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FACULTY OF ELECTRICAL AND COMPUTER ENGINEERING

RELIABILITY ASSESSMENT AND ENHANCEMENT OF POWER DISTRIBUTION NETWORK BY OPTIMAL PLACEMENT OF SECTIONALIZERS

(CASE:-STUDY ON ALABA DISTRIBUTION SUBSTATION)

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER

OF SCIENCE IN POWER SYSTEM AND ENERGY ENGINEERING

BY

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RELIABILITY ASSESSMENT AND ENHANCEMENT OF POWER DISTRIBUTION NETWORK BY OPTIMAL PLACEMENT OF SECTIONALIZERS

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

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HAWASSA UNIVERSITY

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ADVISORS'S APPROVAL SHEET

This is to certify that the thesis entitled "RELIABILITY ASSESSMENT AND ENHANCEMENT OF POWER DISTRIBUTION NETWORK BY OPTIMAL PLACEMENT OF SECTIONALIZERS (CASE:-STUDY ON ALABA DISTRIBUTION SUBSTATION)" submitted in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering with specialization in Power system and Energy Engineering, The Graduate Program of the Department of Electrical and Computer Engineering, and has been carried out by Yeshiwas Alemu ID No-GPPosyR/018/12 under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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APPROVED BY BOARD OF EXAMINERS

We the under signed board of examiners of the final open defense by Yeshiwas Alemu have read and evaluated thesis entitled "Reliability Assessment and Enhancement of Power Distribution Network by Optimal Placement of Sectionalizers (Case:-Study On Alaba Distribution Substation)" and examined the candidate. Therefore, to certify that thesis has been accepted in partial fulfillment of the requirements for the degree.

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DECLARATION

I declare that this thesis is my original work, and the work described in this thesis has not been previously presented for fulfillment of a degree in this or any other university, and all sources and materials used for the thesis have been fully acknowledged.

All examiners' comments are duly incorporated:-

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This is to certify that the statement made above by the candidate is true to best of my knowledge and this thesis has been submitted for examination with my approval as university advisor.

Dr. Muluneh Lemma ____________ _____________

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Mr.Mesfin Jarso ____________ _____________

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ABSTRACT

Electrical power distribution unreliability reduces user power consumption and seriously affects day today activities. This thesis tries to assess reliability and mitigation strategy of the Alaba distribution substation which has faced frequent power interruption problem. 15kv Durame distribution feeder, according to the last three years consecutive data, has high interruption problem among the four feeders of Alaba distribution substation. The interruptions mainly caused by the earth fault and short circuit. There are also planned outages for operation and maintenance purpose. The feeder's System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) are 167.79 interruptions per customer per year and 218.93 hours per customer per year, respectively calculated by Monte Carlo simulation. The Feeder is not reliable compared with Ethiopia Electric Agency (EEA) standard which has set SAIFI as equal to 20 interruptions per customer per year and SAIDI which is around 25 hours per customer per year. It is required to find best solution for enhancement of reliability. Therefore, the objective of the study is to enhancement the reliability of the distribution system by determination and optimal placement of sectionalizer switches by using whale optimization algorithm techniques and compared with particle swarm optimization. The historical outage interruption data of years 2019 to 2021G.C has been used as a base year. The reliability indices calculated by Monte Carlo simulation Algorithm techniques have been done with the help of Matlab 2016a software. Electrical Transient Analysis programs (ETAPS 16.0.0) software has been used for modeling existing system. The reliability of distribution system has improved by optimal placement sectionalizer switches. Therefore, the overall reliability of Durame city feeder indices SAIFI by 85.98% (Decrease from 167.79 to 23.52 interruption per customer per year), SAIDI by 80.93% (Decrease from 218.93 to 41.73 hours per customers per year) EENS by 67 % (Decrease from 2,224.79 to 734.199 Megawatt hours per year), and Cost of EENS by 66.44% (Decrease From 4,449,590.4 to 1,468,398 Birr per year) has been improved as compared with the existing system. The economic analysis indicates that the selected solution results in a cost saving of 2,981,192.4 ETB per year from the unsold energy of one feeder only with 0.79 year payback period investment.

Key Words:-optimal placement, particle swarm optimization, reliability enhancement, whale optimization algorithm.

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LIST OF ABBREVIATIONS

CAIFI	Customer Average Interruption Frequency Index
EEA	Ethiopia Electric Agency
EEP	Ethiopia Electric Power
EEU	Ethiopia Electric Utility
EEP	Ethiopia Electric Power
ETAPS	Electrical Transient Analysis Program Software
EENS	Excepted Energy Not Supplied
GA	Genetic Algorithm
GoE	Government of Ethiopia
kVA	Kilo Volt Ampere
kwh	Kilowatt hour
PSO	Particle Swarm Optimization
MVA	Mega Volt Ampere
MCS	Monte Carlo Simulation
WOA	Whale Optimization Algorithm
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index

CHAPTER ONE

INTRODUCTION

1.1 Background

The distribution system is the part of the electric power system that transmits power from transmission substations to consumers. Distribution substation is the final stage in the delivery of electricity from the transmission system to customers (end users). A distribution system network contains of feeders, distributors and service mains. Distribution Feeders are large current carrying conductors that have the capacity to transfer the current in bulk to the consumer. Generally, no tapings are taken from feeder so that the current in it remains the same throughout it. A distributor is a conductor from which tapings are taken for supply to the consumers. It is inconstant because tapings are taken at different places along length. And the service mains are the small cables that transmit electricity from low tension line to the consumer meter board [1].

The Ethiopia Electric Power system has primary transmission systems with 132KV, 230KV and 400KV and Sub-transmission systems with 66KV and 45KV, 33KV and 15KV are at distribution system.66 kV/45kV substations power transformers of various ratings like 25 /12 /6.3/3MVA are installed for step down of voltage to 15kV for feeding to Distribution Transformers. In radial fashion connected the outgoing feeders are 33kV and 15kV voltages are further reduced by distribution transformers to 220 volts single-phase or 380 volts three-phase supply and delivered to commercial ,industrial and residential customers.

Reliability is measured as one of the major power system operation, mainly in distribution system areas. Occasionally poor reliability may cause power interruption, decreased efficiency of appliance, blackouts, blackening of light bulbs and damage of electronic and electrical appliances [2]. Having a reliable supply of electricity is essential for the operation of any firm. In most developing countries, however, electricity supply is highly not reliable [3].

Nowadays, electric power distribution system is needed to reduce or eliminate system disturbance and continuous electrical supply to its customers in efficient, reliable and economical manner. Different types of techniques used to improve power reliability some are distributed generation, sectionalizer switches, distribution Network Reconfiguration, etc. are implemented to minimize system outages and the amount of customers affected by permanent outages.

