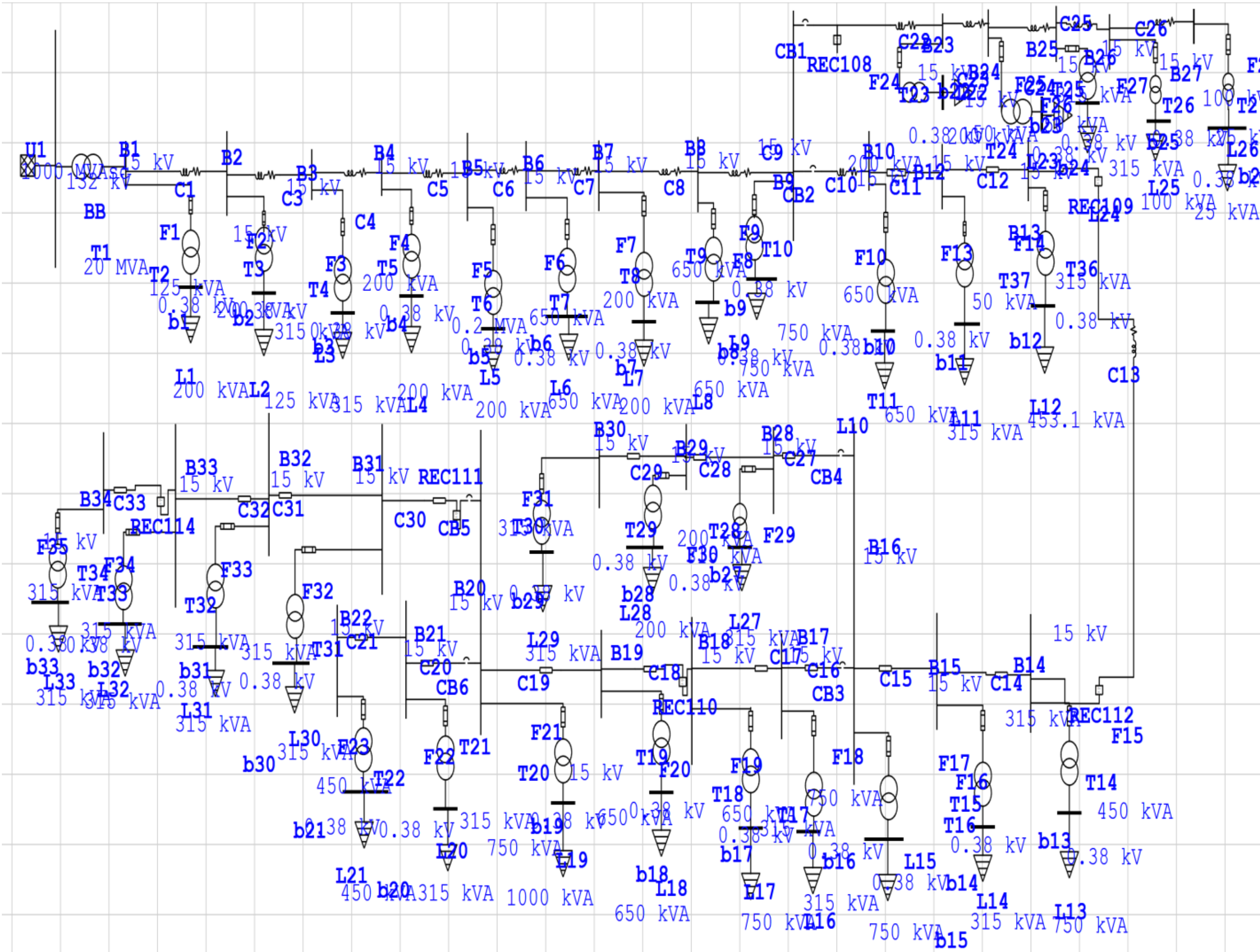
Appendix-A

Branch No	Sending end	Receiving end	Resistance	Reactance	Distance (km)	Node No	Active power (kw)	Reactive Power (kvar)
1	1	2	1.16	1.45	7.20	1	0	0
2	2	3	0.29	0.55	5.20	2	25.46	14.76
3	3	4	0.21	0.53	4.60	3	199.6	148.82
4	4	5	0.28	0.70	7.20	4	26.95	16.50
5	5	6	0.057	0.15	5.70	5	20.46	12.54
6	6	7	0.25	0..63	6.50	6	26.95	16.50
7	7	8	0.15	0.38	7.20	7	26.95	16.50
8	8	9	0.041	0.105	4.20	8	25.46	14.76
9	9	23	0.098	0.25	6.50	9	0	0
10	10	11	0.051	0.13	5.40	10	25.46	14.76
11	11	12	0.116	0.2935	7.50	11	199.6	148.82
12	12	13	0.13	0.17	6.20	12	20.46	12.54
13	13	14	1.245	1.255	4.60	13	199.58	148.81
14	14	15	1.117	1.435	5.20	14	49.9	32.3
15	15	16	0.588	0.756	6.50	15	199.58	148.81
16	16	17	0.0512	0.1305	4.20	16	199.6	148.82
17	17	18	0.0261	0.44	7.20	17	0	0
18	18	19	1.245	1.255	5.40	18	212.6	198.4

19	19	20	0.48	0.33	6.50	19	199.5 8	148.81
20	20	21	1.45	1.55	4.60	20	199.6	148.81
21	21	22	1.245	1.255	7.50	21	212.6	198.4
22	22	23	0.48	0.33	7.20	22	199.5 8	148.81
23	23	24	1.45	1.55	6.20	23	199.6	148.82
24	24	25	1.245	1.255	4.60	24	199.5 8	148.81
25	25	26	1.45	1.55	5.60	25	0	0
26	26	27	0.56	0.0522	7.20	26	49.89	32.22
27	27	28	0.496	0.339	4.60	27	199.5 8	148.81
28	28	29	1.245	1.255	6.50	28	199.6	148.82
29	29	30	1.45	1.55	7.20	29	199.5 8	148.81
30	30	31	1.245	1.255	7.20	30	199.6	148.82
