ENHANSING RELIABILITY BY OPTIMIZATION OF POWER DISTRIBUTION SYSTEM

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FACULTY OF ELECTRICAL AND COMPUTER ENGINEERING

ENHANSING RELIABILITY BY OPTIMIZATION OF POWER DISTRIBUTION SYSTEM

(Case study - Harar City Electrical Power Distribution Substation III)

BY

HIKMA TADESSE TAMRAT

OCTOBER, 2017.

BAHIR DAR, ETHIOPIA
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By:-

HIKMA TADESSE TAMRAT

A THESIS

Submitted to the school of Research and Graduate Studies of Bahir Dar Institute of Technology, BDU in partial Fulfillment of the Requirements for the Degree of MASTER OF SCIENCE in Power System Engineering in the Faculty of Electrical and Computer Engineering

Advisor: Dr.-Ing. BELACHEW BANTEYIRGA

OCTOBER, 2017
BAHIR DAR, ETHIOPIA
DECLARATION

I, Hikma Tadesse, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have dually acknowledged and referred all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the university and can also evoke penal action from the sources which have not been properly cited or acknowledged.

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Ato Solomon Lule
To my father
ACKNOWLEDGMENT

No achievement in life is without the help of many individuals who have impacted our lives. We owe every measure of our success to the array of input from so many. Here are just a few who made this work possible:

My heartfelt appreciation goes to my advisor Dr.Ing. Belachew Banteyirga for his constructive comments and support from the commencement to the end of this research work. His priceless advice and remarks helped me a great deal to shape the paper into its present form. Without his help, this research work could not have been accomplished successfully.

To Aze, thank you for your support and being the tremendous source of inspiration. In addition, my special thanks go to my family: My brother Eske, My sisters Emuti and Mariti; they all kept me going and this theses would not have been possible without them.

Finally, I also wish to thank Genet Mekasha for being always there for me and my son during the toughest time of my life and when I was away from home for my studies. Joye, my prince, You were always there cheering me up, "mom berchina temari". You are an ecstasy to be around! Love you very much. Keep growing and learning!

Sam, you are my best friend, one of a kind!
ABSTRACT

Every aspect of our day-to-day life is linked with electricity. The quality of life and the development of a given country depend on the quality and reliability of electric power supply systems. The assessment of distribution system reliability gives information about the system performance and helps to know the cost or losses incurred by the utility and its customers as a result of power interruption. Distribution system reliability has acquired importance these days, because the distribution system performance can directly affect the customers. The distribution system reliability mainly deals with the interruption frequency and interruption duration of customers. If these values are large, the reliability of system is poor. The historical reliability assessment of Harar city Substation III, 15KV distribution system for the year 2007 and 2008 EC is carried out using analytical methods. The average power interruption frequency and duration over the period of study for the test system is 470 interruptions and 405 hours of duration respectively.

There are many measures to assess the reliability of a power distribution network. The most common measures are SAIFI, SAIDI, EENS, CENS and ASAI. Many measures are used to estimate the reliability of a distribution network. In this research, the focus of the reliability measure is the lost revenue as a result of EENS and the incurred cost as an action to improve reliability through installing optimal number of sectionalizing switches.

To improve the system reliability, heuristic optimization methods are applied. These methods are BDSA and BPSO based on multi objective optimization methodology to determine the optimal number and location of new installed sectionalizing switches in electric power distribution networks. To illustrate the performance of the proposed algorithms, an actual 15KV overhead line distribution feeder (line 2) with 62 segments is selected as a test system and the program is written and simulated in MATLAB software. The predictive reliability assessment is calculated by considering no sectionalizing switch, by placing sectionalizing switches on all the segments and by optimal placement of number and allocation of sectionalizing switches for both proposed methods. From the test results the BDSA has better minimized CENS and it also has better computational efficiency. As the result of the optimal placement of switches the cost of EENS is reduced from $6.5861 \times 10^7$ to $3.9289 \times 10^7$ birr at the incurred cost of switches which is $4.4196 \times 10^5$ birr.

Key Words: Reliability Indices, distribution system, SAIFI, SAIDI, CENS, BPSO, BDSA
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LIST OF ACRONYMS

AI         Artificial Intelligence
ASAI       Average System Availability Index
BDSA       Binary Dynamic Search Algorithm
BPSO       Binary Particle Swarm Optimization
CAIDI      Customer Average Interruption Duration Index
CAIFI      Customer Average Interruption Frequency Index
CENS       Cost of Energy Not Served
DT         Distribution Transformers
EENS       Expected Energy Not Served
EEU        Ethiopian Electric Utility
IEEE       International Electrical and Electronics Engineers
MTTF       Mean Time To Failure
MTTR       Mean Time To Repair
PSO        Particle Swarm Optimization
SAIDI      System Average Interruption Duration Index
SAIFI      System Average Interruption Frequency Index

LIST OF SYMBOLS

c         Acceleration coefficient
KV        Kilo Volt
La        Average Load
MWh       Mega Watt Hour
r         Repair Time/ Outage Time
U         Annual Outage Time
v         Velocity
w         Inertia weight
x         Position
λ         Failure Rate
CHAPTER ONE: INTRODUCTION

1.1. Overview

The basic function of the power system is to provide an adequate electrical supply to its customers as economically as possible with reasonable level of reliability. With growing demand and increasing dependence on electricity supplies, the necessity to achieve an acceptable level of reliability, quality and safety at an economic price, the utility have to evolve and improve the systems continuously depending upon the requirement of the customers. Over the past, distribution systems have received considerably less attention devoted to reliability modelling and evaluation than the generating and the transmission systems [1]. The reasons for this are that the generating stations and the transmission systems are capital intensive and the generation and the transmission inadequacy can have widespread catastrophic consequences for both society and the environment. A distribution system, however, is relatively cheap as compared to the other two as its effects are localized. Therefore, less effort has been devoted to quantitative assessment of the adequacy of various alternatives and reinforcements. On the other hand, analysis of the customer failure statistics of most utilities shows that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer [1]. The distribution systems account for up to 90% of all customer reliability problems, improving distribution reliability is the key to improving customer reliability [2]. Since the primary purpose of the system is to satisfy customer requirements and the proper functioning and longevity of the system are essential requisites for continued satisfaction, it is necessary that both demand and supply considerations are appropriately viewed and included in the systems. Therefore, the distribution reliability is one of the most important in the electric power industry due to its high impact on the cost of the electricity and its high correlation with customer satisfaction.

Distribution system reliability evaluation is a measure of continuity and quality of supply to the customers, which mainly depends up on interruption profile, based on system topology and component reliability data. Performing distribution system reliability assessment is used to identify the relevant improvement techniques to get better reliability of the system. To run distribution system reliability assessment different approaches and techniques can be used. Normally two approaches to quantitative reliability evaluation are used, namely historical assessment and predictive assessment. The historical distribution reliability is described as measuring the past performance of a system, it generally summarizes discrete interruption events occurring at a specific locations over specific time periods, some of the basic indices that have been used to assess the past performance are:

- SAIFI
- SAIDI
whereas predictive assessment estimates the future behaviour of systems by combining component failure rates and repair times with system configurations.

Reliability assessment can be carried out using both simulation and analytical techniques. Simulation techniques estimate the reliability indices by directly simulating the actual process and the random behaviour of the system and its components. These techniques can provide both average values of the reliability indices and their probability distributions. Analytical techniques represent the system by mathematical models and evaluate the reliability indices from these models using direct mathematical solutions.

Protective devices play a fundamental role in improving distribution system reliability. Automatic line sectionalizing devices such as line re-closers, interrupters, sectionalizers and fuses are often needed to reduce the total number of customers affected for a single outage by automatically isolating the faulted section. They also reduce the frequency of outage for customers on the source side of these devices and reduce the duration of outages by expediting the task of locating the faulted feeder section. The more the automatic devices installed on a distribution feeder, the better the service reliability. In addition, there are some application limitations such as co-ordination between devices and the cost of the installation, maintenance and operation.

From the many measures which are used to estimate the reliability of a distribution system, this thesis focuses on the reliability measurement of Expected Energy Not Supplied (EENS) and its cost. On the process of improving the reliability of an actual distribution network, a combinatorial optimization problem comes to picture. This problem is the selection of the optimal locations for installing sectionalizing devices in the network. The research primarily presents the 15 KV radial feeder of Harar city, following the historical reliability assessment, the predictive reliability assessment is calculated for the feeder by placing the new switches optimally. Then the planned index which is the expected Energy Not Supplied and its cost for the three cases using the two methods are compared. The index for both cases of the two methods has also presented.

1.2. Statement of The Problem

Electricity networks are, and will continue to be a critical part of our energy infrastructure, and we have the responsibility to ensure that they are developed consistently and in a manner that meets future demands of society and customers. The process of network development should be directed towards a long term vision aligned with the expectations of the present and future
customers. After corporatization and forming as utility company, EEPCo’s mission is to transmit, distribute and supply adequate electricity in a safe, reliable and efficient manner and this has to be accomplished.

The main problem facing by electric power utilities in developing countries today is that the power demand is increasing rapidly where supply growth is constrained by scarce resources, environmental problems and other societal concerns. This has resulted in a need for more extensive justifications of the new system facilities, and improvements in production and distribution of electricity. System planning and operation based on reliability cost/worth evaluation approach provides an opportunity to justify one of the scrutinized and vulnerable economic sectors in Ethiopia.

The analysis of the customer failure statistics reveal that the distribution system makes highest individual contribution to the unavailability of supply to the customer. With the existing system, the customer average interruption duration for the test system (line 2) is 405 hrs/year. And most of the interruption has been caused due to the failure in the distribution system in Harar. Comparing with other utilities around the world, reliability standards are very low in distribution system of Harar. Hence it is felt necessary to improve the reliability of the system in order to improve the utility’s performance and to keep its valued customers satisfied.

1.3. Objectives

1.3.1. General Objective

The main objective of this thesis is to minimize the number of customer power interruption for any failure on the feeder of the distribution system. Resulting in improved reliability measured using the selected indices.

1.3.2. Specific Objective

- Assess, Evaluate and Compute reliability indices of the existing system of Harar city distribution system.
- Evaluate available fault statistic information for the distribution system.
- Describe outage consequences.
- Based on those indices, develop appropriate optimization method to improve reliability of the power distribution systems by optimal selection of number and location of sectionalizing switches considering the cost of Expected Energy Not supplied and the incurred cost of the newly to be purchased switches.
1.4. Research Methodology

The methodologies of this research include:

**Literature Review**: Several papers, articles, transactions, journals and books on the title reliability assessment methods and switch placement algorithms have been reviewed.

**Data Collection**: In order to assess the performance of the distribution network of Harar city, monthly power interruption readings for two consecutive years 2007 and 2008 were obtained from East Region EEU, Harar Distribution Substation III.

**System Analysis**: The aforementioned collected data have been analyzed and organized to make suitable for reliability assessment and modeling of the study area.

**System Modeling**: For predictive assessment, the reliability model of the selected feeder (line 2) has been modeled.

**BDSA and BPSO programming**: For the switch placement multiobjective optimization problem based on binary dynamic search algorithm and binary particle swarm optimization technique, programs are written using MATLAB software.

1.5. Significance of the Thesis

This thesis will have a significant importance of measuring the existing performance of reliability and provide reliability improvement solutions as well as serving as a benchmark for the prediction of the future of any electrical distribution system in the frame of the research.

Generally the expected importance of this study are:

- To indicate the influence of power interruption on economy of the power supplier utility.
- Methods to apply Binary Particle Swarm Optimization (BPSO) AI optimization methods
- To apply Binary Differential Search Algorithm (BDSA) method to improve system reliability.

1.6. Scope of the Thesis

The research primarily focuses on one of the substation located in Harar city (Harar distribution substation III). From many of the outgoing feeders and transmission lines from the substation the reliability performance is calculated for only one outgoing feeder called line 2. The limitations for calculating the reliability indices from historical interruption data is that the cause for power cut is not recorded for most of the cases, which forces the predictive reliability improvement to focus on
the installation of optimal sectionalize switches considering the cost of the expected energy not served (CENS).

1.7. Literature Review

The percentage of system faults in a distribution network is more compared to that in other parts of a power grid system. The reduction of momentary and sustained outages reacting more quickly to system disturbances can be achieved by protection schemes and leading edge equipment, such as modern remote-controlled switches, breakers, reclosers, and fault indicators. In order to achieve a high level of reliability, more investment should be accomplished by the utilities and the best locations for installing these switches should be found so that the most possible benefit is gained. Determination of the optimal number of switches and best switch location is an optimization problem. The selection of an adequate number of switches and their locations is a difficult task in distribution system planning. Utilities use their past experience, customer data and other consideration in selecting a suitable number of switches. An artificial intelligence technique with multi agent system was used by Bouhouras et al [14] for performing cost/worth assessment of reliability improvement in distribution networks. Haifenga [15] adopted Monte Carlo simulation based approach for providing a basis for using a parallel computing environment in power system reliability and cost evaluations. Switch allocation problem has been a topic of research interest for decades and many studies have been performed [16], [17], [18].