1.2. Statement of the Problem

In Alaba distribution system, reliability and cost of Energy not supply (power loss) are the major issues for the consumers and utility. Since system reliability indices Alaba distribution selected feeder are System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI) and Expected Energy not Supply (EENS) are 167.79 interruptions per customer per year, 218.93 hours per customer per year and 2,224.79 MWh/ year, respectively that is very far from the standard of Ethiopian Electric Agency (EEA) and different international settings (which is SAIFI as equal to 20 interruptions per customer per year and SAIDI which is around 25 hours per customer per year). The interruption of power in a given area leads to several losses. Power interruptions occur several hours in a day i.e. it is becoming a day-to-day phenomenon in the city. Such an interruption of power resulted in:-

- Sensitive equipment to be damaged
- Low product quality and level of productivity of the customers
- Increment of cost on customers
- Dissatisfaction among customers

This thesis found best solution for enhancement of reliability. Determination and optimal placement of sectionalizer switches in distribution feeders has significant impact in reliability and minimization of cost, this will be further evaluated along with the outage minimization techniques for the distribution system in Alaba. Therefore, in this thesis, emphasis on the distribution system of Alaba has been considered, mainly targeting on selected feeder based on more interruption happened.

1.3. Objectives

1.3.1. General Objective

The general objective this thesis is reliability assessment and enhancement of power distribution network by optimal placement of sectionalizer switches using whale optimization technique.

1.3.2. Specific Objectives

- Identify the major causes of power interruptions in the existing system based on historical outage data.
- To compute reliability indices of the study area using Monte-Carlo simulation.
- To carry out reliability analysis of the system by using Whale optimization algorithm techniques.
- To estimate the cost of implementing the proposed method of reliability improvement.

1.4 Methodology

For successful completion this study the following steps, methods, task and procedures conducted.

- **Introduction:** Some general introduction about power reliability has been discussed.
- **Literature review:** A number of published paper and the reliability analysis and enhancement of power network have been reviewed in different papers, journals, articles, lectures and materials.
- **Data collection:** collect all input data required for mathematical analysis and required for simulation test.
- **Data analysis:** based on data collection and simulation result of monte-carlo algorithm the network is reliable or unreliable has been decided.
- **Component modeling:** modeling the sectionalizer switches.

- **System modeling:** modeling the single feeder with 156 bus network using ETAPS software and simulation result of whale optimization algorithm used for the determination and allocation of sectionalizer switches.
- **System simulation result and discussion:** Evaluate the proposed method achieves its general objective of the study or not.
- **Conclusion:** Based on the result the effectiveness of sectionalizer switches for overall reliability performance improvement is compared.

1.5 Scope of the Study

This thesis covers, studying the existing power system reliability problems of the substation and compare the techniques to develop optimum methods, their causes, percentage of improvements gained by different techniques to the present Alaba distribution substation. The existing model has been developed using ETAPS software.

1.6 Significance of the Study

This thesis out put a significant importance of determining the existing network performance of reliability and energy not supply (power loss) which provide reliability improvement and cost of energy not supply (power loss) reduction solutions for Alaba electric distribution network. In general it has the following advantages.

- ✓ Specify the influence of power interruption on the economy of customers and utility.
- ✓ Assess average duration and frequency of power interruption per year in the system.
- ✓ Improve reliability and reduce energy not supply (power loss) using optimal placement of Sectionalizing switches by Whale optimization algorithm.

The economic and social effects of loss of electric service have significant impacts on both the utility supplying electric energy and the end users of electric service. Therefore, maintaining a reliable power supply is a very important issue for power systems design and operation [4].

1.7 Thesis Layout

This thesis composed of five chapters with detailed explanations. Chapter one presented a general introduction to the power reliability, statement of problem, thesis objectives, significant and scope of the study and methodology. Chapter two discussed the literature review and theoretical background, reliability evaluation and improvement strategy of the research. Chapter three described the data collection and analysis. Chapter four presented simulations, results and discussion. Chapter five presented the conclusion, recommendations and future work of the study.

CHAPTER TWO

LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 Introduction

This thesis presents the studies that would conduct on reliability assessment and enhancement of power distribution network by optimal placement of sectionalizers by whale optimization algorithm.

Related research works published in the technical literature are described and the concepts of reliability assessment and improvement of power distribution network by different techniques.

2.2 Summary of Literature Review

In 2019,Mandefro Teshome Asefa presented that the reliability of the system has been improved significantly by implementing reliability improvement solutions that are justified economically [5] but only used analytical methods based on mathematical models are used to solve reliability indices so it's not give effective solution some complex issues happening.

Masoud Ahmed, et al. [6] suggested a new technique to determine the optimal number and locations of auto reclose and sectionalize switches in distribution networks. The costs of AR/S investment, switch maintenance, and undistributed energy as well as reliability coefficients are considered in the objective function. Reliability parameters such as SAIFI, SADI, MAIFI, and ENS are evaluated in the case study system. As a new method, the weights of the reliability parameters are obtained by decision-makers using the Analytical Hierarchy Process (AHP). The optimal size, type, and location of automatic switches are determined by minimizing the objective function using the Particle Swarm Optimization (PSO) algorithm. The paper did not describe about power restoration. Therefore, by including power restoration mechanisms reliability can be improved more and more.

IN 2016, M. Ahmed discussed the reliability of the distribution system in the smart grid context is assumed to improve the distribution adequacy by application of automatic reclosers in the existing distribution system [7]. Reliability indices were used to quantify and state the reliability of the distribution system.

IN 2013, S.K. Singh.et.al. Presented the reliability analysis of a large scale radial and reconfigurable electrical distribution system [8].It is discussed the improvement in reliability over a time varying load curve. There results presented that distributed generation (DG) is one of the best methods to improve distribution systems reliability.

IN 2015 S. Ray.et.al. Studied Differential Search Algorithm (DSA) was planned to solve a distribution system reliability optimization problem. Optimum repair time and failure rate of the different distributor segments of a distribution network were calculated to enhance the reliability of radial distribution system, both without DG and incorporating DG as standby unit.

IN 2016,M. Demsew and J. Ameche, "Reliability Assesment of Debre Markos Distribution System Found In Ethiopia'' journal evaluates power reliability indexes of Debre Markos substation 230/15 KV 23MVa transformer with two outgoing feeders. Authors analyses reliability indices by DIGSILENT software which results two major system indices; SAIFI is 608.168 inter./customer and SAIDI is 597.476 hr/customer. This justifies that Debre Markos substation is no reliable [10]. But it did not provide any improvement options as to enhance reliability of the system.

IN 2018 Tesfay Gebreegziabher, "Smart Grid System for Improvement of Power Distribution System Reliability of Addis Ababa District" describes an effective method to reconfigure a radial power distribution system of a 33-bus test system using genetic algorithm. Reconfiguration is done to improve reliability and to reduce losses. The reliability at the load points is evaluated using probabilistic reliability approach. For finding minimal cut sets and losses different algorithms are used. To improve the reliability and to reduce the losses, the status of the switch is controlled using genetic algorithm.

The feeder reconfiguration in four selected Distribution Networks of IEEE 33-bus using an iterative algorithm in ETAP 12.6. The main objective in feeder reconfiguration is to regain as much load as possible by transferring essential load of the out-of-service to the nearby healthy feeder. This method reduced the losses only by 5% as compare to the existing methods and it improved the voltage regulation [11].