31	20	32	1.45	1.55	4.20	31	212.6	198.4
32	32	33	0.56	0.0522	5.20	32	199.6	148.82
33	33	34	1.245	1.255	6.20	33	199.5 8	148.81

Appendix-B

Single line diagram of Gorche feeder with auto recloser by using PSO


U1
1000 MVAsc
132 kV
BB
T1
20 MVA
B1
15 kV
C1
F1
T2
125 kVA
0.38 kV
b1
L1
200 kVA
B2
B3
B4
B5
B6
B7
B8
B9
B10
B11
B12
B13
CB1
CB2
CB3
CB4
CB5
CB6
REC108
REC109
REC110
REC111
REC112
REC114
L10
B16
15 kV
B30
B31
B32
B33
B34
B20
B21
B22
B19
B18
B17
B15
B14
453.1 kVA
1000 kVA

SUMMARY

System Indexes

ACCI	kVA / customer
AENS	13.1070 MW hr / customer.yr
ALII	kVA pu
ASAI	0.9963 pu
ASUI	0.00371 pu
CAIDI	1.136 hr / customer interruption
CTAIDI	hr / customer
ECOST	2,675,686.00 $ / yr
EENS	432.532 MW hr / yr
IEAR	6.186 $ / kW hr
SAIDI	32.5413 hr / customer.yr
SAIFI	28.6512 f / customer.yr

Appendix-C

Frequency of Interruption for 15kv feeders in Hawassa old substation

Feeder name	2012 E.C	2013 E.C
Feeder 1	409	507
Feeder 2	422	558
Feeder 3	512	619
Feeder 4	569	653
Feeder 5	593	689
Feeder 6	617	701
Feeder 12	739	859

Duration of Interruption for 15kv feeders in Hawassa old substation

Feeder name	2012 E.C	2013 E.C
Feeder 1	2503.27	2603.27
Feeder 2	2551.72	2600.12
Feeder 3	2601.72	2657.22
Feeder 4	2789.11	2997.12
Feeder 5	2904.74	3006.22
Feeder 6	3009.11	3056.7
Feeder 12	3110.22	3370.22