Allocation of switches has been considered in [19], [20], [21], [22]. Optimal placement of switches and reclosures has been considered in [23], [24]. Abiri-Jahromi et al. [25] utilized mixed integer linear programming (MILP) for optimal placement of sectionalizing switches. Viotto Romero et al. [26] proposed a dedicated Taboo Search (TS) algorithm for optimal switch allocation in distribution systems for automatic load transfer. Bernardon et al. [21] proposed a methodology to consider the impact of RCS when computing the reliability indices and the algorithm for multi-criteria decision making to allocate these switches. Sectionalize switches are gaining importance in reliability improvement studies. Some studies are have been carried out in order to develop strategies for Sectionalize switch without covering allocation of switches [27] [28]. Benavides et al. [29] proposed a new iterated sample construction with path relinking (ISCPR) to solve distribution system switch allocation problem. Zheng et al. [30] studied the quantitative impact of automatic switches on the reliability of power distribution systems. Esmaeilian and Fadaieinedjad [31] adopted a Binary Gravitational Search Algorithm (BGSA) for network reconfiguration and capacitor placement in distribution system in order to improve reliability. Tippacon and Rerkpreedapong [32] adopted multi-objective ant colony optimization (MACO) whereas Pombo et al. [33] adopted a memetic algorithm combining Non dominated Sorting Genetic Algorithm II (NSGA-II) with a local search algorithm for switch and reclosure allocation in order to minimize the
reliability indices namely average interruption frequency index (SAIFI) and system average interruption duration index (SAIDI) as well as the cost of equipments. Golestani and Tadayon [34] used Linear Fragmented Particle Swarm optimization for optimal switch placement in distribution system. Assis et al. [35] proposed a memetic algorithm based optimization methodology to sectionalizing, tie, manual, and automatic switches in distribution networks. Amanulla et al. [36] used binary particle swarm optimization-based search algorithm to find the optimal status of the switches in order to maximize the reliability and minimize the real power loss. Zou et al. [37] adopted methods including feeder reconfiguration, recloser installation, recloser replacement, and distributed generation (DG) installation to minimize system average interruption duration index (SAIDI), an important reliability index. Brown et al. [38] used sequential feeder method and a multi-objective genetic algorithm (GA) together to solve the optimization of the feeder addition problem in an islanded distribution system with DGs. Vitorino et al. [39] presented the application of an improved genetic algorithm (IGA) to optimize simultaneously loss and reliability of a radial distribution system through a process of network reconfiguration as an optimization. Zhang et al. [40] proposed a reliability-oriented reconfiguration (ROR) method for improving distribution reliability and energy efficiency, based on interval analysis. Pfitscher et al. [41] presented a new methodology for automatic reconfiguration of distribution network, in order to improve network performance indicators, such as losses and reliability. Kavousi-Fard and Akbari-Zadeh [42] proposed a multiobjective distribution feeder reconfiguration problem for reliability enhancement as well as loss reduction. Raofat [43] adopted a GA based method to allocate DGs and RCSs simultaneously in order to reduce energy loss and improve reliability considering multilevel load.

Recently, Pinar Civicioglu [44] introduced a new algorithm named differential search (DS) algorithm to solve the problem of transforming geocentric cartesian coordinates into geodetic coordinates and compared its performance with classical methods and other computational intelligence algorithms. DS algorithm adopts the seasonal migration behavior of many organisms where they shift from one habitat to a more efficient one, in terms of efficiency of food areas. The individual organisms form a superorganism which as a whole move toward more efficient area. The effectiveness of DS algorithm has already been compared with other algorithms such as artificial bee colony algorithm (ABC), self-adaptive differential evolution algorithm (JDE), adaptive differential evolution algorithm (JADE), strategy adaptation based differential evolution algorithm (SADE), differential evolution algorithm with ensemble of parameters (EPSDE), gravitational search algorithm (GSA), particle swarm optimization (PSO) and covariance matrix adaptation evolution strategy (CMA-ES). DS algorithm has been found to solve the problem at a very high level of accuracy [44]. Unlike other algorithms such as differential evolutionary algorithm (DE), JDE, and ABC, DS algorithm may simultaneously use more than one individual during updating steps. An
important advantage of DS algorithm over many other algorithms is that DS algorithm has no inclination to correctly approach the best possible solution. Therefore, exploration ability of the algorithm is significantly improved compared to many other existing algorithms. In this thesis the number of switches to be used for optimal operation and their location is solved using both BDSA and BPSO.

1.8. Over view of Case Study Area

Modern Harar is the capital of the Harari People National Regional State, which covers a small area of about 350 sq. kilometres in the eastern part of Ethiopia, inside the Oromiya region. The city lies just off the southern edge of the south-eastern plateau dividing the Great Rift Valley from the plains of the Ogaden region. The elevation above sea level of the city varies from 1,600 to 1,900 metres and its urban morphology presents two main parts, the ancient city and the recent one that has developed from the late 19th century. The ancient walled city (named Jugal) has a high population density in an area of 62 hectares with internal differences of level ranging from 0 to 60 metres.

1.8.1. Existing distribution line and transformers of the case study area

1.8.1.1. Harar Substation I
It is called Harar old substation. It consists of transformers which partially supply power to Harar city and other transformers which transmits power to neighbouring towns with 45kV overhead primary distribution lines. All other outgoing feeders from this substation to the city are 15kV distribution lines.

1.8.1.2. Harar Substation II
It is a near by substation to the old harar substation (Harar substation I). It also consists of distribution transformer which steps down voltage level from 66kV to 15kV and distribute power to the city.

1.8.1.3. Harar substation III
Harar substation III is new substation built 13 years ago, planned to transmit power to near by rural towns and to feed power partially to Harar city. There are four 15kV and two 33kV outgoing feeders from the Substation. In existing system, 33kV lines are used mainly for far flung rural areas and from the 15kV lines, line 1 feed near by rural area called “Kombolcha”, line 2 feeds the city, line 3 feeds the city partially and feeds the near by places called “Aweday” and “Hamaresa” and the last 15kV line is for two factories namely Harar Brewery and Hamaresa Edible Oil factory.
1.9. Thesis Outline

Chapter One: This chapter introduces the basics about reliability. The chapter explains the statement of the problem, thesis objectives, scope of the thesis, literature review in which many literatures are reviewed, it also introduces about the the case study area.

Chapter Two: The first section of this chapter is all about issues of reliability from different technical point of views. It also gives some highlights about the system analysis of distribution system from the point of view of reliability.

Chapter Three: This chapter deals with the modeling of distribution system equipments considering reliability improvement.

Chapter Four: On this chapter the optimization techniques for solving multi-objective optimization problems are discussed briefly.

Chapter Five: The result for all the simulation are explained in the result and discussion part of the thesis.

Chapter Six: Finally this chapter consists the conclusion and the recommendation of the thesis.
CHAPTER TWO: DISTRIBUTION SYSTEM RELIABILITY ISSUES

2.1. Overview on Reliability

Electric power is a vital element in any modern economy. The availability of a reliable power supply at a reasonable cost is crucial for the economic growth and development of a country. Electric power utilities throughout the world 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. An analysis throughout the world shows that around 90% of all customer reliability problems are due to the problem in distribution system, hence, improving distribution reliability is the key to improving customer reliability [2].

Due to its localized effect and minimal cost on the outages while comparing with the generation and transmission system, less effort have been devoted to distribution system in quantitative assessment of the adequacy of the various alternative designs and reinforcements. However, analysis of the different sectors of the customer failure statistics reveals that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer. Statistics such as these reinforce the need to be concerned with the reliability evaluation of distribution system, to evaluate quantitatively the merits of various reinforcement schemes available to the planner and to ensure that the limited capital resources are used to achieve the greatest possible incremental reliability and improvement in the system. Therefore, it is necessary to ensure a reasonable balance in the reliability of the various constituent parts of a power system, i.e. generation, transmission and distribution [1]. Once the distribution systems are planned, designed and built, they must be continually monitored, adjusted, expanded and repaired. This distribution operation plays an important role in distribution reliability.

The Mitigation Techniques like electric or non electric methods could be used to improve the reliability in the system. Modern automation technologies can reduce contingency margins, improve utilization and economy of operation and even provide improved scheduling and effectiveness of maintenance and service. However, they must be applied well, with the technologies selected to be compatible with systems need and targeted effectively. On the other hand, non-electric method such as vegetation management, system improvements, crew placement and management, maintenance practices plays an important role in improving reliability in the system. Recent significant increase in energy costs, concern with conservation of resources, and impacts of government and environmental groups have resulted in a need for more adequate justification of new system facilities and operating reliability levels. A major aspect of this justification is the assessment of worth or benefit of power
system reliability to its customers or conversely, the cost of losses which result from system unreliability. [3]

2.1.1. Reliability Evaluation
The ultimate goal of reliability analysis is to help answer questions like “is the system reliable enough?”, “which scheme will fail less?” and “where can the next dollar be best spent to improve the system?” [4]

Reliability in power system can be divided in two basic aspects; System adequacy and System security. Adequacy relates to the capacity of the system in relation to energy demand and security relates to the dynamic response of the system to disturbances (such as faults). Since distribution systems are seldom loaded near their limits, system adequacy is of relatively small concern and reliability emphasis is on system security.

The two main approaches applied to reliability evaluation of distribution systems are [5];

- Simulation methods based on drawings from statistical distributions (Monte Carlo).
- Analytical methods based on solution of mathematical models

The Monte Carlo techniques are normally very “time” consuming due to large number of drawings necessary in order to obtain accurate results. The fault contribution from each component is given by a statistical distribution of failure rates and outage times. The analytical approach is based on assumptions concerning the statistical distributions of failure rate and repair times. The most common evaluation techniques using a set of approximate equations are failure mode analysis or minimum cut set analysis. This method is less time consuming than the simulation methods, but suffers from problems of representing repair times adequately.

2.1.2. Reliability Indices
Quantitative reliability evaluation of a distribution system can be divided into two basic segments: measuring of the past performance and predicting the future performance [6]. Some of the basic indices that have been used to assess the past performance are;

- System Average Interruption Frequency Index (SAIFI)
- System Average Interruption Duration Index (SAIDI)
- Customer Average Interruption Duration Index (CAIDI)
- The Average Service Availability Index {Unavailability} ( ASAI){ASUI}
- Energy not supplied(ENS)

Past performance statistics provide valuable reliability profile of the existing system. However, distribution planning involves the analysis of future systems and evaluation of system reliability
when there are changes in; configuration, operation conditions or in protection schemes. This estimates the future performance of the system based on system topology and failure data of the components. Due to stochastic nature of failure occurrence and outage duration, it is generally based on probabilistic models. The basic indices associated with system load points are ; failure rate, average outage duration and annual unavailability.

SAIFI indicates how often an average customer is subjected to sustained interruption over a predefine time interval where as SAIDI indicates the total duration of interruption an average customer is subjected for a predefined time interval. CAIDI indicates the average time required to restore the service. ASAI specifies the fraction of time that a customer has received the power during the predefine interval of time and is vice versa for ASUI. ENS specifies the average energy the customer has not received in the predefined time.

2.1.3. Reliability Cost and Worth
As a concept, reliability is an inherent characteristics and a specific measure that describes the ability of any system to perform its intended function. The primary technical function of a power system is to supply electrical energy to its end customers. This has always been an important system issue and power system personnel have always strive to ensure that customers receive adequate and secure supplies within reasonable economic constraints [7]. The system adequacy basically means the availability of enough generation, transmission and distribution capacities to meet the customer demand. While on the other hand security is considered to relate to the ability of the system to respond to disturbances arising within the system. Therefore, adequacy assessment represents the static conditions, where as security assessment pertains to the dynamic conditions of the power system [1].

Utilities, in a venture to supply power at an economic price with an adequate level of reliability, often faces challenges to balance the high level of reliability at relatively low cost, since these two aspects counters each other. Direct evaluation of reliability worth is a difficult task, therefore, a practical alternative, which is being widely used is to evaluate the impacts and monetary losses incurred by the utility due to power failures. When an interruption is occurred by a supplier company, there is an amount of money that the company loss because of unsold energy due to the interruption and this amount is referred to cost of expected energy not served. As such, to maximize the reliability, utility should balance their reinforcement cost for reliability improvement. Therefore, the optimal level of reliability is said to be achieved when the sum of utility cost and the cost which is incurred due to the improved reliability is at minimum.
2.2. Factors Influencing Power System Reliability

The factors influencing power system reliability can be broken down into four categories. They are component reliability, environmental conditions, system configuration and time varying load.

2.2.1. Component Statistics

A power system consists of various components, such as lines, cables, transformers, breakers, switches, reactors, and capacitors. Any single component outage may cause a partial or even entire system outage. The availability of component functionally is characterized by failure rates and repair time. This factor will be analyzed thoroughly in system design and analysis.

2.2.2. Environmental Conditions

Power system components are exposed to various weather conditions and hazards. Animals, motor vehicle accidents, rain, ice, and tree contact can all lead to faults and failures. Environment dependent failures may be of short duration. However, during such events, the probability of failure of components increases dramatically. Many utility companies have given this increased attention, especially with weather dependent failures.

2.2.3. System Configurations

System configurations include various issues, including topology, transportation capacity, protection/coordination schemes, and DG placement. These factors all influence the reliability level of a system to some extent. Several researches have been conducted on optimal placement of switches and protective devises in distribution system to increase the system reliability. In this research work, predictive reliability is done to look for the optimal number and location of sectionalize switches using one of the suitable AI techniques and Differential Search Algorithm (DSA).

2.2.4. Time-varying Load

The load demands in distribution systems vary from time to time, and each class of customers follows a different pattern. Sometimes the difference between the maximum load point and minimum load point may reach 50% of the peak load. It is obvious that the applicability of a reliability analysis algorithm to a practical system is limited if only a constant load model is considered. The loading condition changes the system reliability in two different ways. First, excess load speeds up equipment aging; on the other hand, mild load may prolong the life-span of an electric component. Second, loading conditions change the power interchange capability among the adjacent circuits. So for a given configuration of the power system, loading conditions also affect the system reliability.