Table 2.1: Literature review summary

Authors	**Titles**	**Advantage**	**Limitations**
Mandefro Teshome Aseffa	Reliability assessment and its improvement of power.	By implementing reliability improvement solutions that are justified economically	But only used analytical methods based on mathematical models are used to solve reliability indices so it's not give effective solution some complex issues happening. Didn't use optimization method.
Masoud Ahmed	Reliability improvement distribution network using optimal placement of auto reclose and sectionalizer switchs by PSO technique.	Improved the distribution reliability by application of automatic reclosers in the existing distribution system.	The paper did not describe about power restoration.
S.K. Singh.et.al.	Reliability analysis of a large scale radial and reconfigurable electrical distribution system.	This paper more evaluated the improvement in reliability over a time varying load curve.	This paper represent the DG is the best improvement method of reliability without comparing other techniques.

S. Ray.et.al	Differential search algorithm for reliability enhancement of radial distribution system.	Enhance the reliability of radial distribution system, both without DG and incorporating DG as standby unit.	It required high investment cost.
M. Demsew and J. Ameche	Reliability Assesment of Debre Markos Distribution System Found In Ethiopia.	Authors analyses reliability indices by DIGSILENT software and justifies that Debre Markos substation is Unreliable	But it did not provide any improvement options as to enhance reliability of the system.
Tesfay Gebreegziabher	Smart Grid System for Improvement of Power Distribution System Reliability of Addis Ababa District.	Reconfiguration is done to improve reliability and to reduce losses.	This method reduced the losses only by 5% as compare to the existing methods.
Yeshiwas Alemu	Reliability assessment and enhancement of power distribution network by optimal placement of sectionalizers.	Used Monte-Carlo Algorithm to evaluation of reliability index. Used WOA is superior to other algorithm. Has less investment cost.	Reliability improved and power enhanced only one feeder of Alaba distribution substation.

2.3 Research Gap

Since above all reviewed thesis and paper used analytical method to evaluate the reliability indices it is difficult to evaluate a complex system and reduce accuracy of the result. In this study, narrow the above mention gap and use Monte-Carlo Simulation to evaluation complex system and to accuracy of the result and improve the customer oriented reliability indexes to IEEE standard. WOA is superior to other algorithms in that WOA has good determination and allocation optimal number of sectionalizer switches.

2.4 Reliability Analysis

Reliability analysis for the electric power system is carried out to study the Generation station reliability, composite generation and transmission reliability, substation reliability and distribution reliability.

Power distribution reliability is an added effect of the system adequacy and system security. The system adequacy refers to the availability of enough generation, transmission and distribution capacities to meet the customer demand. Thus, adequacy assessment represents the static conditions analysis. And system security is the ability of the system to respond to disturbances arising within the system. Thus, security assessment deals with the dynamic conditions of the power system. Since distribution system components are seldom loaded near their limits, system adequacy is of relatively small concern and hence, reliability emphasis on system security [12].

Basically, reliability analysis is to quantify, predict, and compare reliability indices for various reliability improvement initiatives. In general, reliability evaluation study is important to evaluate past performance and predict future performance of the distribution system, to identify the problematic components in the system that can impact reliability, to ensure appropriate system reliability levels and to provide effective information for regulatory bodies to set proper benchmarks, to predict the reliability performance of the system after any expansion and quantify the impact of adding new components to the system [13].

There are several techniques of distribution system reliability evaluations which have been presented by different researchers. Each of the technique uses different mechanisms and algorithms which aides to assess and improve reliability of the power delivered to the customers of industrial, commercial and domestic sectors.

Reliability of distribution system is an important issue in power engineering for both utilities and customers. Techniques for reliability evaluation are important in the planning, operation or both phases of distribution system. Operation and maintenance costs due to low reliability can be reduced by adequate planning, monitoring system behavior and taking proper control actions [14].

Reliability analysis is a vital tool for critical identification of sensitive components of the electrical power systems that need more attention for better improvement and hence to increase the system's availability. Basically, it is to quantify, predict, and compare reliability indices for various reliability improvement initiatives.

General, reliability evaluation is important to:-

- Evaluate past performance and predict future performance of the distribution system.
- Identify the problematic components in the system that can impact reliability.
- Ensure appropriate system reliability levels and to provide effective information for regulatory bodies to set proper benchmarks.
- Predict the reliability performance of the system after any expansion and quantify the impact of adding new components to the system.

2.4.1 Reliability Indices Evaluation

The basic indices that are used to evaluate reliability of a distribution system can be classified in to two categories. The first category is load point indices that include load point failure rate (λ), the average outage time (r) and the average annual outage time (u). And the second category is system indices that can be obtained from the above three load point indices and information on the number of customers and load connected at each load point in the system.

In order to evaluate the severity of a system outage, the expanded sets of indices listed below must be calculated using the three basic indices mentioned above. The two expanded sets of indices include the number and average load of customers connected at each load point in the system and the customer interruption cost. The first set is the system reliability index that includes [25]:

- System Average Interruption Frequency Index
- (SAIFI) System Average Interruption Duration Index (SAIDI)
- Customer Average Interruption Duration Index (CAIDI)
- Average System Availability Index (ASAI)
- Average System Unavailability Index (ASUI)

The second set includes the reliability cost/worth indices:

- Expected Energy Not Supplied (EENS)
- Expected Interruption Cost (ECOST)
- Interrupted Energy Assessment Rate (IEAR)

Reliability indices help engineers and other operations personnel see and show an interconnected nature of the many independent system components that make up an electrical distribution system. This connection makes apparent the fact that overall system design impacts fundamental reliability. From substation and distribution design to fusing schemes, the physical factors of system design impact system reliability [15].

There are two methods that are used to calculate the reliability indices: analytical and simulation approaches.

1. Analytical Method of Reliability evaluation

Analytical techniques represent the system with simplified mathematical models derived from mathematical equations and evaluate the reliability indices using direct mathematical solutions. The reliability indices that have been evaluated using analytical concepts are the three primary ones: average failure rate, average outage duration and average annual unavailability or average annual outage time. The reliability of a distribution system can be described using two sets of reliability parameters. These are the load point reliability indices and the system reliability indices [25].

A. Load Point Indices

Three basic reliability indices can be used to describe the degree of service continuity are the load point average failure rate (λ), average outage time (r) and the average annual unavailability or average annual outage time (U). The average failure frequency is approximately equal to the average failure rate and indicates the number of failures a load point will experience during a given period of time. The average outage time is the average duration of failure at the load point. The average annual outage time is the average total durations of outage in a year experienced at the load point. It is the product of the average frequency of failure and the average outage time. These reliability indices are expected values and represent the long-run average values [26].