Appendix-D

MATLAB script Code

```
clc
clear
close all
format short g
rng(1,'twister')
SearchAgents_no=100; % Number of search agents
disp('GOA is now estimating the optimum location and size for recloser....')
Function_name='F1';
Max_iteration=100; % Maximum numbef of iterations
 % Load details of the selected benchmark function
start=0;
x=0;
[LSI1,LSI2,Vm,PTloss,QTloss,power_f_active]=GOA(start,x);
% disp(' ')
disp('=====================================================')
disp('Results of 34 bus system without Reclouser')
% disp(' ')
% disp(['Total active loss is: ' num2str(PTloss) ' kW'])
```

```
Kp=168; % $/Kw.
T_cost=Kp*PTloss;
% disp(['Total annual cost is: ' num2str(T_cost) ' $'])
% [value_v,index_v]=sort(abs(Vm));
% disp(['Minimum voltage is: ' num2str(value_v(1)) ', at bus ' num2str(index_v(1))])
% disp(['Maximum voltage is: ' num2str(value_v(end-1)) ', at bus ' num2str(index_v(end-1))])
% disp(' ')
start=2;
N=4;
%% parameters setting
a=numel(LSI1(:,1))/2;
a=round(a);
disp(' ')
disp('========================================')
lb=[LSI1(1:a,2)' 0*ones(1,a)]; % lower bound
ub=[LSI1(1:a,2)' 1*ones(1,a)];  % upper bound
nvar=2*a; % number of variable
NP=200;             % number particle
T=10;              % max of iteration
G=1;
B1=2;
B2=2;
alpha=0.05;
%% initialization
tic
empty.pos=[];
empty.cost=[];
empty.velocity=[];
```

```
particle=repmat(empty,NP,1);
for i=1:NP
particle(i).pos=lb+rand(1,nvar).*(ub-lb);
[particle(i).cost]=Get_Functions_details(N,particle(i).pos,start);
particle(i).velocity=0;
end
bparticle=particle;
[value,index]=min([particle.cost]);
gparticle=particle(index);
%% main loop
best=zeros(T,1);
AVR=zeros(T,1);
for t=1:T
    for i=1:NP
  particle(i).velocity=G*particle(i).velocity...
                        +B1*rand(1,nvar).*(bparticle(i).pos-particle(i).pos)...
                        +B2*rand(1,nvar).*(gparticle.pos-particle(i).pos);
        particle(i).pos=particle(i).pos+particle(i).velocity;
             particle(i).pos=min(particle(i).pos,ub);
        particle(i).pos=max(particle(i).pos,lb);
        [particle(i).cost]=Get_Functions_details(N,particle(i).pos,start);
        if particle(i).cost<bparticle(i).cost
            bparticle(i)=particle(i);
             if bparticle(i).cost<gparticle.cost
                gparticle=bparticle(i);
            end
        end
         end
```

```
    G=G*(1-alpha);
 best(t)=gparticle.cost;
 AVR(t)=mean([particle.cost]);
  disp([ ' t = ' num2str(t)   ' BEST = '  num2str(best(t))]);
end
 %% results
% disp('=================================================')
% disp([' Buses are   =  '  num2str(gparticle.pos(1:a))])
% disp([' sizes are   =  '  num2str(gparticle.pos(a+1:end))])
 x=gparticle.pos;
for i=1:numel(x)/2
if x(i+(numel(x)/2))>0 && x(i+(numel(x)/2))<=0.125
            x(i+(numel(x)/2))=150;
        elseif x(i+(numel(x)/2))>0.125 && x(i+(numel(x)/2))<=0.25
            x(i+(numel(x)/2))=300;
        elseif x(i+(numel(x)/2))>0.25 && x(i+(numel(x)/2))<=0.375
            x(i+(numel(x)/2))=450;
        elseif x(i+(numel(x)/2))>0.375 && x(i+(numel(x)/2))<=0.5
            x(i+(numel(x)/2))=15.5;
        elseif x(i+(numel(x)/2))>0.5 && x(i+(numel(x)/2))<=0.625
            x(i+(numel(x)/2))=750;
        elseif x(i+(numel(x)/2))>0.625 && x(i+(numel(x)/2))<=0.75
            x(i+(numel(x)/2))=15.5;
        elseif x(i+(numel(x)/2))>0.75 && x(i+(numel(x)/2))<=0.875
            x(i+(numel(x)/2))=1050;
        elseif x(i+(numel(x)/2))>0.875
            x(i+(numel(x)/2))=1200;
end
```

```
end
 j=0;
for i=1:a
    if x(a+i)~=0
    j=j+1;
    Branches(j)=x(i);
    Sizes(j)=x(a+i);
    end
end
    disp(' ')
   disp('Total number of recloser and rating ')
disp('===============================================')
    disp(' Branches   Size(kV) ')
    disp([Branches' Sizes'])
    disp(' ')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 [LSI1,LSI2,Vm,PTloss,QTloss,power_f_active]=GOA(start,gparticle.pos);
disp('============================================================')
disp('Results of 34 bus system with Reclouser')
disp(' ')
% disp(['Total active loss is: ' num2str(PTloss) ' kW'])
Kp=168; % $/Kw
Kc=10000; % cost of single recloser $/15kV
life_exp=10; %life expectancy
T_cost=Kc*PTloss;
% disp(['Total annual cost is: ' num2str(T_cost) ' $'])
% [value_v,index_v]=sort(abs(Vm));
num_of_recloser=5; % number of recloser
```

```
% disp(['Minimum voltage is: ' num2str(value_v(1)) ', at bus ' num2str(index_v(1))])

% disp(['Maximum voltage is: ' num2str(value_v(end-1)) ', at bus ' num2str(index_v(end-1))])

Total_Rec_cost=Kc*num_of_recloser;

Inst_cost=0.1*Total_Rec_cost; % installation cost is 10% of recloser cost

Main_cost= 0.02*Total_Rec_cost; % maintenance cost is 2% of recloser cost

Total_inv_cost=Total_Rec_cost+Inst_cost+Main_cost;

disp(['Total cost of Reclouser is: ' num2str(Total_Rec_cost) ' $'])

disp(' ')

disp(['Total installation cost of Reclouser is: ' num2str(Inst_cost) ' $'])

disp(' ')

disp(['Total maintenance cost of Reclouser is: ' num2str(Main_cost) ' $'])

disp(' ')

disp(['Total investment cost of Reclouser is: ' num2str(Total_inv_cost) ' $'])

disp(' ')
```