2.3. Reliability Improvement Aspects

Power delivery systems are subjected to abnormal operations caused by events such as accidents, component failures, and weather conditions. These events are random and are beyond the control of
man. Such random events can be taken into account in designing a system that can sustain certain levels of disturbances. How much should be invested in improving reliability? It will never be possible to make the system 100% reliable. A decision has to be made to accept a certain level of risk. In this decision-making process, quantitative reliability evaluation is the basis. On the other hand, this process is more than reliability evaluation, and it involves technical, economic, and environmental assessments.

2.3.1. From component statistics point of view

Power system devices are designed to minimize the effects of disturbances caused by random events to the power system and its customers. The process of clearing a disturbance or the disturbance itself can result in the customer experiencing a complete loss of power or a decrease in the supplied power. Reducing the number of interruptions in the distribution lines is the primary focus of reliability programs of power utility companies [8].

In the area of power quality and reliability of distribution circuits, there is significant emphasis on techniques and technologies that can be used to react to utility system faults. One of the trends concerning distribution faults is the implementation of more preventive measures instead of reactive measures. In other words, we would like to prevent faults from happening rather than restore the system after faults happen. The prevention of distribution faults is a difficult task, not only because the fault causes are affected by many different variables, but also because distribution faults have their own local properties [8]. Different geographical locations require different methods of fault prevention.

Power system component failures can be reduced by replacing aged components, especially those entering their wear out stage. This measure requires accurate statistical data. And there is the chance that equipment, such as transformers, can function for many years beyond their expected lifetime. Therefore, a replacement policy to improve reliability may be effective, but costly, to implement. Looking at statistical data associated with equipment failure rates is sometimes not good enough, because equipment failures can be linked to other external factors that may affect failures more than aging.

2.3.2. From system configuration point of view

From the system configuration point of view, setting up redundant paths is a common method of improving reliability. However, it is also commonly recognized that in most cases utilities cannot financially justify idle redundancy. So, the goal is to find some means to configure the system (flexible enough) so that the reliability of the system is enhanced.
New techniques have been developed to improve distribution system reliability, such as automatic learning techniques [9], automatic switches [10], Microprocessor Relays [11], distribution system automation, feeder reconfiguration and restoration, and so on. However, the financial aspect of these new techniques is seldom considered.

In distribution systems where automation is not applied the allocation/reallocation of protective and switching devices is a solution for improving the reliability of the system [12]. Optimal allocation of switches in distribution power systems can improve reliability of a power system by reducing the total time of fault detection, isolation and restoration. In this paper, a binary version of Particle Swarm Optimization (PSO) algorithm and Binary Dynamic Search Algorithm are developed and presented to determine the optimum number and locations of sectionalize switches in radial distribution systems.

2.4. Interruption Data Collection Scheme

In today’s competitive economic situation it has become imperative for utilities and supply companies to accurately measure the performance of their systems. Reporting reliability performance indices at customer level gives these distributors an in-depth insight to the operational effectiveness and status of their supply networks thus giving them a leading edge over their competitors. Additionally, most electrical distributors are required by statutory governance to accurately and consistently report on the performance of their networks.

These measures are required at operational and strategic levels within utilities. Distribution Network Interruption Performance Reporting is the standardized reporting of measures that reflect the performance of an electrical distributed network. The measures used for reporting network performance is guided by several international industry standards e.g. Institute of Electrical and Electronics Engineers (IEEE) and International Council on Large Electric Systems (Cigre).

Inconsistent, unreliable and non-standardized reporting of reliability indices across distributors are the main problems within the industry. This is due to distributed application systems and different interpretations of international standards when calculating reliability indices.

The IEEE 1366 Standard is a widely accepted international guide that stipulates the required reporting indices to reflect electrical distribution system performance. Additionally, the standard refers to how these indices should be calculated and defines data definitions, requirements and business rules that need to be applied. “Along with the variety of definitions of reliability come a variety of ways to measure it. A metric for reliability is required for assessment of past performance, consideration of reliability in design, and setting of reliability goals. Many indices have been defined
as measures of reliability. They measure different aspects of reliability or combinations of different aspects. Only a small number of these are common across several utilities and the ones that are commonly used are not always defined in the exact same manner. [11]

Among different utilities, the outage data collection methods can differ in terms of the differences in the interruption data collection systems (ranging from manually entered paper systems to completely automated computer-based systems), the ability to collect interruption data from the system (ranging from the substation level down to the customer service drop), the use or non-use of step restoration when collecting interruption data, the determination of the start time, the definition of sustained interruption (ranging from >1 to >5 min), the definition of a customer (account, meter, premise, etc.), and interruption delineations (forced interruptions, scheduled interruptions, major events, etc.). Localization of systems by location such as system characterization (rural, suburban, and urban) and climatic information (hot, cold, wet, dry, lightning, etc.) is important. In addition, classification of distribution systems by system design characteristics such as system layout (radial, loop, two-transformer station, etc.) and system placement (underground, overhead, etc.) makes a significant impact on system reliability performance.

Reporting Reliability Performance Indices requires the following:

- Capturing of source data related to outages on the electrical networks.
- Transforming the source data into the applicable formats using the business rules stipulated in international standards.
- Calculating reliability indices using the formulae stipulated in the standards
- Presenting the results in a standard report format

One of the biggest challenges experienced by supply distributors and by different supply utilities is to consistently and accurately report reliability indices in conformance with international standards. Many factors can cause variation in the indices reported by different utilities. Some examples of differences are namely, the following:

- Level of automated data collection
- Geography
- System design
- Data classification (Application of business rules)

Information included in distribution system performance data collection are, categories for system characterization, interruption causes, responsible systems, conditions, voltages, devices, device
initiation, and restorations. A utility system is usually characterized into three categories, namely, rural, suburban, and urban systems, based on some arbitrary target value of customer density per mile. Seven general interruptions cause categories that are suggested for data collection purposes [13]. These are intentionally broad categories that will make possible more precise benchmark comparisons between different distribution utilities. There are numerous categories that could be chosen, but with the goal of uniformity for comparison purposes, the following seven broad categories can be used for data collection:

1. Scheduled
2. Tree contact
3. Defective equipment
4. Adverse weather
5. Adverse environment
6. Human element
7. Foreign interference

2.5. Reliability Assessment and Reliability Indices

Distribution reliability is the ability of the distribution system to perform its function under stated conditions for a stated period of time without failure. Distribution reliability is becoming significantly important in the current competitive economic climate because the distribution system feeds the customer directly. The distribution system is the face of the utility to the customer. Its assessment is to determine the system reliability and customer satisfaction. Rigorous analytical treatment of distribution reliability requires well defined units of measurement, referred to as indices. Many utilities across the world today use reliability metrics to track the performance of the utility or a region or a circuit. Regulators require most investor owned utilities to report their reliability indices. The regulatory trend is moving to performance based rates where performance is penalized or rewarded based as quantified by reliability indices. Most of the utilities also pay bonuses to managers or others based in part on reliability achievements. Even some of the commercial and industrial customer ask utilities for their reliability indices when planning to find a location for their establishments.

2.5.1. Reliability Analysis

Reliability analysis of electrical distribution system is considered as a tool for the planning engineer to ensure a reasonable quality of service and to choose between different system expansion plans that cost wise were comparable considering system investment and cost of losses [5]. There are two main approaches applied for reliability evaluation of distribution system, namely Simulation method based on drawings from statistical distributions (Monte Carlo) and Analytical methods based on solutions of mathematical models. The Monte Carlo techniques are normally time consuming due to large
number of drawings necessary in order to obtain accurate results. The analytical approach is based on assumptions concerning based on statistical distributions of failure rates and repair times. The usual method of evaluating the reliability indexes is an analytical approach based on failure modes assessment and the use of equations for series and parallel networks. The common indices used for evaluation: the expected failure rate ($\lambda$), the average outage time($r$), and the expected annual outage time($U$) which are adequate to the simple radial system. In distribution system whether the networks are radial or meshed, they are operated radially mostly, is simple to assess. The process is more complex for parallel or meshed networks. The basic theory for reliability analysis is discussed below.

2.5.1.1. Markov Chain Model

A Markov model is quite popular in the quantitative reliability analysis, and that is suitable to give fair idea about reliability analysis principle. On the basis of Markov models, a simple formula can be developed that can be used to calculate the reliability of the radial distribution network. The method is called like duration-frequency technique, and the starting point is the failure of the individual component. In a so-called stationary Markov process, it basically operates with two central concepts.

- Failure frequency ($\lambda$)
- Repair time ($r$)

It is assumed for example that a component-wise reliability can only be in one of the following conditions;

Condition 1: Component is in the function (in);

Condition 2: Component is in repair (out).

This is illustrated in two state model diagram in figure 4-1 represented by 0(component in failed state) and 1(component is in a normal state).

![Figure 2.1 Transitional diagram of component states](image)

Where,\[
\lambda = \frac{\text{Number of outages on component in a given period}}{\text{Total time component is in operation}} \quad (2.1)
\]
The figure 2.2 illustrates expected functional and outage time for a component (so called state cycle). The system can be represented by Markov process and equations developed for the probabilities of residing in each state in terms of state transition rates are as follows:

![Figure 2.2 Average state cycle](image)

The average function time, \( m \), is given by; \( m = \frac{1}{\lambda} \)

Where, \( m = \) MTTF, mean time to failure \( = \frac{1}{\lambda} \)

\( r = \) MTTR, mean time to repair \( = \frac{1}{\mu} \)

\( m+r = \) MTBR, mean time between failures \( = T = \frac{1}{f} \)

\( f = \) cycle frequency \( = \frac{1}{T} \)

The probability of component to be in either one of the two states are shown in the figure;

\[ P_1 = \frac{r}{m+r} = \frac{\lambda}{\lambda+\mu} = \frac{r}{T} = \frac{f}{\mu} = \frac{\sum(\text{down time})}{\sum(\text{down time}) + \sum(\text{up time})} \tag{2.2} \]

where, \( f = \mu \cdot P_1 \)

\[ P_0 = \frac{m}{m+r} = \frac{\mu}{\lambda+\mu} = \frac{m}{T} = \frac{f}{\lambda} = \frac{\sum(\text{up time})}{\sum(\text{down time}) + \sum(\text{up time})} \tag{2.3} \]

where, \( f = \lambda \cdot P_0 \)

\( f = \lambda \cdot P_0 = \mu \cdot P_1 \)

### 2.5.1.2. Series System

The distribution systems in Harar town are designed, constructed and operated in radial system. A radial system basically consists of set of series components like; breakers, lines, switches, transformers and at the end a “Customers”. In the series structure both components must be intact for the system to function, "a chain is no stronger than its part" while in the parallel structure both must fail for the system to stop functioning. In this case, all the components are connected in series as shown in figure 2.3 and the equations needed to evaluate the basic indices are as follows:

![Figure 2.3 Series System](image)

Average failure rate for the system is:

\[ \lambda_s = \lambda_1 + \lambda_2 = \sum_{i=1}^{2} \lambda_i \tag{2.4} \]
Average outage time of the system is:

\[ r_s = \frac{\lambda_1 r_1 + \lambda_2 r_2}{\lambda_1 + \lambda_2} = \frac{\sum \lambda_i r_i}{\sum \lambda_i} = \frac{U_s}{\lambda_s} \]  \hspace{1cm} (2.5)

If \( \lambda_1 \lambda_2 r_1 r_2 \ll \lambda_1 r_1 \) or \( \lambda_2 r_2 \),

Average annual outage time:

\[ U_s = f_s \cdot r_s = \lambda_s \cdot r_s \]  \hspace{1cm} (2.6)

where \( \lambda_i \) is the failure rate at node \( i \), \( r_i \) is the outage time at node \( i \).

2.5.1.3. Parallel system

In this case the failure modes of the load point involve overlapping outages, two or more components must be on outage at the same time in order to interrupt a load point as shown in figure 2.4. It is assumed that the failures are independent and that restoration involves repair or replacement, the equations used to evaluate the indices of the overlapping outage are as shown below:

\[ \lambda_p = \frac{\lambda_1 \lambda_2 + (r_1 + r_2)}{1 + \lambda_1 r_1 + \lambda_2 r_2} = \lambda_1 + (r_1 + r_2) \]  \hspace{1cm} (2.7)

where, \( \lambda_1 \) and \( \lambda_2 \) usually \( \ll 1 \)

Average outage time of the system

\[ r_p = \frac{r_1 r_2}{r_1 + r_2} \]  \hspace{1cm} (2.8)

Average annual outage time of the system:

\[ U_p = \lambda_p r_p \]  \hspace{1cm} (2.9)

These are adequate for simple radial system and more extended indices are have to be used for general distribution systems (mixed radial and meshed systems).

Since the configuration of the case study area has radial structure the modelling is taken as series system.
2.5.2. Reliability Indices
Reliability indices are statistical aggregations of reliability data for a well defined set of loads, components or customers. Most reliability indices are average values of a particular reliability characteristic for an entire system, operating region, substation service territory, or feeder. Comprehensive treatment is not practicable, but the following sections discuss the most important reliability indices used around the world. The utility indices have traditionally only included long duration interruption (usually defined as interruptions longer than 5 minutes). A common way of defining reliability is in terms of customer and load based indices.