(i).Failure rate (λ) per Km = $\frac{\text{Number of Interruptions}}{\text{Total feeder length}*\text{Number of Interruption Years}}$ (2.1)

(ii). Mean time to repair (MTTR) or Average outage time (r):- is the time (hours) required to repair a component outage and/or restore the system in to normal operating state.

$$\text{MTTR(r)} = \frac{\text{Total Duration of Interruptions}}{\text{Total Number of Interruption}} \tag{2.2}$$

(iii). Average annual outage time (u) = (λ $*$ MTTR) (2.3)

(iv). Average Repair Rate (μ): - is the frequency of a repair.

$$\mu = \frac{8760}{\text{MTTR}} \tag{2.4}$$

(v). Mean time to failure (MTTF):- is expected time that the component will be in failure.

$$\text{MTTF} = \frac{1}{\lambda} \tag{2.5}$$

(vi). Mean time between failures (MTBF):- is the expected time between component failures.

$$\text{MTBF} = \frac{\text{Total System Operating Time}}{\text{Number of Iterruptions}} = \text{MTTF} + \frac{\text{MTTR}}{8760} \tag{2.6}$$

B. System Reliability Indices

Systems reliability indices indicate the annual average performance of the network in terms of interruption frequency and duration. These indices can be obtained from the above three load point indices and information on the number of customers and load connected at each load point in the system. That means these indices are weighted by the number of customers or energy supplied. Quantitative reliability evaluation of a distribution system can be divided into two basic segments; measuring of the past performance and predicting the future performance.

Some of the basic system indices that have been used to assess the past performance are:

(i) System average interruption frequency index (SAIFI) it is the average frequency of sustained interruptions per customers over a predefined area. Total number of customer interruptions per year divided by the total number of customers served.

$$SAIFI = \frac{\text{Total number of customer interruptions}}{\text{Total number of customers served}} \tag{2.7}$$

(ii) System average interruption duration index (SAlDI) it is normally referred to as customer minutes of interruption or customer hours and provides information as to the average time the customers are interrupted.

$$SAIDI = \frac{\text{Sum of customer interruptions durations}}{\text{Total number of customers served}} \tag{2.8}$$

(iii). Customer average interruption duration index (CAlD) This index show the average frequency of continued interruptions for those customers experiencing sustained interruptions. It is the value of total number of customer interruptions divided by total number of customers affected.

$$CAIDI = \frac{\text{Sum of customer interruptions durations}}{\text{Total number of customers interruptions}} \tag{2.9}$$

(iv). Excepted energy not supplied index (EENS):

$$\text{EENS}=\sum (L*U) \tag{2.10}$$

Where,

L is the average peak load at load point.

U is average annual outage time at load point.

(v)The cost of energy that is not supplied (Cost of ENNS): to the customers is given by the following equation:

$$ENNS = \text{Average peak load} * \text{Outage time per year}$$

$$\text{Cost of } EENS = ENNS * \text{cost}/KWh \tag{2.11}$$

Where, EENS = Expected Energy Not Served

SAIFI, SAIDI and EENS are the most commonly used and known indices to measure reliability performance of utilities [26].

2. Monte Carlo Simulation (MCS)

Although analytical models and techniques have been enough to provide planners and designers with the results required to make objective decisions, the results are not still accurate. Thus, the resulting analysis can lose some or much of its significance. The simulation methods are the most flexible due to two reasons, first, it considers the random occurrence of faults and second, it gives the variability of indices. Additionally, Simulation technique is very vital in the reliability assessment of a complex system. It once more estimates the reliability indices by simulating the actual process and random behavior of the system.

A power system is stochastic in nature and therefore Monte Carlo simulation techniques can be applied for reliability evaluation of a power system. The Simulation uses the failure and repair statistical distributions of individual equipment units to model the system behavior over time when it is applied for reliability analysis. The simulation results can be used to make more accurate decisions for improving the reliability of the system.

There are two kinds of Monte Carlo simulation techniques: Non sequential Monte Carlo technique and sequential technique. Sequential Monte Carlo technique is used to simulate system operating cycle obtained by combining all component cycles. That means the sequential approach simulates the basic intervals in chronological order. Thus, it is used to obtain accurate frequency and duration indices, and to synthesize annual reliability index probability distribution. This makes it advantageous over non sequential technique.

Two major advantages when using sequential Monte Carlo simulation method are the capacity to obtain accurate frequency and duration indices, and the opportunity to create reliability index probability distributions which define the annual index variability [17].

A. Time Sequential Monte Carlo simulation and its Models

The time-sequential Monte Carlo simulation technique can be used on any system that is stochastic in nature. The up and down states are modeled using a random number generator and the probability distributions of the component failure and restoration processes. A sequence thus generated is used to study the distributions surrounding the expected values of the reliability indices.

The Monte Carlo simulation process begins with the generation of uniformly distributed random numbers using a uniform random number generator. Since perfect random numbers are not attainable using a computer program, pseudo-random numbers are used. The built-in random number generator has been used to create uniformly distributed pseudo-random numbers in the interval [0, 1]. The generated random numbers are then converted into values representing a non-uniform probability distribution by using the inverse transform method, composition and acceptance-rejection techniques [24].

These pseudo-random numbers are used to get the times to failure (TTF) and times to repair (TTR) for each component. The inverse transform method can be used to convert the uniform distribution of random numbers into an exponential distribution of failure times.

- The probability density function (PDF) of a uniformly distributed random number U is given by the equation:

$$\boldsymbol{fu(U) = \begin{cases} 1, & 0 \leq u \leq 1 \\ 0, & else \end{cases}} \quad \textbf{(2.12)}$$

- The cumulative distribution function of the PDF in (2.12) above is given by:

$$\boldsymbol{fu(U) = U, 0 \leq U \leq 1} \quad \textbf{(2.13)}$$

- PDF of exponential distribution function for the other random number T is given by:

$$\boldsymbol{fu(U)} = \begin{cases} \boldsymbol{\lambda e^{-\lambda t}}, & \boldsymbol{0 \le u \le 1} \\ \boldsymbol{0}, & \boldsymbol{else} \end{cases} \qquad \textbf{(2.14)}$$

- The cumulative PDF (probability density function) for the exponential PDF of equation (2.14) will be:

$$\boldsymbol{FT(t) = \int_0^t \lambda e^{-\lambda u}\, du = 1 - e^{-\lambda t}} \qquad \textbf{(2.15)}$$

- Equating equations (2.14) and (2.15) and taking the inverse transformation (natural logarithm), the generated random number can be converted in to another random number T as expressed below:

$$\mathbf{U=1-}\boldsymbol{e^{-\lambda t}}$$

$$\mathbf{1-U=}\boldsymbol{\lambda e^{-\lambda t}}$$

- Using an inverse transform method of the equation (14) we get the random variable T:

$$\boldsymbol{T = \frac{-ln(1-u)}{\lambda}}$$

- Since (1-U) is distributed the same way as U in the interval [0, 1], then:

$$\boldsymbol{T = \frac{-ln(U)}{\lambda}}$$

Where U and T are uniformly and exponentially distributed random variables, respectively

If the present state is up state, λ is a failure rate of the component otherwise it is the repair rate of the component.

In time sequential simulation, an artificial history that shows the up and down times of each element of the system is generated in chronological order using random number generators and the probability distribution of the element’s failure and restoration parameters [24].

All components of distribution system can be modeled with its element parameters for the simulation as shown in the figure below.