Load flow Analysis MATLAB code

```
function[pl_base,ql_base,vm_base,Costp_lossbefore]=scenario1_basecase
clearvars;
clc;
close all
baseMVA=100;
f=zeros(30,1);
bus=load('busdata.m');
sump=sum(bus(:,2));
sumq=sum(bus(:,3));
%% BUS DATA ABOVE

%% line data above alex

[Zt,It,PQt,ZIPt,BUS_I,PD,QD,BS,TYPE,VM,VA,BASE_KV,VMAX,VMIN]=idx_bus;
[F_BUS,T_BUS,BR_R,BR_X,BR_STATUS,TAP,RATE_A]=idx_branch;
%stat=branch(:,BR_STATUS)
%% INSERT BELOW

n=30;
dim=5;% Dimmension of searching space
```

```
%x=load('swarm33.m');% Creating a swarm
%x=populatin;
%z=x';
%y=x';
vnew=rand(n,dim);% Creating a randomized initial velocity
sig=zeros(n,dim);
vold=vnew;
fitness=zeros(1,n);
%pbest=load('swarm33.m');% Creating pbest matrice
%pbest=x;
gbest=[4 10 24 30 12];% Introducing a randomized gbest
wmax=0.9;
wmin=0.4;
r1=rand(n,dim);% Creating a randomized matrice, size (20x3)
r2=rand(n,dim);% Creating a randomized matrice, size (20x3)
iter=0;

%% PSO parameter initialization

 % Calculating fitness function for pbest THIS IS AT ZERO ITERATION
 fpbest=zeros(n,1);
 for i=1:n
    f(i)=50000;
 end
 fgbest=fpbest(1);

 %% PSO START HERE

% Main loops
%while iter<maxiter% changed while to for never satisfied
maxiter=300;
% for q=1:maxiter

%  for k=1:n  % PROBLEM CREATURE
    dim=5;                    % Calculating fitness function for each particle
   % LINE DATA BELOW ALEX

   %% Line Data

%% BARDAR DATA BELOW
  %% Line Data
 branch=load('linedata.m');

%a=1.09*branch(:,4:5)
%branch(:,4:5)=a;
```

```
%a;

% LINE DATA ABOVE ALEX
    % y=[x]';
     % y=x';


        %  aa=find(branch(:,5)==0); %ALEX
% for i=1:dim
    %x;
 %branch(y(i,k),5)=0;%BECAUSE ALL LOOPS CLOSED BEFORE
 %branch(x(k,i),6)=0;%BECAUSE ALL LOOPS CLOSED BEFORE
 bb=find(branch(:,6)==0);% ALEX

               %matran(x(k,i),:)=0
% end

           %% RADIALITY CHECK BELOW

  %% RADIALITY CHECKING  ABOVE ALEX

%% INSERT ABOVE ALEX
stat=branch(:,BR_STATUS);
st=stat==0;% alex
ind=find(stat==0);% alex
branch(find(stat==0),:)=[]; % Actual branch matrix in which current flowing
nl=length(branch(:,F_BUS));% Total No. of branches in service
nb=length(bus(:,BUS_I));% Total no. of buses
%baseKV=max(bus(:,BASE_KV));
baseKV=15;
Zbase=(baseKV^2)/baseMVA; % base impedance
%R=branch(36:61,BR_R)/Zbase; % Line resistance in p.u. as R in ohms
%X=branch(36:61,BR_X)/Zbase; % Line Reactance in p.u.
%branch(36:61,BR_R)/Zbase; % Line resistance in p.u. as R in ohms
%branch(36:61,BR_X)/Zbase; % Line Reactance in p.u.
R=4.05212*branch(:,BR_R); % Line resistance in p.u. as R in ohms
X=1.37*branch(:,BR_X); % Line Reactance in p.u.