2.5.2.1. Customer Based Indices
The utilities commonly used the following two reliability indices for frequency and duration to quantify the performance of their systems.

i. System Average Interruption Frequency Index (SAIFI) is designed to give information about the average frequency of sustained interruptions per customer over a predefined area.

\[ SAIFI = \frac{\text{Total number of interruption}}{\text{Total number of customers served}} = \frac{\sum \lambda_i N_i}{\sum N_i} \]  \hspace{1cm} (2.10)

where \( \lambda_i \) is the number of failure rate and \( N_i \) is the number of customers of load point i.

ii. System Average Interruption Duration Index (SAIDI) is commonly referred to as customer minutes of interruption or customer hours, and is designed to provide information about the average time that the customers are interrupted.

\[ SAIDI = \frac{\text{Sum of customers interruption durations}}{\text{Total number of customers served}} = \frac{\sum U_{iN_i}}{N_T} \]  \hspace{1cm} (2.11)

where, \( U_i \) is the annual outage time and \( N_i \) is the number of customers of load point i.

iii. Customer Average Interruption Duration Index (CAIDI) is the average time needed to restore service to the average customer per sustained interruption:

\[ CAIDI = \frac{\text{Sum of customer interruption durations}}{\text{Total number of customer interruptions}} = \frac{\sum U_{iN_i}}{\sum \lambda_i N_i} = \frac{SAIDI}{SAIFI} \text{ (hr)} \]  \hspace{1cm} (2.12)

where, \( \lambda_i \) is the failure rate, \( U_i \) is the annual outage time and \( N_i \) is the number of customers of load point i.
iv. **Customer Average Interruption Frequency Index (CAIFI):** is designed to show trends in customers interrupted and helps to show the number of customers affected out of whole customer base.

\[
CAIFI = \frac{\text{Total number of interruption}}{\text{Number of customers affected}} = \frac{\sum U_{Ni}}{\sum N_i}
\]  

(2.13)

v. **Average Service Availability Index (ASAI)**

\[
ASAI = \frac{\text{Customers hours of available service}}{\text{customers hours demanded}} = \frac{\sum N_i \times 8760 - \sum U_{iNi}}{\sum N_i \times 8760}
\]  

(2.14)

where 8760 is the number of hours in a calendar year

### 2.5.2.2. Load and Energy Based Indices

Two of the oldest distribution reliability indices weight customer based on connected KVA instead of weighing each customer equally. From a utility perspective, ASIFI and ASIDI represents better measure of reliability than SAIFI and SAIDI. Larger KVA corresponds to higher revenue and should be considered when making investment decisions.

i) **Average System Interruption Frequency Index (ASIFI)**

\[
ASIFI = \frac{\text{Connected KVA Interrupted}}{\text{Total connected KVA served}} (/\text{year})
\]  

(2.15)

ii) **Average System Interruption Duration Index (ASIDI)**

\[
ASIDI = \frac{\text{Connected KVA hours Interrupted}}{\text{Total connected KVA served}} (/\text{year})
\]  

(2.16)

However, one of the important parameters required in the evaluation of load and energy oriented indices is the average load at each load point busbar [1].

i. **Expected Energy Not Supplied Index, EENS**

\[
\text{EENS} = \text{Total Energy not supplied by the system} = \sum L_{a(i)} U_i
\]  

(2.17)

where \( L_{a(i)} \) is the average load connected to load point \( i \), \( U_i \) is the average outage time

ii. **Average energy not supplied, AENS** or **Average system curtailment index, ASCI**

\[
AENS = \frac{\text{total energy not supplied}}{\text{total number of customers served}} = \frac{\sum L_{a(i)} U_i}{\sum N_i}
\]  

(2.18)

### 2.6. System Performance

The customer and load based indices described in the above sections are useful for assessing the severity of system failures in future reliability prediction analysis. They can be used, however, as a
means of assessing the past performance of a system. The assessment of system performance is a valuable procedure for three important reasons [1];

- It establishes the chronological changes in system performance and therefore helps to identify weak areas and the need for the reinforcement.
- It establishes existing indices which serves as a guide for acceptable values in future reliability assessments.
- It enables previous predictions to be compared with actual operating experience.

**SAIDI and SAIFI** – When making reliability investments, reductions in SAIDI and SAIFI are proportional to the number of affected customers. This means projects that affect many customers are preferred to those that affect few customers. However, feeders with many customers typically have better than average reliability, and feeders with few customers have worse than average reliability. Therefore, reliability investment based on SAIFI and SAIDI can drive investments towards densely populated areas where reliability is already satisfactory.

**CAIDI** – Although popular with many utilities and regulators, CAIDI is problematic as measure of reliability. This is because, many view CAIDI as a measure of operation efficiency; when utility responds more quickly after a fault, CAIDI will go down. In fact, CAIDI is mathematically equal to SAIDI divided by SAIFI. That is reliability could be improving in both frequency and duration, but CAIDI could be increasing. Because of the above problem, the use of CAIDI is decreasing in today’s world.

### 2.7. Impacts of Mitigation Techniques and Protection System on Reliability

A properly co-ordinated protection system is vital to ensure that an electricity distribution network can operate within preset requirements for safety of individual items of equipment, staff and public, and the network overall. Suitable and reliable equipment should be installed on all circuits and electrical equipment and to do this, protective relays are used to initiate the isolation of faulted sections of a network in order to maintain supplies elsewhere on the system. This then leads to an improved electricity service with better continuity and quality of supply. This can reduce the permanent outages and its durations. Nowadays, with the increase of sensitive load with the end users, to improve the power quality and to mitigate the momentary interruptions is also equally important. The first step is to find out the root cause of the problem and apply mitigation solutions to a circuit that affects the largest number of customers.

A better over-current protection scheme can reduce number of customers affected by temporary and permanent faults. The reliability of the system depends on the mitigation techniques being used by
the utility namely, electric and non electric mitigation techniques. So, historical data can be used to quantify improvements and predict the best locations for sectionalizing devices for reliability improvements. Adding numbers of re-closer at optimal locations can reduce SAIFI, SAIDI but it should be economically viable. The location and installation of number of Auto-re-closer, Switches, Load Break Switches and Sectionalizes either manual or automated helps to reduce fault rate, repair time and sectioning time which directly reduces the impacts on the system when fault occurs. The Mitigation Techniques applied shall depend on the need of utility whether it wants to reduce fault rate, repair time or both or outage duration.
CHAPTER THREE: SYSTEM MODELING

3.1. Data collection scheme

As discussed in chapter two, the interruption data collection scheme is important for the quality of the analysis, the more the data, the more accurate and representative the findings and conclusions. In order to assess the performance of the distribution network of the Harar city, monthly power interruption readings for two consecutive years 2007 and 2008 E.C. were obtained from East Region EEU Harar distribution substation 3 and distilled into a spread sheet database using the Microsoft excel package from which further statistical analyses were performed.

For the complete assessment of reliability the coincident demand and connected number of customers at each Distribution Transformer (DT) is necessary. However, as is the case with most utilities, neither peak demand and coincident demand nor number of customers at each transformer are available. This is not unusual as distribution transformer loads are not monitored even with the presence of most distribution management programs. Maximum loads maybe available but, the distribution transformer supplies in EEU system in general are not metered with electronic meters and hence the operation data is not available.

The available data is the active & reactive power or Amps loading, Power factor and voltage recorded by feeder meters at the substation and the capacity of DTs. The demand recorded at the substation represents the aggregate of simultaneous demands of all transformers plus the power loss in the feeder segments. The method used here is to convert the power rating of each transformer into the active power demand of the total connected loads assuming 90% of loading of the rating considering power factor of 0.8. This enables the evaluation of the index which is the EENS more practical.

3.2. Reliability Assessment

The reliability assessment is carried out for the existing system and predictive reliability analysis for the future system with the help of MATLAB 2011b. For reliability analysis of the existing system, the reliability indices are calculated. For predictive reliability analysis of the future system, the reliability index is simulated considering new switches installed. Calculated values are obtained based upon the historical data of interruption frequency and interruption duration. The predictive analysis is carried out on 15kV distribution feeder which is fed from Harar substation III. The alternative from all the possible number and allocation of switches which gives minimum cost of non delivered energy based on cost benefit ratio shall be considered.
3.2.1. Historical Reliability Assessment
Two approaches to reliability evaluation of distribution systems are normally used, namely, historical assessment and predictive assessment [5]. Historical assessment involves the collection and analysis of distribution system outage and customer interruption data. It is essential for electric utilities to measure actual distribution system reliability performance levels and define performance indicators to assess the basic function of providing cost-effective and reliable power supply to all customer types. Historical assessment generally is described as measuring the past performance of a system by consistently logging the frequency, duration, and causes of system component failures and customer interruptions.

3.2.2. Measuring Reliability Indices
The reliability indices are the performance measurements of distribution systems. The effects of interruption on customer satisfaction is described with reliability indices such as SAIDI and SAIFI. The revenue lost by utility due to energy not served is described with CENS. For the existing Harar distribution system, from the interruption data collected all the reliability indices are calculated based on equations described in chapter two for the test system (feeder 2).

3.2.3. Cause and Reasons of interruption
Faults are not evenly distributed along lines. Not all faults are inevitable “acts of nature.” Most of them are from specific deficiencies at specific structures. On overhead circuits, most faults result from inadequate clearances, inadequate insulation, old equipment, or from trees or branches falling onto a line. A first step in eliminating faults is to identify what is causing them. Keeping in mind that most faults result from specific structural deficiencies, field identification of fault sources is a key part of construction-improvement programs. Field personnel can be trained to spot pole structures where faults have occurred or might likely occur. Common structural deficiencies include poor jumper clearances; old equipment (such as expulsion arresters); bushings or other equipment unprotected against animals, ground leads or grounded guys near phase conductors; poor clearances with polymer arresters; damaged insulators; damaged covered wire; and dangerous trees or branches present. When attempting to improve reliability, it is important to know the greatest contributing factors to these indices. However, predictive root cause analysis is different than historical root cause analysis which typically identifies the physical cause of faults where predictive root cause analysis computes each components contribution to reliability indices.

3.2.4. Predictive Reliability Analysis
Reliability predictions are one of the most common forms of reliability analysis. Reliability predictions predict the failure rate of components and overall system reliability. These predictions are used to evaluate design feasibility, compare design alternatives, identify potential failure areas,
trade-off system design factors, and track reliability improvement. Reliability Prediction has many roles in the reliability engineering process. The impact of proposed design changes on reliability is determined by comparing the reliability predictions of the existing and proposed designs.

The ability of the design to maintain an acceptable reliability level under environmental extremes can be assessed through reliability predictions. Predictions can be used to evaluate the need for environmental control systems. Predictive reliability assessment, combines historical component outage data and mathematical models to estimate the performance of designated configurations. Predictive techniques therefore rely on two basic types of data to compute service reliability, these are the component reliability parameters and network physical configurations. This is discussed in the previous chapter.

The reliability data for the components in the system starting from the source to the load point for the test system (feeder 2) is shown in table 3.1. The failure rate data for the segments is proportional to their length [45]. The components which are taken to be a part in the analysis are evaluated according to the minimal cut set theory or series systems. These component are the feeder lines(segments) and the secondary distribution transformers. Table 3.1 also shows total load connected at each load point, and length of the segments to each load point. Repair and restoration time are taken as 6hrs and 1hr respectively.

Taking the failure rate, repair time, restoration time of the components (lines, transformers) and the physical configuration of the system as inputs to the program, predictive reliability assessment is done.
### Table 3.1 Load and Reliability data of the Test System

<table>
<thead>
<tr>
<th>No.</th>
<th>Load [KW]</th>
<th>Data</th>
<th>Segment length[m]+trafo</th>
<th>Failure rate of the seg and transformer</th>
<th>Total Failure Rate[λ/yr]</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>72</td>
<td>3300</td>
<td>+ transformer 1</td>
<td>4.92, 0.14</td>
<td>5.06</td>
<td></td>
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<td>2</td>
<td>72</td>
<td>3325</td>
<td>+ transformer 2</td>
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<td>5.10</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>144</td>
<td>3950</td>
<td>+ transformer 3</td>
<td>5.89, 0.14</td>
<td>6.03</td>
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<td>72</td>
<td>4300</td>
<td>+ transformer 4</td>
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<td>6.65</td>
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</tr>
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<td>5</td>
<td>226.8</td>
<td>5350</td>
<td>+ transformer 5</td>
<td>7.98, 0.14</td>
<td>8.12</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>144</td>
<td>5600</td>
<td>+ transformer 6</td>
<td>8.36, 0.14</td>
<td>8.50</td>
<td></td>
</tr>
<tr>
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<td>144</td>
<td>5100</td>
<td>+ transformer 7</td>
<td>7.61, 0.14</td>
<td>7.75</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>144</td>
<td>5650</td>
<td>+ transformer 8</td>
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<td>8.57</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>144</td>
<td>5150</td>
<td>+ transformer 9</td>
<td>7.68, 0.14</td>
<td>7.82</td>
<td></td>
</tr>
<tr>
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<td>36</td>
<td>4600</td>
<td>+ transformer 10</td>
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<td>7.00</td>
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<td>144</td>
<td>4800</td>
<td>+ transformer 11</td>
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</tr>
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<td>12</td>
<td>226.8</td>
<td>4200</td>
<td>+ transformer 12</td>
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<td>72</td>
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<td>226.8</td>
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<td>+ transformer 14</td>
<td>7.53, 0.14</td>
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<td>6150</td>
<td>+ transformer 16</td>
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<td>9.32</td>
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<tr>
<td>17</td>
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<td>5400</td>
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<td>5550</td>
<td>+ transformer 20</td>
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</tr>
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<td>+ transformer 21</td>
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<td></td>
</tr>
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<td>7.68, 0.14</td>
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<td></td>
</tr>
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<td>5700</td>
<td>+ transformer 23</td>
<td>8.50, 0.14</td>
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<tr>
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<td>+ transformer 25</td>
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<tr>
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<tr>
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<td>6550</td>
<td>+ transformer 40</td>
<td>9.77, 0.14</td>
<td>9.91</td>
<td></td>
</tr>
</tbody>
</table>

The Total Failure Rate is according to Modelling of Series System (Equation 2.4)
CHAPTER FOUR: RELIABILITY IMPROVEMENT WITH OPTIMAL SWITCH PLACEMENT

4.1. Introduction

Distribution system reliability has proved to be of great concern in the present days of power system operation. With the deregulation of power system and enhanced competitive environment, the demand for uninterrupted quality power has increased. As distribution system has the greatest contribution to the interruption of supply to a consumer [1]; hence, improving distribution system reliability is of serious concern in today’s power market. The enhancement of reliability always incurs a cost as it involves some additional preventive and corrective measures. So, the reliability improvement methods need to be adopted keeping in view the cost involved in the process. Failure rate, repair time and restoration time are some important parameters of defining reliability. Reducing the values of one or more of the above parameters can improve reliability considerably. Several approaches can be adopted to improve reliability, out of which, the optimal placement of sectionalize switch in the radial distribution network. Sectionalizers are devices, which can isolate or connect a section of a network. Suitable locations of sectionalize switch in a network may reduce the time to resume power and thus improve reliability. Placing one sectionalizer switch at each segment of a network definitely improves reliability greatly, but at the same time it may incur a high installation and maintenance cost, as the number of switches required is large. Hence, a compromise is required, and here lies the importance of optimal allocation of sectionalize switch.