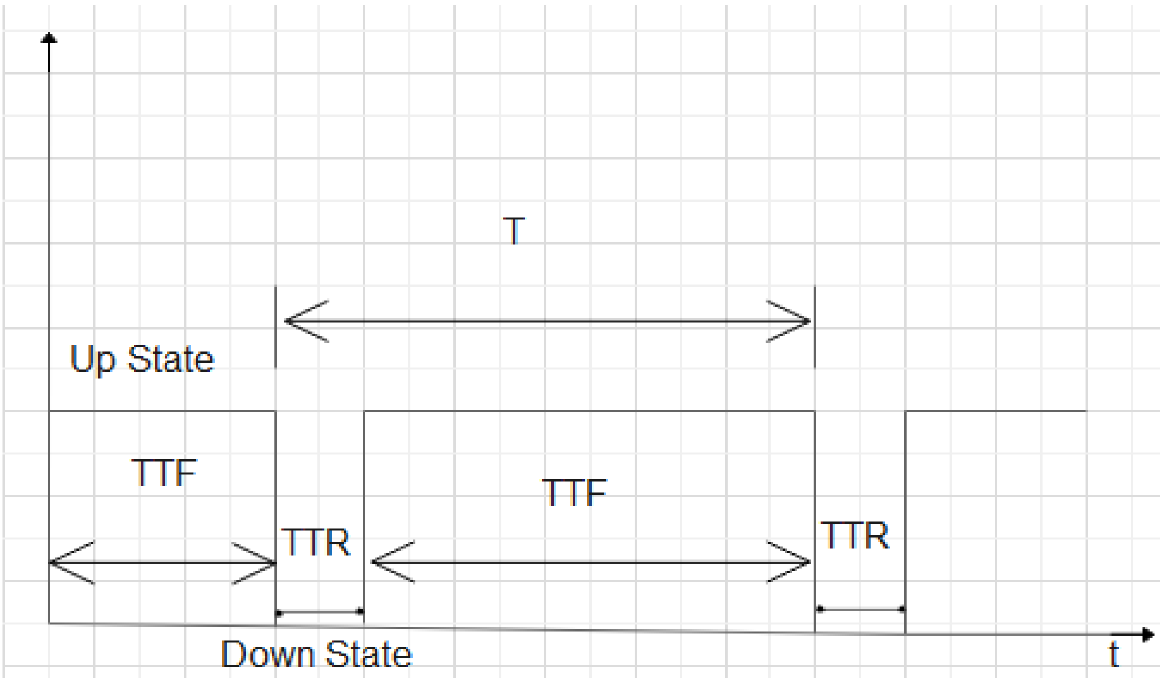

Figure 2.1 Average state cycle

The time during which the element remains in the up state is called the time to failure (TTF). And the time during which the element is in the down state is called the restoration time or the time to repair (TTR). The process of transiting from the up state to the down state is the failure process. Transition from an up state to a down state can be caused by the failure of an element or by the removal of elements for maintenance.

Thus, the sequence of operating repair cycles of the system is obtained from the history of the components using the relationship between the element states and the system states as given in equations (2.16) and (2.17) below.

$$TTF = -MTTF * \ln U \qquad (2.16)$$

$$TTR = -MTTR * \ln U' \qquad (2.17)$$

The algorithm used in this Thesis work to determine the distribution system reliability indices using the time sequential Monte Carlo simulation consists of the following steps:

Step1: The initial state of each component is specified. Generally, it is assumed that all components are initially in upstate.

Step 2: Generate a uniform random number for the feeder line (s).

Step 3: Convert the generated random number into time to failure (TTF) corresponding to the probability distribution of the element parameters.

Step 4: Find the element with minimum TTF

Step 5: Generate a random number and convert this number into the repair time (TTR) of the component or system with minimum TTF according to the probability distribution of the repair time.

Step 6: Calculate the three basic load point indices of each feeder line's operating history using the equations given below:

$$\boldsymbol{\lambda} \mathbf{i} = \frac{\mathbf{N}}{\sum \mathbf{TTF}} \qquad \textbf{(2.18)}$$

$$\mathbf{ri} = \frac{\sum \mathbf{TTR}}{\mathbf{N}} \qquad \textbf{(2.19)}$$

$$\mathbf{Ui} = \frac{\sum \boldsymbol{TTR}}{\sum \boldsymbol{TTF} + \sum \boldsymbol{TTR}} \qquad \textbf{(2.20)}$$

Where

- **i** refers to the line section

- **U** is the number of transitions between up and down states during the given year.

Step 7: Finally, Evaluate the system indices using equations (2.12) to (2.20).

For calculating common reliability parameters in the process of evaluating any simple radial system the subsequent steps will be followed:-

1. Acquire feeder topology
2. The location and number of the switches, line segments and load points.
3. Average failure rates of each segments and load lines.
4. The number of customers connected and the average consumption of each load.
5. The Average repair time of automatic or manual switches.
6. Identify switches to operate to isolate faults.
7. Whole switch operation time.
8. Identify loads affected by feeder outage.
9. Compute number of customers with power outage.
10. Calculate reliability indices

Since the distribution systems in Alaba are basically designed, constructed and operated in radial system the above steps are necessarily followed in the next sections [22].

2.5 Reliability Improvement Strategy

In this concern, the main improvement strategy is diminishing the number and duration of power interruption. However, how to reduce the number of power outages is a major problem because some of the methods that will be applied are expensive.

To improve the reliability is one of big issues for distribution system to know where to start and when making improvement decisions. However, at a utility where reliability indices are collected, it is easy for engineers and other operation personnel to choose a reasonable starting point for improvement.

The distribution system reliability can be improved reducing both duration and frequency of faults. The main strategy to improve reliability and power quality to customers are to eliminate faults as fast as possible and then to minimize the effect of faults on customers even if it occurs. Different techniques have been suggested for improving the system reliability, such as electrical and non-electrical techniques [23].

i) Electrical improvement techniques include:

- Installing additional protective devices (re-closers and fuses) and switching devices, system reconfiguration, feeder reconnecting and sectionalizing devices.
- Improving checkup and preventive maintenance practices for distribution system equipment such as lines, poles, transformers, fuses, etc.

ii) Non-electrical improving techniques include:

- Performing tree trimming along the right-of-way for overhead lines
- Fixing animal guards on distribution circuits
- Installation of lightning arresters,
- Placement of crews and human factors

2.6 Electrical (Power) Improvement Techniques

There are various types of techniques used to improve power reliability. Some of them are listed below.

- ✓ Distributed generation
- ✓ Sectionalizing switch and
- ✓ Distribution Network Reconfiguration etc.

2.6.1 Distributed Generation

Distributed generation (DG) is used to improve voltage profile, reduction power loss and decrease loading of existing electric equipment, installation time is very low, safe, clean and reliable production but requires high installation cost, does not consider fault , depend on whether condition and less reliable.

2.6.2 Distribution System Reconfiguration

Network reconfiguration is increase the feeder's capacity to handle load growth, balancing the load, is extremely fulfill to minimize the losses and improves voltage profile. The challenge may the requirement of additional investment and it takes time.

2.6.3 Sectionalizer Switches

A sectionalizer is an automated switching device that is planned to isolate faults, and is typically used in combination with an upstream recloser or (circuit breaker). The sectionalizer counts the number of operations of the upstream recloser or (circuit breaker) to control if the fault is permanent or temporary. After a presetting number of counts within a set time period, the sectionalizer will identify a permanent fault and open while the recloser or (circuit breaker) is open, thereby isolating the faulted section. Upon the sectionalizer opening, the upstream recloser is allowed to reclose and restore power to the non-faulted section of the circuit. The sectionalizer decides the fault is temporary when the fault clears prior to the predetermined number of counts are met within a set time period. After this set time period is met, the sectionalizing switch will reset to original state. Has less investment cost, proper protection and it improves reliability.