j=sqrt(-1);% defining iota
Z=(R+j*X); % Impedance in p.u.
 [BIBC,BCBV,DLF]=basecase_makeBIBCandDLF(Z,bb,baseMVA,baseKV,bus,branch);
% Calling BIBC and DLF matrix
%fnew2=load_flow2(busdata_value,BIBC,BCBV,DLF,S2_final,imped_value,ploss_out);
%% START OF LOAD FLOW
% base case load follow
 pd=complex(bus(:,2),bus(:,3));
```

```
pd(1)=[];
voltage_minimum=0.9;
voltage_maximum=1.05;
capmaxsij_maximum=100;
distmaxij_maximum=10;
source_num=1;
nbus=34;
%baseKV=15;
baseMVA=100;
PBASE=baseMVA;
%VBASE=(baseKV^2)/baseMVA;
busdata_value=bus;
linedata_value=branch;
%linedata_value(:,4:5)=(linedata_value(:,4:5)/VBASE);
%resistance_val=linedata_value(:,4); % take point
%reactance_val=linedata_value(:,5);% take point
resistance=R;
reactance=X;
actual_imped=complex(R,X);
busdata_value(:,2:3)=(busdata_value(:,2:3))/(1000*PBASE);
real_power= busdata_value(:,2);
imped_value=actual_imped;

complex_load_d=complex(busdata_value(:,2),busdata_value(:,3));
% complex power load
complex_load_g=zeros(size(busdata_value,1),1);

PG=0;
final_load_matrix=(complex_load_d-complex_load_g);% TAKE POINT HERE ALEX
final_load_matrix(length(source_num))=[];
initial_volt_value=ones(size(busdata_value,1)-length(source_num),1);
% initial bus voltage
voltage_drop_value=initial_volt_value;
max_iter=300;
%% STAR ITER BELOW
for ind_lop=1:max_iter
%backward sweep
inject_current_data=conj(final_load_matrix./voltage_drop_value);
% injected current at each bus
%IB=final_bibc_matrix*inject_current_data;
IB=BIBC*inject_current_data;
%get the cumulative injected current flowing through each branch
old_volt=voltage_drop_value;
volt_drop_each=DLF*inject_current_data;
%voltage drops along each branch.
voltage_drop_value=initial_volt_value-volt_drop_each;
```

```
old_volt1=(old_volt);
new_volt=(voltage_drop_value);
error_volt_tolr=max(abs(old_volt1-new_volt));
ind_lop;
end
%% FINISH ITER ABOVE
final_volt_data=[ones(length(source_num),1); voltage_drop_value];
rvolt=real(final_volt_data);
ivolt=imag(final_volt_data);
%% check limit alex

%% check limit above alex
final_volt_data=complex(rvolt,ivolt);
vm=abs(final_volt_data);
%h=abs(final_volt_data)

%ploss=((volt_diff_value1.^2).*resistance_val)./(abs(imped_value).*abs(
imped_value))*10^3;
ploss=abs(IB.^2).*(real(imped_value))*10^5;
qloss=abs(IB.^2).*(imag(imped_value))*10^5;

ploss_sum=sum(ploss)
qloss_sum=sum(qloss);
powerloss_data=complex(ploss,qloss);
loss_mag=abs(powerloss_data);
% Each Line Loss in kVAr
pl_base=ploss_sum;
ql_base=qloss_sum;
Costp_lossbefore=8760*733*pl_base;
vmin=min(vm)
%plot(vm);
%plot(ploss)
%grid on
%vm_base=vm;

end
```