4.2. Sectionalize Switches in radial distribution network and reliability indices

In radial network, sectionalize switches use to isolate a faulty section from the rest of the network. The location of the switch can contribute to enhance the reliability of a network to a great extent. The basic reliability indices commonly used are failure rate, repair time, restoration time and outage duration. Failure rate denotes the frequency of occurrence of failure. Repair time represents the time required to repair a faulty section after a fault occurs. Restoration time represents the time required to restore service after an interruption occurs. Outage duration represents the annual duration of outage and is given either by the product of failure rate and repair time or by the product of failure rate and restoration time, as applicable. While sectionalize switches does not affect the failure rate, however, it can have a considerable impact on the outage duration. Optimal placement of sectionalizers can reduce the outage duration to a considerable extent, thus improve the reliability. If there is a fault, located at downstream to the load point, and if there is no switch in between the fault and the load point of consideration, time to restore power to the load point will be equal to the time needed to repair the fault i.e. repair time. On the other hand, if there is a switch in between the load point of consideration and fault location (downstream to the load point) it can reduce this time to the
operating time of the switch i.e. restoration time, as the opening of switch will isolate the faulty segment from the healthy portion and power can be restored to the healthy portion. As these indices do not take into account the number of customers and load connected, the severity of the fault is not revealed by these indices. To get a clear picture of the severity of the fault, customer oriented indices are derived from the basic indices. Among several customer oriented indices, expected energy not supplied (EENS) is the index of concern in this work which is given by

\[ EENS = \sum L_j U_j \]  \hspace{1cm} (4.1)

where

\[ U_j = \sum_{i_0=1}^{n_{j0}} \lambda_{i_0} \text{rep}_{i_0} + \sum_{i_1=1}^{n_{j1}} \lambda_{i_1} \text{res}_{i_1} \]  \hspace{1cm} (4.2)

\( \lambda_{i0} \) and \( \text{rep}_{i0} \) denote the failure rate and repair time of \( i^{th} \) distributor segment, and \( n_{j0} \) denotes the total numbers of segments where the fault has occurred and power can be resumed to the \( j^{th} \) load point only after repairing of those faults. \( \lambda_{i1} \) and \( \text{res}_{i1} \) denote the failure rate and switching time or restoration time of \( i^{th} \) distributor segment, and \( n_{j1} \) denotes the total numbers of segments where the fault has occurred and power can be restored to the \( j^{th} \) load point through switching operation before repairing of those faults. \( U_j \) denote the annual outage duration for \( j^{th} \) load point. \( L_j \) is the average load connected at \( j^{th} \) load point.

### 4.3. Logic for Energy Interruption Duration Calculation of a Given Load Point

Distribution segments are branches of a distribution network. The failure rate (\( \lambda \)), repair time (\( \text{rep} \)) and restoration time (\( \text{res} \)) of distribution segments affect the reliability of load points. A load point experiences interruption of power for a failure in any segment if either:

- a) The segment is in the path between the source and the load or
- b) The segment is not in the path between the source and the load but there is no fuse in between the segment and the load point.

After a failure occurred in such a distribution segment, the time to resume power to the load point may be repair time or restoration time. This can be selected using following conditions:

- a. If the segment is in the path between the source and the load, time to resume power will be repair time.
- b. If the segment is not in the path between the source and the load and there is no sectionalizing switch in between the segment and the load point, time to resume power will be repair time.
c. If, the segment is not in the path between the source and the load and there is at least one sectionalizing switch in between the segment and the load point, time to resume power will be restoration time i.e. switching time.

EENS of a particular load point is obtained by the multiplication of annual outage duration and load of that load point. The annual outage duration is obtained by the multiplication of failure rate and time to resume power (either repair time or restoration time, as applicable), as presented in (4.2).

Hence, the failure rate and repair time/restoration time of distribution segments have a direct impact on the EENS of a load point. With the increase of the failure rate and repair time/restoration time, EENS also increases

4.4. Problem Formulation

In this research work, the objective is to obtain the optimum number and location of sectionalize switch in radial distribution system. Increasing the number of switches may reduce the EENS but at the same time, it may increase the cost involved. A multi-objective formulation is developed with a view to reduce the EENS cost without excessive increase in the switch cost. Here, the target is to find a compromised solution such as to improve the reliability (by reducing equivalent cost of EENS) without excessive increase in the sectionalize switch cost.

The objective function to reduce EENS is

$$ objf_1 = \sum_{j=1}^{n} EENS_j * C_1 * CPV_1 \quad (4.3) $$

where EENS\textsubscript{j} corresponds to the EENS of jth load point, n corresponds to the total number of load points, C\textsubscript{1} stands for per unit cost of EENS (Birr/Kwh) and CPV\textsubscript{1} is the cumulative present value (CPV) of EENS cost. The CPV method converts all costs and benefits of a plan during the lifecycle to the first year of operation and thus helps to evaluate the total costs and benefits during the economic lifecycle of the equipments [43].

CPV\textsubscript{1} is calculated as follows:

$$ CPV_1 = \frac{1- (PV_1)^{EL}}{1-PV_1} \quad (4.4) $$

where

$$ PV_1 = \frac{(1+I_{inf})(1+LG)}{(1+I_{int})} \quad (4.5) $$

EL is the economic lifetime of the equipments, I\textsubscript{inf} is the inflation rate, I\textsubscript{int} is the interest rate and LG is the load growth rate.

The objective function to reduce the switch cost is

$$ objf_2 = (n_{sw} * C_i) + (C_m * CPV_2) \quad (4.6) $$
where \( n_{sw} \) denotes the total number of switches present in the system.

\[ C_i \] stands for switch and installation cost and \( C_m \) stands for the maintenance cost of each switch. \( CPV_2 \) is the cumulative present value (CPV) of maintenance cost of switch cost which is expressed as follows:

\[
CPV_2 = \frac{1-(PV_2)^{EL}}{1-PV_2}
\]

(4.7)

where

\[
PV_2 = \frac{(1+I_{int})}{(1+I_{inf})}
\]

(4.8)

Therefore, the overall objective function to represent multi objective formulation is expressed as:

\[
objf = w \cdot objf_1 + (1-w) \cdot Objf_2
\]

(4.9)

where, \( w \) is the weight age value assigned to a single objective, in order to find the Pareto Optimal solution. Here both the number of switches and position of switches have been considered as variable while minimizing the objective function.

### 4.5. Algorithm for switch allocation

#### 4.5.1. Solution Methodology Using Dynamic Search Algorithm (DSA).

DSA is a nature inspired meta-heuristic optimization algorithm developed by Civicioglu [44], and it is described for multimodal optimization solution. The concept behind its development is the seasonal migration of different species of nature for the search of fruitful living. This means discovering better stopover sites during the movement of organisms. In this algorithm, the individual search organisms together form a bigger population known as superorganisms. The superorganism move towards the target of donors inorder to discover stopover sites. The donors are assumed to be in fertile area. During their movement for discovery, superorganism checks whether some randomly chosen locations meet their transitory area or not. If any location is appropriate for their lays over temporarily during the journey, the individuals of the superorganism \( (x_{superorganism}) \) that revealed the stopover, right away settle in that location and carry on their journey from that location. The discovery of stopover sites \( (x_{stopover}) \) is determined using equation (4.10)

\[
x_{stopover} = x_{superorganism} + Scale(x_{donor} - x_{superorganism})
\]

(4.10)

The successful migration of the superorganism depends on the mechanism of stopover site discovery. The scale factor is estimated using gamma random function (randg) for each generation as shown in equation(4.11). Donors are made up of reshuffling individuals of superorganism as shown in equation(4.12).
Scale = randg[2.rand], (rand − rand)] \tag{4.11}

\[ x_{\text{donor}} = (x_{\text{superorganism}}) \text{random\_shuff}e \tag{4.12} \]

It is worth to mention that some randomly selected participants involve in the search of stopover site discovery and they are considered to discover global minima point of the problem.

In DSA, exploration and exploitation concepts are used simultaneously to escape local minima stagnation and to narrow down the search space for actual optimal solution, respectively. This algorithm has only two control parameters and both of them are stochastic variables. Both parameters are used to randomize the selection process of search participants. As they don't have any direct influence over organism's movement, the initial selection of them does not affect the solution at all. Moreover, the convergence rate is very swift due to minimal factors to be considered during migration. In addition DSA has no inclination to global best, personal best solution. Therefore noisy-stagnation for over-acceleration or under acceleration is easily avoided. All these unique specialities are recommended to solve complex multimodal optimization problems.

\subsection{4.5.2. Particle Swarm Optimization (PSO)}

There are two versions of the basic PSO algorithm, the Continuous/real-valued Particle Swarm Optimization (PSO) version and Discrete Binary Particle Swarm Optimization (BPSO). A short description of both versions is presented below.

\subsubsection{4.5.2.1. Real-valued particle swarm optimization}

Assume that our search space is \( d \)-dimensional, and the \( i^{\text{th}} \) particle of the swarm can be represented by a \( d \)-dimensional position vector \( X_i = (X_{i1}, X_{i2}, X_{i3}, \ldots, X_{id}) \). The velocity of the particle is denoted by \( V_i = (V_{i1}, V_{i2}, V_{i3}, \ldots, V_{id}) \). Also consider best visited position for the particle is \( P_{i\text{,best}} = (P_{i1}, P_{i2}, P_{i3}, \ldots, P_{id}) \) and also the best position explored so far is \( P_{g\text{,best}} = (P_{g1}, P_{g2}, P_{g3}, \ldots, P_{gd}) \). So the position of the particle and its velocity is being updated using following equations:

\[
V_i(t + 1) = wV_i(t) + c_1r_1(P_{i\text{,best}} - X_i) + c_2r_2(P_{g\text{,best}} - X_i) \tag{4.13}
\]

\[
X_i(t + 1) = X_i(t) + V_i(t + 1) \tag{4.14}
\]

Where \( c_1 \) and \( c_2 \) are positive acceleration constants, \( r_1 \) and \( r_2 \) are random variables with uniform distribution between 0 and 1. In this equation, \( w \) is the inertia weight which shows the effect of previous velocity vector on the new vector. An upper bound is placed on the velocity in all dimensions \( V_{i\text{,max}} \). This limitation prevents the particle from moving too rapidly from one region in search space to another. This value is usually initialized as a function of the range of the problem. \( P_{i\text{,best}} \) for each particle is updated in each iteration when a better position for the particle or for the
whole swarm is obtained. The feature that drives PSO is social interaction. Individuals (particles) within the swarm learn from each other, and based on the knowledge obtained then move to become similar to their "better" previously obtained position and also to their "better" neighbours. Individual within a neighbourhood communicate with one other. Based on the communication of a particle within the swarm different neighbourhood topologies are defined. One of these topologies which is considered here, is the star topology. In this topology each particle can communicate with every other individual, forming a fully connected social network. In this case each particle is attracted toward the best particle (best problem solution) found by any member of the entire swarm. Each particle therefore imitates the overall best particle. So the $P_{gbest}$ updated when a new best position within the whole swarm is found.

4.5.2.2. PSO Algorithm Parameters
There are some parameters in PSO algorithm that may affect its performance. For any given optimization problem, some of these parameter’s values and choices have large impact on the efficiency of the PSO method, and other parameters have small or no effect. The basic PSO parameters are swarm size or number of particles, number of iterations, velocity components, and acceleration coefficients illustrated bellow.

4.5.2.2.1. Swarm size
Swarm size or population size is the number of particles $n$ in the swarm. A big swarm generates larger parts of the search space to be covered per iteration. A large number of particles may reduce the number of iterations need to obtain a good optimization result. In contrast, huge amounts of particles increase the computational complexity per iteration, and more time consuming.

4.5.2.2.2. Iteration numbers
The number of iterations to obtain a good result is also problem-dependent. A too low number of iterations may stop the search process prematurely, while too large iterations has the consequence of unnecessary added computational complexity and more time needed.

4.5.2.2.3. Velocity Components
The velocity components are very important for updating particle’s velocity. There are three terms of the particle’s velocity.

1. The term $wV_{i(t)}$ is called inertia component that provides a memory of the previous flight direction that means movement in the immediate past. This component represents as a momentum which prevents to drastically change the direction of the particles and to bias towards the current direction.

2. The term $c1r1(P_{ibest} − X_i)$ is called cognitive component which measures the performance of the particles relative to past performances. This component looks like an individual memory of the
position that was the best for the particle. The effect of the cognitive component represents the tendency of individuals to return to positions that satisfied them most in the past.