2.7 Optimization Techniques Used to Improve Reliability

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

1. Particle Swarm Optimization (POS)

Particle Swarm optimization (POS) is one of the bio-inspired algorithm and by the social behavior of a flock of migrating birds trying to reach an unknown destination. In Particle Swarm Optimization, each solution is a bird in the flock and is referred to as a particle. A particle is analogous to a chromosome in GAs. As opposed to GAs, the evolutionary process in the PSO does not create new birds from parent ones. Rather, the birds in the population only evolve their social behavior and accordingly their movement towards a destination. Each bird looks in a specific direction and when communicates together, they identify the bird that is in the best location. Accordingly, each bird speeds towards the best bird using a velocity that depends on its current position. Each bird, then investigates the search space from its new local position, and the process repeats until the flock reaches a preferred destination. The search space of the algorithm is a set of branches (switches) which are normally closed or normally opened, this search space may be dissimilar for different dimensions.

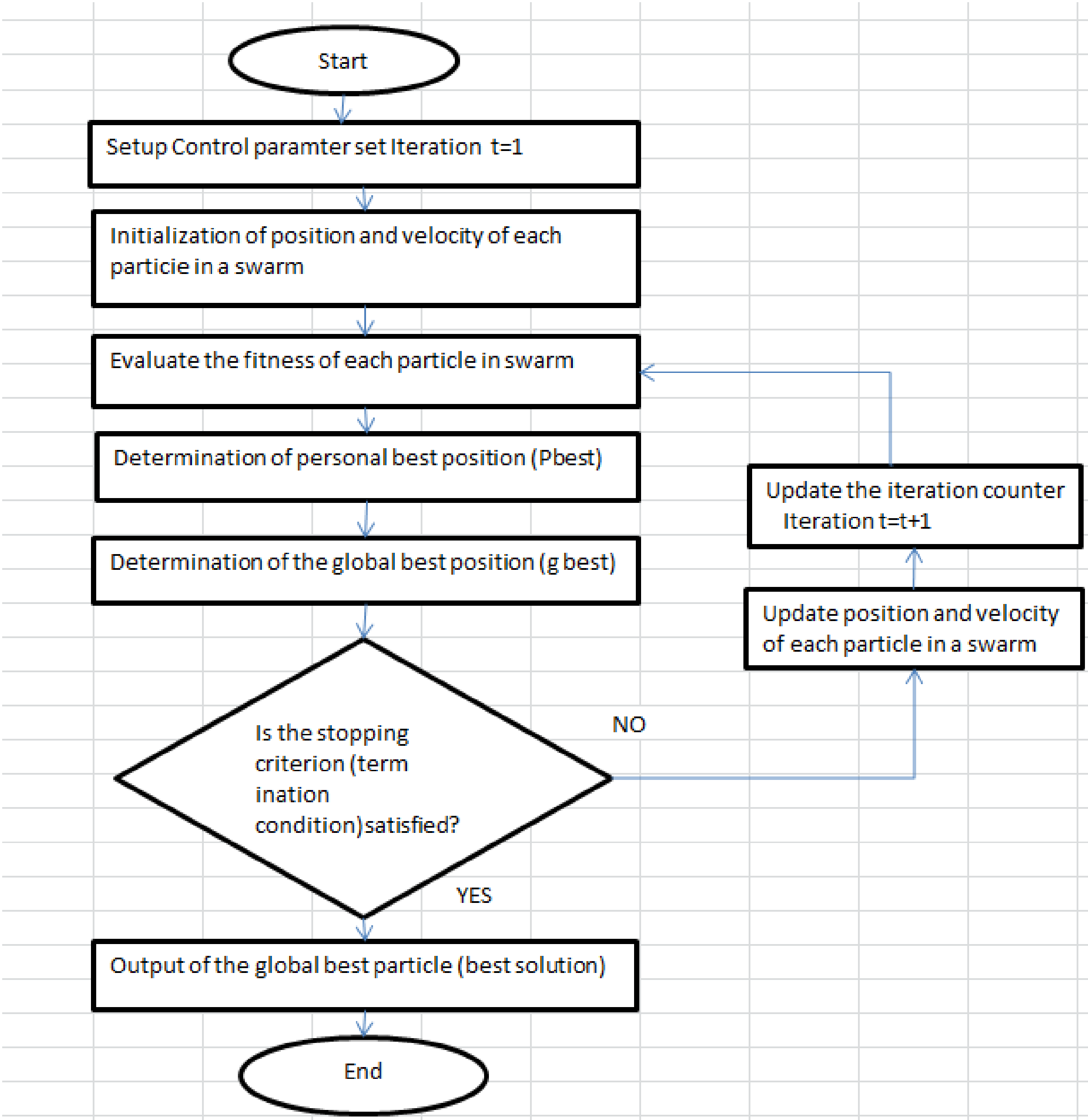

Figure 2.2 PSO flow chart

2. Whale optimization Algorithm (WOA)

Whale optimization algorithm was proposed by Mirjialili and Lewis [16] in 2016 it is a new swarm intelligence optimization algorithm that simulates humpback whale hunting behavior. Whales are the biggest mammal on earth with attractive behavior.. They are considered to have great intelligence with emotions resembling humans. This different behavior of whales is due to presence of spindle cells in their brains. These cells are also found in human brains. As result, whales are responsible for various human characteristics like feelings, reasoning and societal behaviors. Whales can be categorized under seven different types such as Killer, Sei, Blue, Humpback, Finback, Right and Minke. Humpback whales (Megastore novaeangliae) are one of the biggest whales. They like to hunt krills (malacostraca crustacean) and little fish schools. Humpback whales exhibit a very special hunting methodology called bubble-net feeding methodology. They choose to attack group of krill or tiny fishes near the surface. For this, humpback whales create unique bubbles in a circular fashion or '9-shaped path'. They submerge approximately 12 m below the surface and start creating bubbles in an exceedingly spiral shape encircling the prey and go swimming headed for the surface. The mathematical model of whale optimization algorithm is explained with in three parts: The Main concept of whale optimization algorithm is encircling prey, second is bubble net attacking and the third is search for prey.

The mathematical model of WOA is described in the following sections.

1. Encircling prey
2. Bubble net hunting method and
3. Search the prey

A. Encircling Prey

Finding the position of the prey, Humpback whales start forming a circle around them. At the start, it is not clear to locate the optimum solution within the search place. From this time present best candidate solution is supposed to be the target prey. Once the finest search agent is defined, the other search agents revise their positions in the direction of the best search agent. This behavior is modeled in [16] and by equations 21 and 22 as follows:

$$\vec{D} = | \vec{C} \cdot \overrightarrow{X*}(t) - \vec{X}(t) | \tag{21}$$

$$\overrightarrow{X*}(t+1) = \overrightarrow{X*}(t) - \vec{A} \cdot \vec{D} \tag{22}$$

In these equations,'**t**' denotes the iteration in progress, $\vec{\boldsymbol{A}}$ and $\vec{\boldsymbol{C}}$, denotes coefficient vectors, $\overrightarrow{\boldsymbol{X}*}$ is optimally best obtained position vector among others. $\vec{\boldsymbol{X}}$, denotes the current position vector**,** | | is the absolute value, and · is an element-by-element multiplication.

The vectors $\vec{A}$ and $\vec{C}$ are computed in [22] by using equation 23 and 24 as follows:

$$\vec{A} = 2.\vec{a} \cdot r1 - \vec{a} \tag{23}$$

$$\vec{C} = 2 \cdot r2 \tag{24}$$

In these equations, elements of a are decreased from 2 to 0 in a linear manner in successive iterations and $r1$ and $r2$ are random vectors in [0,1].

B. Bubble-net Attacking

The bubble net attacking behavior of humpback whales is modeled by the following two methods:

(a) Shrinking Encircling Mechanism: This method is accomplished by numerically mitigating the value of $\vec{a}$ in the Eq. (3). Is the arbitrary value of the range [-a,a]. The search zone **0 ≤ A ≤ 1** helps the whale to switch their position from X, Y to X*, Y* as shown in fig.1

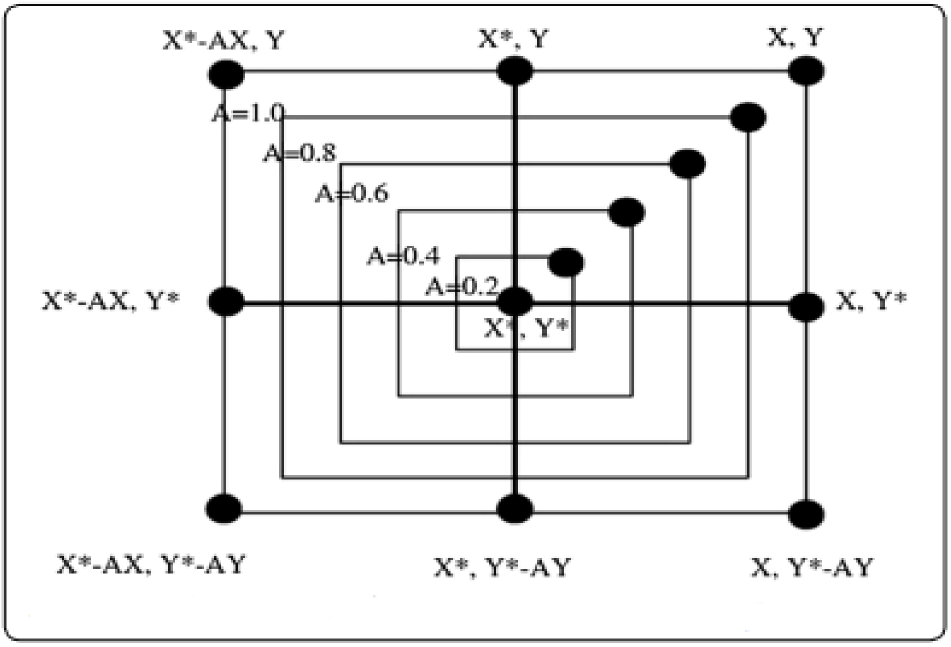

Figure 2.3 shrinking encircling pattern

(b) Spiral Updating Position: In this method, the distance between the whale placed at (X, Y) and prey positioned at (X*, Y*) is computed. Then, the spiral shaped motion of the humpback whales is simulated by the equation between the position of whale and position of the prey as shown in the equation (25) as follows:

$$\vec{X}\,(t+1) = \vec{D} \cdot e^{bl} \cdot \cos(2\pi l) + \overrightarrow{X*}\,(t) \tag{25}$$

In the above equation, $\vec{D} = |\overrightarrow{X*}(t) - \vec{X}(t)|$ denotes the distance between the ith whale and the prey (best solution came across so far), b denotes a constant defining the contour of the logarithmic spiral, l is an arbitrary number in [−1, 1], and denotes an element-by-element multiplication.

The concurrent movement of the humpback whales round the prey and along a contracting circle is modeled by assuming equal probability for both throughout the optimization. The simulation of this behavior is represented in [16] by equation (6) as follows

$$\vec{X}\,(t+1) = \begin{cases} \overrightarrow{X*}\ t - \vec{A}\,.\vec{D} & if\ P < 0.5 \\ \vec{D}\,.e^{bl}\ .\cos(2pil)\ x*(t) & if P \geq 0.5 \end{cases} \tag{26}$$

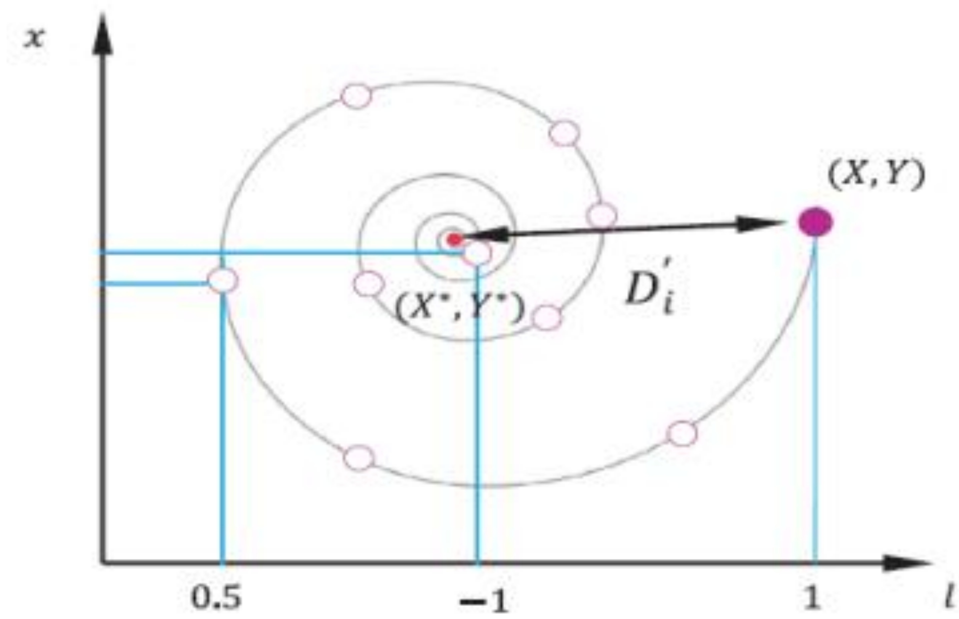

Figure 2.4 bubble net Spiral behavior

In this equation, p is an arbitrary number in [0,1].

C. Search for prey

The search for prey method of search process is based on the randomly hunting the prey location. By varying the $\vec{\mathbf{A}}$ vector, the global search process being taken into consideration. $|\vec{\boldsymbol{A}}|>\mathbf{1}$ implies exploration which allows whale optimization algorithm for the global search. Mathematically the behavior can be expressed by:

$$\vec{D} = | \vec{C} \cdot \vec{X}rand - \vec{X} | \tag{27}$$

$$\vec{X}(t+1) = | \vec{X}rand - \vec{A} \cdot \vec{D} | \tag{28}$$

Where indicates the arbitrary location of whale in the current iteration. The flow chart of WOA is shown in figure 2.5 the complete step by step sequence of the WOA can be understood in $\vec{\boldsymbol{A}}$ easier way with the help of flow chart.