3. The term \( c_2 r_2 (P_{\text{gbest}} - X_i) \) is called social component which measures the performance of the particles relative to a group of particles or neighbours. The social component’s effect is that each particle flies towards the best position found by the swarm.

4.5.2.2.4. Acceleration coefficients particle’s neighbourhood
The acceleration coefficients \( c_1 \) and \( c_2 \), together with the random values \( r_1 \) and \( r_2 \), maintain the stochastic influence of the cognitive and social components of the particle’s velocity respectively. The constant \( c_1 \) expresses how much confidence a particle has in itself, while \( c_2 \) expresses how much confidence a particle has in its neighbours.

- When \( c_1 = c_2 \), all particles are attracted towards the average of \( P_{\text{ibest}} \) and \( P_{\text{gbest}} \).
- When \( c_1 \gg c_2 \), each particle is more strongly influenced by its personal best position, resulting in excessive wandering.
- When \( c_1 \ll c_2 \), then all particles are much more influenced by the global best position, which causes all particles to run prematurely to the optima.

Normally, \( c_1 \) and \( c_2 \) are static, with their optimized values being found empirically. Wrong initialization of \( c_1 \) and \( c_2 \) may result in divergent or cyclic behaviour. From the different empirical researches, it has been proposed that the two acceleration constants should be \( c_1 = c_2 = 2 \).

4.5.2.2.5. Inertia Weight
The inertia weight governs how much of the previous velocity should be retained from the previous time step. The best performance, however, was obtained by using an inertia weight that decreases from 0.9 to 0.2 during the first course of a simulation [46]. This setting allows the PSO to explore a large area at the start of the simulation, when the inertia weight is large, and to refine the search later by using a smaller inertia weight. In addition, damping the oscillations of the particles around \( g_{\text{best}} \) is another advantage gained by using a decreasing inertia weight. These oscillations are recorded when a large constant inertial weight is used. Accordingly, damping such oscillations assists the particles of the swarm to converge to the global optimal solution.

4.5.3. Binary particle swarm optimization
Kennedy and Eberhart proposed a discrete binary version of PSO for binary problems. In their model a particle will decide on "yes" or "no", "true" or "false", "include" or "not to include" etc. also this binary values can be a representation of a real value in binary search space. In the binary PSO, the particle's personal best and global best is updated as in real-valued version. The major difference
between binary PSO with real-valued version is that velocities of the particles are rather defined in terms of probabilities that a bit will change to one.

Using this definition a velocity must be restricted within the range [0, 1]. So a map is introduced to map all real valued numbers of velocity to the range [0, 1] [47]. The normalization function used here is a sigmoid function as:

$$V'_{ij}(t) = \text{sig}(V_{ij}(t)) = \frac{1}{1+e^{-V_{ij}(t)}} \quad (4.15)$$

Also the equation (4.13) is used to update the velocity vector of the particle. And the new position of the particle is obtained using the equation below:

$$X_{ij}(t+1) = \begin{cases} 1 & \text{if, } r_{ij} < \text{sig}(v_{ij}(t + 1)) \\ 0 & \text{otherwise} \end{cases} \quad (4.16)$$

where, 

$rij$ is a uniform random number in the range [0,1].

\[4.5.3.1. \text{Application of BPSO to solve the Switch allocation Problem}\]

The complete computational flow of the binary PSO algorithm for optimal placement of sectionalize switches is given in the following steps.

Step 1: Initialization
1. Read input data (reliability data) of the distribution system
2. Generate $n$ particles randomly which have an element equal to number of switches,
   $$\text{pop}^t = [X_1^t, X_2^t, X_3^t, ..., X_{NP}^t], \quad (4.17)$$
   $X_{NP}$ shows the existence of the switch (0 or 1) in the section (NP).
3. Generate the initial velocities of all particles randomly.
4. Evaluate each particle in the swarm using the objective function.
5. For each particle $i$ in the swarm, set $P_{best_i}^0 = X_i^0$ along with its best fitness value.
6. Set the global best
   $$f_{gbest}^0 = \min(P_{best_i}^0) \quad (4.18)$$

Step 2: Update iteration counter
   $$t = t + 1 \quad (4.19)$$

Step 3: Update velocity by using equation (4.13)
Step 4: Update dimension (position) by using the sigmoid function, equation (4.15)
Step 5: Update particles best.

Each particle is evaluated again with respect to its updated position to see if particle best will change,

if

$$f_i^t(X_i^t, i = 1,2,3, ... , n) < f_i^{P_{best}}(PB_{i}^{-1}, i = 1,2,3, ... , n) \quad (4.20)$$

then
\[
f^\text{Pbest}_i(PB^t_i, i = 1, 2, 3, \ldots, n) = f^t(X^t_i, i = 1, 2, 3, \ldots, n)
\] (4.21)

\[
f^\text{Pbest}_i(PB^t_i, i = 1, 2, 3, \ldots, n) = f^\text{Pbest}_i(PB^{t-1}_i, i = 1, 2, 3, \ldots, n)
\] (4.22)

Step 6: Update global best
\[
f^\text{gbest}(G^t) = \min (f^\text{Pbest}_i(PB^t_i, i = 1, 2, 3, \ldots, n))
\] (4.23)

If
\[
f^\text{gbest}(G^t) < f^\text{gbest}(G^{t-1})
\] (4.24)

then
\[
f^\text{gbest}(G^t) = f^\text{gbest}(G^{t-1})
\] (4.25)

else
\[
f^\text{gbest}(G^t) = f^\text{gbest}(G^{t-1})
\]

Step 7: Stopping Criterion
If there is no significance improvement in the evaluation of the objective function stop otherwise go to step 2.

According to the proposed algorithms the program is written using matlab codes for the multiobjective optimization problem. The code for both methods is given in Appendix B1 and B2.
CHAPTER FIVE: RESULT AND DISCUSSION

5.1. Historical Reliability Assessment of the Existing System

Harar distribution substation has six outgoing feeders excluding the new 33kV distribution line for Harar water production from a nearby rural area called Erer. The monthly interruption frequency and interruption duration is shown in Appendix A1 and A2. The interruption data is recorded when the outgoing circuit breaker is open meaning when all customers connected to the feeder are out of power. Interruptions at each load point or at each customer level are not included, the reason is there are no any customer or load point interruption data recorded. Frequency and duration of interruption for the two consecutive years (2007 EC and 2008 EC) for all the feeders are shown in the following figures.

![Figure 5.1 Frequency of Interruption for all outgoing feeders of the Substation (2007 E.C)](image)

![Figure 5.2 Duration of Interruption of all outgoing feeders of the Substation (2007 E.C)](image)
From figure (5.1 and 5.2) above, the average power outage frequency and duration of feeders in 2007 are 250 and 488 hours per year respectively.

![Figure 5.3 Frequency of Interruption for all the outgoing feeders of the Substation (2008 E.C)](image)

**Figure 5.3 Frequency of Interruption for all the outgoing feeders of the Substation (2008 E.C)**

![Figure 5.4 Duration of Interruption for all the outgoing feeders of the Substation (2008 E.C)](image)

**Figure 5.4 Duration of Interruption for all the outgoing feeders of the Substation (2008 E.C)**

From figures (5.3 and 5.4) above, the average power outage frequency and duration in 2008 are 352 and 714 hours per year respectively.
5.2. Causes and Reasons of Interruptions

There is no record of cause of interruption. The data available is only with the reason of interruption. The reasons for power interruption are five in number. They are planned Interruption(PI), Temporary Short Circuit(TSC), Permanent Short Circuit(PSC), Temporary Earth Fault (TEF) and Permanent Earth Fault(PEF). Duration and frequency of interruption for all the five types are compared for each considered year and are shown in the charts given below.

![Figure 5.5 Interruption Reasons and their percentage Frequency (2007 E.C)](image)

From the figures it may be seen that more than 29% of the interruptions are due to maintenance, this can be reduced by optimal placement of sectionalizing switches and protective devices along with scheduled maintenance.

![Figure 5.6 Interruption Reasons and their percentage Frequency (2008 E.C)](image)
5.3. The Test System

5.3.1. Description of the Test System

A 40 load point radial 15KV overhead distribution line is considered as the test system. The feeder consists of 62 segments and contains a circuit breaker before segment number 1. The sectionalizing switch are considered to be allocated at the beginning of any distribution segment. The network topology of the test system is shown in figure 5.1 below.

![Figure 5.7 Topology of the Test system](image)

5.3.2. Reliability Indices of the Test System

The reliability of a power system is affected highly by population of connected (urban and rural)customers and the nature and type of customers. The selected feeder feeds the urban area. Based on the feeder wise recorded data the reliability indices of the feeder for the two considered years are calculated and summarized in table 5.1. The estimated number of customers is 7000. The
calculation is done using equations (2.10),(2.11),(2.12),(2.13),(2.14) and (2.17) for SAIFI, SAIDI, CAIDI, CAIFI, ASAI and EENS respectively.

**Table 5.1 Reliability Indices of the test system (feeder 2) of the Substation**

<table>
<thead>
<tr>
<th>No.</th>
<th>Reliability Indices</th>
<th>2007(E.C)</th>
<th>2008(E.C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SAIDI [Hrs/yr]</td>
<td>402</td>
<td>409</td>
</tr>
<tr>
<td>2</td>
<td>CAIDI [Hrs/cust/yr]</td>
<td>33.5</td>
<td>34.1</td>
</tr>
<tr>
<td>3</td>
<td>SAIFI[int/yr]</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>CAIFI[int/cust/yr]</td>
<td>0.0047</td>
<td>0.0057</td>
</tr>
<tr>
<td>5</td>
<td>ASAI(%)</td>
<td>95.41</td>
<td>95.33</td>
</tr>
<tr>
<td>6</td>
<td>EENS[MWhr]</td>
<td>2,108.57</td>
<td>2,145.29</td>
</tr>
</tbody>
</table>

The reliability indices calculated in table 5.1 are compared with the reliability performance of the USA and some countries of Europe and found to be very poor. The reliability performance for SAIDI and SAIFI of the USA and some European countries of the year 2007 G.C are listed in table 5.2.

**Table 5.2 International Reliability Performance**

<table>
<thead>
<tr>
<th>Country</th>
<th>SAIDI[min/yr]</th>
<th>SAIFI[int/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>240</td>
<td>1.5</td>
</tr>
<tr>
<td>Austria</td>
<td>72</td>
<td>0.9</td>
</tr>
<tr>
<td>Denmark</td>
<td>24</td>
<td>0.5</td>
</tr>
<tr>
<td>France</td>
<td>62</td>
<td>1.0</td>
</tr>
<tr>
<td>Germany</td>
<td>23</td>
<td>0.5</td>
</tr>
<tr>
<td>Italy</td>
<td>58</td>
<td>2.2</td>
</tr>
<tr>
<td>Netherlands</td>
<td>33</td>
<td>0.3</td>
</tr>
<tr>
<td>Spain</td>
<td>104</td>
<td>2.2</td>
</tr>
</tbody>
</table>

5.4. Predictive Reliability Assessment

The complete program for calculating the cost of expected energy not supplied(CENS) and the total cost of the new installation of switches with their optimal location has been developed using the failure mode analysis technique. The BDSA algorithms is implemented on the test system and its performance is compared with BPSO for verifying its feasibility for solving optimization problems of distribution system reliability. The algorithm is coded in MATLAB software 2011b on a processor of specification Intel (R) Core (TM) i5-3235M CPU 2.60GHz with 8GB RAM.
Given the failure rate of the equipments which appear between the source and a load point the program calculates the minimal of the two costs. The program also takes the repair time and restoration time as the other two inputs. As for a load point data the active power consumption at the secondary of the transformer is taken as the total connected load to that transformer.

Assuming that,
- Radial configuration of the system
- the statistical independence of all failures
- Failures are cleared before the occurrence of the next fault.

5.4.1. System Simulation

5.4.1.1. Parameters for the MATLAB Code

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Number of parameters</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>100</td>
<td>Number of Super organism</td>
</tr>
<tr>
<td>G</td>
<td>100</td>
<td>Maximum Iteration</td>
</tr>
<tr>
<td>Number of organisms</td>
<td>63</td>
<td>Dimension of the problem</td>
</tr>
<tr>
<td>c1=c2</td>
<td>0.3</td>
<td>Control parameters</td>
</tr>
<tr>
<td>w</td>
<td>0.5</td>
<td>Inertia weight</td>
</tr>
</tbody>
</table>

5.4.1.2. Parameters for the MATLAB Code

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Number of Parameters</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>100</td>
<td>Number of population</td>
</tr>
<tr>
<td>G</td>
<td>100</td>
<td>Maximum iteration</td>
</tr>
<tr>
<td>Number of particles(D)</td>
<td>63</td>
<td>Dimension of the problem</td>
</tr>
<tr>
<td>c1=c2</td>
<td>0.3</td>
<td>Control parameters</td>
</tr>
<tr>
<td>w</td>
<td>0.5</td>
<td>Inertia weight</td>
</tr>
</tbody>
</table>

The switches used in the proposed techniques are all pole top gang operated, at a cost of 11,438.71Birr/switch. The switch cost includes the installation cost, the annual maintenance cost is assumed to be 2% of the annual investment cost and interest rate is 5%. The life of the switch is assumed to be 20 years. The load growth and inflation rate are taken as 12.7% and 9.4%. The per KW cost is 0.4709 birr/hr

The number of switches and the locations were determined using the BDSA and BPSO optimization technique and the results are presented below. The algorithms were applied on the test system considering three cases.
Case 1: No sectionalizer switches are allocated, when switch cost is zero.

Case 2: Allocation of 62 sectionalizer in the distribution feeder, when cost of switch is maximum.

Case 3: Allocation of optimal number of sectionalizer switch in the test system, when the cost of the switch and cost of energy not served are at their optimum. The different costs for each case for both the optimization techniques are shown in the following tables (The comparison also includes the simulation time). The results for the simulation is summarized in table 5.5, 5.6 and 5.7 for the case 1, case 2 and case 3 respectively.

### 5.5. Simulation Result

#### Case 1

**Table 5.5 Best Results for Switch cost minimization obtained using both algorithms**

<table>
<thead>
<tr>
<th>Methods</th>
<th>Variables</th>
<th>Objective Functions</th>
<th>Total Cost(Birr)</th>
<th>Simulation Time(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of Switches</td>
<td>Switch Position</td>
<td>Switch Cost</td>
<td>EENS Cost(birr)</td>
</tr>
<tr>
<td>BDSA</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>6.5861*10^7</td>
</tr>
<tr>
<td>BPSO</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>6.5861*10^7</td>
</tr>
</tbody>
</table>

In the first case (case 1), the switch cost is zero as no switch is installed in the network. The only cost is the revenue lost (cost of EENS) by the utility which is the same for both the methods applied and is equal to 6.5861*10^7 birr. But the computing efficiency of the BDSA is better than the BPSO.

#### Case 2

**Table 5.6 Best Results for EENS cost minimization obtained using both algorithms**

<table>
<thead>
<tr>
<th>Methods</th>
<th>Variables</th>
<th>Objective Functions</th>
<th>Total Cost</th>
<th>Simulation Time(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of Switches</td>
<td>Switch Position</td>
<td>Switch Cost</td>
<td>EENS Cost(birr)</td>
</tr>
<tr>
<td>BDSA</td>
<td>62</td>
<td>1-62</td>
<td>1.1025*10^6</td>
<td>2.7798*10^7</td>
</tr>
<tr>
<td>BPSO</td>
<td>62</td>
<td>1-62</td>
<td>1.1025*10^6</td>
<td>2.7798*10^7</td>
</tr>
</tbody>
</table>

When switch installed in every segment (case 2) of the distribution lines (maximum possible number of switch) the revenue lost by the utility is at its minimum. But the cost incurred will be maximum. The total cost for both is the same, as shown in table 5.6. But the computational efficiency of BDSA is better than that of the BPSO, as the time it takes for simulation for BDSA is shorter than for the BPSO.

#### Case 3

Table 5.7 shows the optimized result for the cost of EENS and cost of the switches for both the methods. The BDSA has better minimized multi-objective optimization property. The optimized cost of EENS has a reduction in 2.6572*10^7 birr compared with case 1. But the cost incurred due to the...
switches is 441,960 birr for the 25 switches installed optimally on the segments listed on the table. Figure 5.8, Shows the optimized location of the switches.

**Table 5.7 Best Results for multi-objective problem obtained using both algorithms**

<table>
<thead>
<tr>
<th>Method</th>
<th>Variables</th>
<th>Objective Functions</th>
<th>Total Cost</th>
<th>Simulation Time(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BDSA</td>
<td>25</td>
<td>5.6,13,15,21,23,24,25,29,30,33,34,36,37,39,42,43,45-47,51,54,55,59,62</td>
<td>4.4196*10⁵</td>
<td>3.9289*10⁷</td>
</tr>
<tr>
<td>BPSO</td>
<td>32</td>
<td>6-8, 12,13,15-17,19,21,25-27,29,31,32,36,39,40,42,45,48,50,51,53,55,57,58,60-62</td>
<td>5.6571*10⁵</td>
<td>4.5638*10⁷</td>
</tr>
</tbody>
</table>

The convergence iteration is 41 and 58 for BDSA and BPSO respectively.

***Bold signifies the best results in terms of quality of solution and computational efficiency.***
6.1. Conclusion

In this thesis both the historical and predictive reliability analysis of the test system is carried out. The most common reliability indices, which include SAIDI, SAIFI, EENS, and ASAI, are used to measure the performance of the distribution system. The results obtained for the historical analysis of the study area for the years 2007 and 2008 E.C showed that the system reliability indices of the study area indicate poor performance, related to other countries.

The reliability improvement techniques suggested as predictive reliability can minimize the power outage frequency and duration. This improvement has a great impact socially and economically both for the utility and the consumers.

Predictive reliability analysis, considering placement of sectionalize switches is carried out for a selected distribution feeder to investigate the reliability improvement of the test system. Failure mode and effect analysis is used for radial distribution system reliability evaluation. Optimal switches arrangement in the network provides a reduction in undelivered energy to consumers, and costs associated with expected energy not served.

This thesis is about the methods of reliability improvement of distribution networks. The BDSA and BPSO algorithms are implemented to find optimum number and location of switches in a radial distribution feeder. From the results for both the optimization techniques the objective of reducing the cost of expected energy not served is achieved. The optimum number of switches to obtain the optimized CENS is 25 and 32 for BDSA and BPSO respectively. $3.973096 \times 10^7$ is the total cost for the BDSA and $4.620371 \times 10^7$ is the total costs for the BPSO, which is the cost of switch and cost of energy not served. The performance of the BDS algorithm is compared with that of the BPSO algorithm. Both single objective and multi-objective formulations are considered and multi-objective formulation proves to provide more realistic solution set, by compromising reliability improvement with the cost incurred. Analysis of all the simulation results reveal that the performance of the BDS algorithm in all aspect is better than in comparison with the BPSO. This is because DS algorithm may simultaneously use more than one individual during updating steps, and it has no inclination to correctly approach the best possible solution. Thus, BDS algorithm may be considered as an efficient tool to solve multi-objective reliability optimization problems.

6.2. Recommendations

The present data recording scheme should be changed to the standard procedures described in chapter two. The gathering of the actual data is important for the accuracy of results. All the historical data and detailed information about the equipments condition obtained from inspection, monitoring, and maintenance record should be provided by the utility. Any missing parameters that
can affect system reliability must be included in the optimization method. The failure of individual components in the system should be maintained so the probability of failure represents its true system. Its repair and restoration time should be separated since its high effect on the reliability indices during predictive reliability analysis.

For the calculation of the failure rate of the system up to the load point, it is assumed that the coordination failure rate of all overcurrent devices (fuses) is 0. So, this can be done with coordination failure rate. In future, both the BDS algorithm and the BPSO algorithm may be tried to solve much more complex reliability optimization problem, considering optimal placement of both sectionalize switches and distribution generators together for system reliability improvement.
REFERENCES


[27] Cox PW, “Self Healing Networks:Performance improvement by automated switching algorithm,” in *Proceedings of the 20th International Conference on electricity*


<table>
<thead>
<tr>
<th>Months</th>
<th>Feeder Name</th>
<th>Reason, frequency and duration of interruption (Harar Substation III/2007 E.C)</th>
<th>Total Interruption (Forced and repair)</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td>PI F D[hr]</td>
<td>TSC F D[hr]</td>
</tr>
<tr>
<td>September</td>
<td>Line 1</td>
<td>2 0.12 10 0.22 7 23 0 0 1 41.3</td>
<td>20 64.64</td>
</tr>
<tr>
<td></td>
<td>Line 2</td>
<td>4 1.30 11 0.38 19 15.66 6 0.22 0 0</td>
<td>40 17.53</td>
</tr>
<tr>
<td></td>
<td>Line 3</td>
<td>2 0.07 7 0.14 4 24.2 2 0.4 0 0</td>
<td>15 24.84</td>
</tr>
<tr>
<td></td>
<td>Line 4</td>
<td>2 0.50 2 0.04 1 14.2 0 0 0 0</td>
<td>5 14.78</td>
</tr>
<tr>
<td></td>
<td>Bedassa</td>
<td>0 0 12 0.26 11 100 2 0.04 0 0</td>
<td>25 100.55</td>
</tr>
<tr>
<td></td>
<td>Feddis 3</td>
<td>1 0.37 3 0.06 1 5.22 2 0.04 0 0</td>
<td>7 5.69</td>
</tr>
<tr>
<td></td>
<td>Line 1</td>
<td>3 5.29 7 0.14 1 1.06 4 0.8 1 10.28</td>
<td>16 17.57</td>
</tr>
<tr>
<td></td>
<td>Line 2</td>
<td>4 2.85 4 0.13 2 2.75 5 0.17 0 0</td>
<td>15 5.90</td>
</tr>
<tr>
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<td>Line 3</td>
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<td>19 8.63</td>
</tr>
<tr>
<td></td>
<td>Line 4</td>
<td>1 0.27 3 0 2 15 0 0 0 0</td>
<td>3 15.27</td>
</tr>
<tr>
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<td>22 147.96</td>
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<td>8 7.28</td>
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<td></td>
<td>Line 4</td>
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</tr>
<tr>
<td></td>
<td>Bedassa</td>
<td>1 10.1 9 0.18 1 1.09 7 0.14 3 17.24</td>
<td>21 28.78</td>
</tr>
<tr>
<td></td>
<td>Feddis 3</td>
<td>4 10.1 9 0.18 1 1.09 7 0.14 3 17.24</td>
<td>21 28.78</td>
</tr>
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<td>26 7.46</td>
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APPENDIX- B1: Matlab Code for BDSA

% put here required data
p1=0.3*rand;  % i.e.,  0.0 <= p1 <= 0.3
p2=0.3*rand;  % i.e.,  0.0 <= p2 <= 0.3

size_of_one_clan=63; % dimension of the problem
c1=0.4709; % per unit cost (Birr/Kwh)
ci=11438.71; % installation cost (Birr/Sw)
cm=228.77; % maintenance cost (Birr/Sw)
cpv1=(1+Iinf)(1+LG)/(1+Iint) and cpv1=(1-(pv)^EL)/(1-pv)
cpv2=27.275;
D=63;
N=100;
size_of_superorganism=N;
G=100;
Iinf=0.094;
Iint=0.05; % current interest rate
LG=0.127;
EL=20; % economic life time of the system

% weighing value
seg=[ 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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      1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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      0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      ...  % additional rows]

55
segment matrix
fr1=[4.4762 0.2238 0.2238 0.2611 0.4103 0.5222 0.8206 0.2238 0.2984 0.5968 0.2984 0.5968 0.9698 0.2238 0.0746 0.4476 0.8206];
fr2=[0.0746 0.3730 0.0746 0.7460 0.2984 0.0746 0.1492 0.2238 0.6714 0.0746 0.2238 0.2984 0.4476 0.8206 0.0746 0.8206 0.5968];
fr3=[0.2238 0.6714 0.1492 0.1492 0.5968 0.8952 0.0746 0.3730 0.2238 0.1343 2.4619 0.1492 0.5968 2.7603 0.0746 0.0746 0.8952];
fr4=[0.1492 0.2984 0.2984 0.4476 0.3730 0.0746 0.5968 0.3730 0.1492 0.4476 1.1937 0.14];
fr=[fr1 fr2 fr3 fr4]; %failure rate for each segment
rept1=[6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6];
rept2=[6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6];
rept=[rept1 rept2]; %repair time
rest1=[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
rest2=[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
rest=[rest1 rest2]; %restoration time
lptsec1=[72 72 144 72 226.8 144 144 144 144 36 144 226.8 72 226.8 72 36 144 72 144 144 226.8];
lptsec2=[226.8 144 226.8 72 72 144 72 72 144 72 226.8 36 72 226.8 226.8 72 144 144 144];
lpt=[lptsec1 lptsec2]; %total load at each load point considering 90% of transformer loading.
% initialize population(superorganism)==>artificial superorganism 'use the % following scripts'
% ==============================================================

56
bt1=[];
btt2=[];
w=0.5;
Artisuperorganism=ones(N,D);
for i=1:N
    for j=1:D
        Artisuperorganism(i,j)=randint(1,1,[0 1]);
    end
end
superorganism=Artisuperorganism;

% evaluate the objective function for given mydata and superorganism above
f=[]; % f=objective function initialization
for h=1:N
    organism=superorganism(h,:); % particle = switch co
    nsw =sum(organism); % no of switches
    sec=[];
    for j=1:40 % n-no of load points
        L=lpt(j); % a single load value
        sel= seg(j,:); % seg between source and load point j
        sel1=organism|sel; % selection of seg under requiring "repair"
        val1=[]; % initialize 1st sum on equation
        for m=1:63 % nj0= no of total segment
            value1= fr(m)*rept(m)*sel1(m); % terms of sum1
            val1=[val1 value1]; % collection
        end
        product1=val1; % final collection
        sum1=sum(product1,2); % add up collection
        sel2=organism;
        val2=[];
        for k=1:63 % nj1=nj0= number of segment
            value2=fr(k)*rest(k)*sel2(k); % terms of sum2
            val2=[val2 value2]; % collect terms
        end
        product2=val2; % final collection
        sum2=sum(product2,2); % add up
        u=sum1+sum2;
        secum=L*u; % secum is EENS for load j
        sec=[sec secum]; % sec is all values of EENS
    end
    elsec =sec; % all collection EENS's elsec
    jval=[]; % initialize j1
    for l=1:40 % n is total no of load point
        prd=elsec(l)*c11*cpv1; % final product
        jval=[jval prd]; % collect all product
    end
    collect=jval;
    j11=sum(collect,2); % final result of objective function1
    j22=nsw*(ci+cm*cpv2);
    objf=w*j11+(1-w)*j22;
    f=[f objf];
end
% note exact word not known just taking fx

fit_superorganism=f;

% start iteration from here for given amount of generation as:
% for e=1:10
% for k=1:G % k is generation
% tic
% BIJECTIVE DSA (B-DSA) (i.e., go-to-rnd DSA);
% philosophy: evolve the superorganism (i.e., population) towards to
"permuted-superorganism (i.e., random directions)"
 donor=superorganism(randperm(size_of_superorganism),:);

% generate active individuals
% strategy-selection of active/passive individuals
 map=zeros(size_of_superorganism,size_of_one_clan);
 if rand<rand,
   if rand<p1,
     % Random-mutation #1 strategy
     for i=1:size_of_superorganism
       map(i,:)=rand(1,size_of_one_clan) < rand;
     end
   else
     % Differential-mutation strategy
     for i=1:size_of_superorganism
       map(i,randi(size_of_one_clan))=1;
     end
   end
 else
   % Random-mutation #2 strategy
   for i=1:size_of_superorganism
     map(i,randi(size_of_one_clan,1,ceil(p2*size_of_one_clan)))=1;
   end
 end

% determine the stopoversites but first 'R'
 R=1./gamrnd(1,0.5); % pseudo-stable walk
 stopover=superorganism+(R.*map).*(donor-superorganism);

% transform real values of 'stopover' into 0 and 1 using %'sigmoid'
 for i=1:N
   for j=1:D
     stopover(i,j)=sigmf(stopover(i,j),[0.5 0]); % used function is sigmoid function.
     stopover(i,j)=stopover(i,j)<rand;
   end
 end

% Boundary checking for all individual of the superorganism and update
 for i=1:N
   for j=1:D
     if stopover(i,j)<0, if rand<rand, stopover(i,j)=1; else stopover(i,j)=0;
     end
     if stopover(i,j)>1, if rand<rand, stopover(i,j)=0; else stopover(i,j)=1;
     end
   end
 end

%==================================================================
%selection

f= []; % f= objective function initialization
for h= 1:100
    organismsto= stopover(h, :); % organism from stopoversite
    nsw = sum(organismsto); % no of switches
    sec= [];
    for j= 1:40 % n-no of load points
        L= lpt(j); % a single load value
        sel= seg(j, :); % seg between source and load point j
        sel1= organismsto | sel; % selection of seg under requiring "repair"
        val1= []; % initialize 1st sum on equation
        for m= 1:63 % nj0= no of total segment
            value1= fr(m) * rept(m) * sel1(m); % terms of sum1
            val1= [val1, value1]; % collection of terms
        end
        product1= val1; % final collection
        sum1= sum(product1, 2); % add up collection
        sel2= organismsto;
        val2= [];
        for k= 1:63 % nj1= number of segment
            value2= fr(k) * rest(k) * sel2(k); % terms of sum2
            val2= [val2, value2]; % collect terms
        end
        product2= val2; % final collection
        sum2= sum(product2, 2); % add up
        sec= sec + sum1 + sum2;
    end
    elsec = sec; % all collection EENS's elsec
    jval= [] ; % initialize j1
    for l= 1:40 % n is total no of load point
        prd= elsec(l) * c11 * cpv1; % final product
        jval= [jval, prd]; % collect all product
    end
    collect= jval;
    j1= sum(collect, 2); % final result of objective function1
    j2= nsw * (ci + cm * cpv2);
    objf= w * j1 + (1- w) * j2;
    f= [f, objf];
end
%note exact word not known just taking fx
fit_stopover= f;
ind= fit_stopover < fit_superorganism;
fit_superorganism( ind)= fit_stopover( ind);
superorganism( ind)= stopover( ind);

%=================================================================
% update results

[globalminimum, indexbest]= min( fit_superorganism);
globalminimizer= superorganism( indexbest, :)
nsw= sum( globalminimizer)
for j= 1:40 % n-no of load points
    L= lpt(j); % a single load value
    sel= seg(j, :); % seg between source and load point j
    sel1= globalminimizer | sel; % selection of seg under requiring "repair"
    val1= [] ; % initialize 1st sum on equation
    for m= 1:63 % nj0= no of total segment
        value1= fr(m) * rept(m) * sel1(m); % terms of sum1
        val1= [val1, value1]; % collection of terms
    end
    product1= val1; % final collection
    sum1= sum(product1, 2); % add up collection
sel2=globalminimizer;
val2=[];
for k=1:63 % nj1=nj0= number of segment
  value2=fr(k)*rest(k)*sel2(k); % terms of sum2
  val2=[val2 value2]; %collect terms
end
product2=val2; %final collection
sum2=sum(product2,2); %add up
u=sum1+sum2;
secesum=L*u; %secesum is EENS for load j
sec=[sec secesum]; %sec is all values of EENS
end
elsec =sec; % all collection EENS's elsec
jval=[]; % initialize j1
for l=1:40 % n is total no of load point
  prd=elsec(l)*c11*cpv1; % final product
  jval=[jval prd]; %collect all product
end
collect=jval;
j1=sum(collect,2) %final result of objective function1
j2=nsw*(ci+cm*cpv2)
toc
end
APPENDIX- B2 : Matlab Codes for BPSO

c1=0.4709; %value on the objective fun.
ci=11438.71;
cm=228.77;
cpv1=136.42;
cpv2=27.275;
D=63;
N=100;
G=100;
Iinf=0.094;
Iint=0.05;
LG=0.127;
EL=20;
c1=0.3;
c2=0.3;
vmax=4;
Gbest1=10^65;
pbest1=10^65;
velo=rand(N,D)-0.6;
one_velo=rand(N,D)-0.6;
zero_velo=rand(N,D)-0.6;
w=0.5; %weighting value

seg=[
  1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
  1 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
  1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
];
segment matrix
fr1=[4.4762 0.2238 0.2238 0.2611 0.4103 0.5222 0.8206 0.2238 0.2984 0.5968 0.2984 0.5968 0.9698 0.2238 0.0746 0.4476 0.8206];
fr2=[0.0746 0.3730 0.0746 0.7460 0.2984 0.0746 0.1492 0.2238 0.6714 0.0746 0.2238 0.2984 0.4476 0.8206 0.0746 0.8206 0.5968];
fr3=[0.2238 0.6714 0.1492 0.1492 0.5968 0.8952 0.0746 0.3730 0.2238 0.1343 2.4619 0.1492 0.5968 2.7603 0.0746 0.0746 0.8952];
fr4=[0.1492 0.2984 0.2984 0.4476 0.3730 0.0746 0.5968 0.3730 0.1492 0.4476 1.1937 0.14];
fr=[ fr1 fr2 fr3 fr4];
%failure rate for each segment
rept1=[ 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6];
rept2=[ 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6];
rept=[rept1 rept2]; %repaire time
rest1=[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
rest2=[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
rest=[rest1 rest2]; %restoration time
lptsec1=[72 72 144 72 226.8 144 144 144 36 144 226.8 72 226.8 72 36 144 72 144 144 226.8];
lptsec2= [226.8 144 226.8 72 72 144 72 144 72 144 226.8 36 72 226.8 226.8 72 144 144 144 226.8];
lpt=[lptsec1 lptsec2]; %total load at each load point considering 90% of transformer loading.
pop=randint(N,D,[1,0]); % pop is initial pop
% N= number of possible switch configuration
% D= segments
% f=objective function initialization
for h=1:N
    particle=pop(h,:); % particle = switch configuration
    nsw = sum(particle); % no of switches
    sec=[];
    for j=1:40 % n-no of load points
        L=lpt(j); % a single load value
        sel= seg(j,:); % seg between source and load point j
        sell=~particle|sel; % selection of seg under requiring "repair"
        val1=[]; % initialize 1st sum on equation
        for m=1:63 % n_j0= no of total segment
            value1= fr(m)*rept(m)*sell(m); % terms of sum1
            val1=[val1 value1]; % collection of terms
        end
        product1=val1; % final collection
        sum1=sum(product1,2); % add up collection
        sel2=particle;
        val2=[];
        for k=1:63 % n_j1=n_j0= number of segment
            value2=fr(k)*rest(k)*sel2(k); % terms of sum2
            val2=[val2 value2]; % collect terms
        end
        product2=val2; % final collection
        sum2=sum(product2,2); % add up
        u=sum1+sum2;
        secsum=L*u; % secsum is EENS for load j
        sec=[sec secsum]; % sec is all values of EENS
    end
    elsec = sec; % all collection EENS's elsec
    jval=[]; % initialize j1
    for l=1:40 % n is total no of load point
        prd=elsec(l)*c11*cpv1; % final product
        jval=[jval prd]; % collect all product
    end
    collect=jval;
    j1=sum(collect,2); % final result of objective function
    j2=nsw*(ci+cm*cpv2);
    objf=w*j1+(1-w)*j2;
    f=[f objf];
end
% note exact word not known just taking fx
fx=f;
pbest= fx;
xpbest= pop;

[gbest r]=min(fx); % global best particles
xgbest= pop(r,:); % current best configuration of switches

for iter=1:G % number of iteration can be varies
    tic
    f=[]; % f= objective function initialization
    for h=1:N % objective func evaluation starts here
        particle=xpbest(h,:); % particle = switch configuration
        nsw = sum(particle); % no of switches
        sec=[];
        for j=1:40 % n-no of load points
            L=lpt(j); % a single load value
            sel= seg(j,:); % seg between source and load point j
            ...
sell=~particle|sel; % selection of seg under requiring "repair"
val1=[]; % initialize 1st sum on equation
for m=1:63 % nj0= no of total segment
    value1= fr(m)*rept(m)*sell(m); % terms of sum1
    val1=[val1 value1]; % collection of terms
end
product1=val1; %final collection
sum1=sum(product1,2); % add up collection
sel2=particle;
val2=[];
for k=1:63 % nj1=nj0= number of segment
    value2=fr(k)*rest(k)*sel2(k); % terms of sum2
    val2=[val2 value2]; % collect terms
end
product2=val2; %final collection
sum2=sum(product2,2); % add up
u=sum1+sum2;
seccessum=L*u; % seccessum is EENS for load j
sec=[sec seccessum]; % sec is all values of EENS
end
elsec =sec; % all collection EENS's elsec
jval=[]; % initialize j1
for l=1:40 % n is total no of load point
    prd=elsec(l)*c11*cpv1; % final product
    jval=[jval prd]; % collect all product
end
collect=jval;
j1=sum(collect,2); % final result of objective function1
j2=nsw*(ci+cm*cpv2);
objf=w*j1+(1-w)*j2;
f=[f objf];
fxx=f;
if fxx(h)<pbest(h)
    pbest(h)=fxx(h); % modifiyng local best
    xpbest(h,:)=xpbest(h,:);
end
end % objective function evaluation ends here
[gb r]=min(pbest);
if gbest>gb
    gbest=gb;
xgbest=xpbest(r,:); % main result
end
swc=xgbest
nsw=sum(swc)
for j=1:40 % n-no of load points
    L=lpt(j); % a single load value
    sel= seg(j,:); % seg between source and load point j
    sell=~xgbest|sel; % selection of seg under requiring "repair"
    val1=[]; % initialize 1st sum on equation
    for m=1:63 % nj0= no of total segment
        value1= fr(m)*rept(m)*sell(m); % terms of sum1
        val1=[val1 value1]; % collection of terms
    end
    product1=val1; %final collection
    sum1=sum(product1,2); % add up collection
    sel2=xgbest;
    val2=[];
    for k=1:63 % nj1=nj0= number of segment
        value2=fr(k)*rest(k)*sel2(k); % terms of sum2
        val2=[val2 value2]; % collect terms
    end
    product2=val2; %final collection
    sum2=sum(product2,2); % add up
    u=sum1+sum2;
    seccessum=L*u; % seccessum is EENS for load j
end
sec=[sec secsum]; %sec is all values of EENS
end
elsec =sec; % all collection EENS's sec
jval=[]; % initialize j1
for l=1:40 % n is total no of load point
    prd=elsec(l)*c11*cpv1; % final product
    jval=[jval prd]; %collect all product
end
collect=jval;
 j1=sum(collect,2) %final result of objective function1
j2=nsw*(ci+cm*cpv2)

oneadd=zeros(N,D); %N-superorganisms size and D dimension matrix initializer
zeroadd=zeros(N,D);
c3=c1*rand;
d3=c2*rand;
for m=1:N %N population size
    for t=1:D
        if xpbest(m,t)==0
            oneadd(m,t)=oneadd(m,t)-c3;
            zeroadd(m,t)=zeroadd(m,t);
        else
            oneadd(m,t)=oneadd(m,t);
            zeroadd(m,t)=zeroadd(m,t)+c3;
        end
        if xgbest(t)==0
            oneadd(m,t)=oneadd(m,t)-d3;
            zeroadd(m,t)=zeroadd(m,t);
        else
            oneadd(m,t)=oneadd(m,t);
            zeroadd(m,t)=zeroadd(m,t)+d3;
        end
    end
end
%modifying the population two matrix updating the velocities
one_velo=onevelo+oneadd;
zero_velo=zero_velo+zeroadd;
for s=1:N
    for k=1:D
        if abs(velo(s,k))>vmax
            zero_velo(s,k)=vmax*sign(zero_velo(s,k));
            one_velo(s,k)=vmax*sign(one_velo(s,k));
        end
    end
end
%velocity update per each element
for z=1:N % number of population size
    for g=1:D
        if xpbest(z,g)==1
            velo(z,g)=one_velo(z,g);
        else
            velo(z,g)=zero_velo(z,g);
        end
    end
end
%update velocity
velon=logsig(velo);

tval=1.635*rand(N,D); %Uj random number determination
for l=1:N
    for e=1:D
        if uval(l,e)<velon(l,e)
            xpbest(l,e)=1; % bit flips
        else
            xpbest(l,e)=0; %bit not flips
        end
    end
end
% checking at each end of iteration for global best Gbest
if Gbest1>gbest 
    Gbest1=gbest;
end
if pbest1>sum(pbest) 
    pbest1=sum(pbest);
end