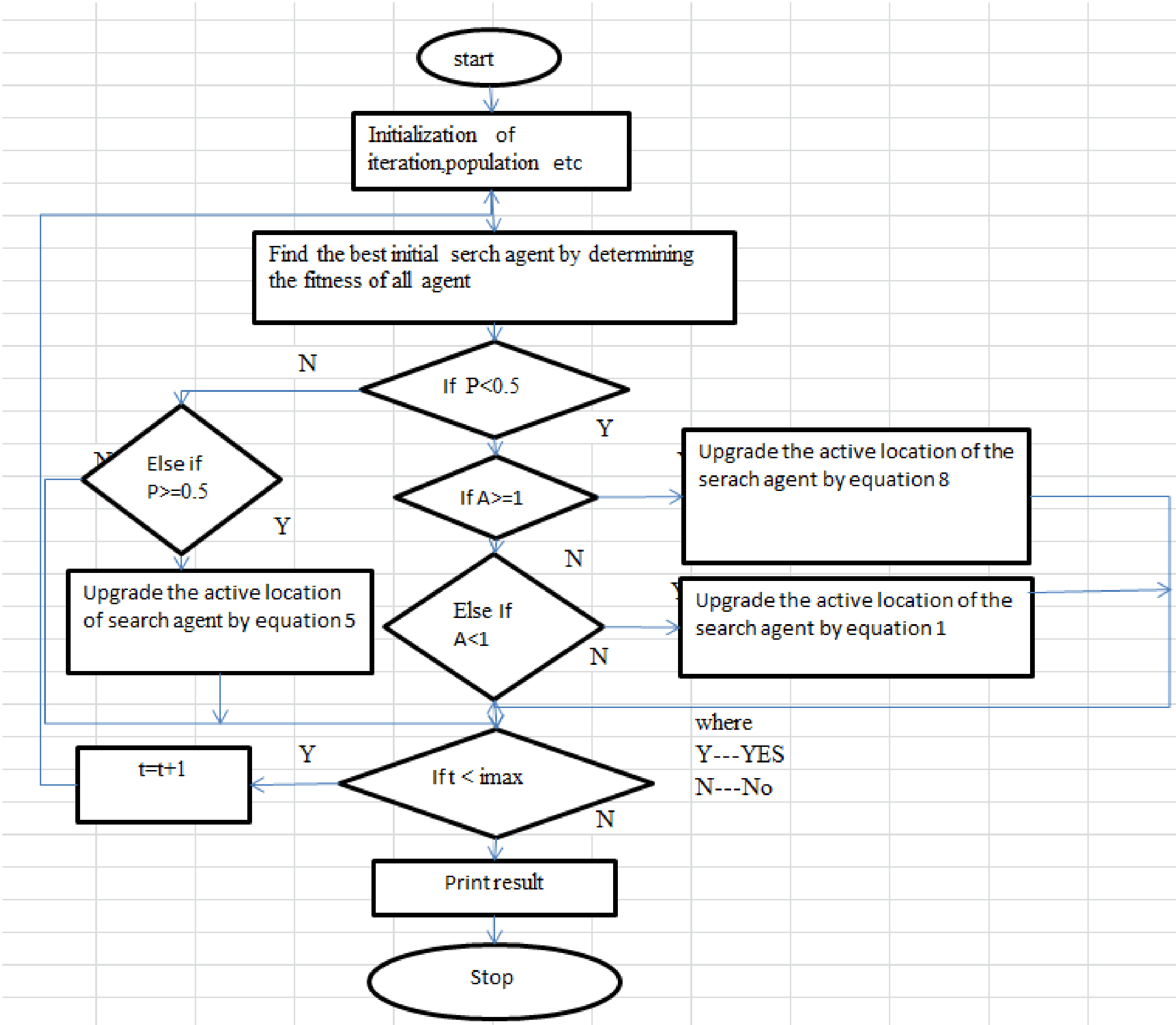

Figure 2.5 Proposed WOA Flow Chart

The modified algorithm steps of the WOA.

a. Initialize the whales' population Xi where i = (1, 2, 3… n) and set the Max gen (maximum number of iterations). Set t = 1.

b. Work out the fitness value of Xi where i = (1, 2, 3… n), identify the superior seek candidate solution X*.

c. Repeat the following: For every $\vec{X}$ (1, 2,3… n), update p, C, A, l, a. If p < 0.5, then if | A |< 1, update the position of the current search agent by Equation. (28) and if | A |≥ 1, select a random search solution $\vec{X}$rand and update the position of the current search agent by equation.(22).But when $p \geq 0.5$,update the position of the current search by the Equation (25) Check if any search agent goes beyond the known search and modify it. Calculate the fitness of $\vec{X}(1, 2, 3 \ldots n)$, and if there is a better solution, find the best search solution$\vec{X}*$. Set t = t +1.Until t reaches maximum number of iterations, the algorithm is finished.

d. Return the best optimization solution $\vec{X}*$ and the best optimization value of fitness values.

2.8 Fault Cause in Power System

Electrical fault is an abnormal condition in a power system or equipment. It happens when the current is partially flowing through a circuit or completely interrupted. Faults can occur for various factors, some are listed hereunder:-

I. Geographical location of service territory such as thick forest, mountainous terrain.

II. Exposure of components to natural elements; for instance, transmission and/or distribution system components may be affected by being exposed to their residing physical environment.

III. Weather condition: Adverse weather condition such as windy rain and lightning.

IV. Effects of vegetation such as tree falls and branch intrusion.

V. Animal activity like birds and pests causing ground faults.

VI. Other factors include:-

- System voltage
- Feeder length and its configuration
  - ✓ The customers connected to the system farthest from the supply point tend to suffer the greatest number of outages and the greatest unavailability.
- Sectionalizing capability

- Redundancy

2.9 Electrical Faults

Electrical fault defined as the abnormality of a current in the system due to which there is a failure of system equipment like transformers, lines, circuit breaker, generators and other equipment. Frequently happening fault on the distributions lines and equipment's are:

2.9.1 Earth Faults

Earth faults is an open circuit faults where any live conductor or power-carrying cable break and gets into contact with the earth's surface. In other words, it is a situation where the current-carrying conductor comes directly in contact with the earth's surface.

2.9.2 Short Circuit Fault

A short circuit is the name given to a very particular electrical current does not pass through all of the wiring, and instead, choose a short route.

Faults are generally classified as forced or scheduled depending on whether it results from tripping of the feeder or it is deliberately taken out of service. The faults can be temporary or permanent based on its nature and duration of stay [27].

- **Transient or Temporary Fault:** are faults for which the causes are not permanent. A fault that disappears either by itself or by de-energization of the faulted circuit and it does not require any immediate repair work. For instance, when a branch of tree touching the line as a result of windy air. For such faults, the circuit breakers remain closed when relays are reset and lines reclosed.

- **Permanent Fault:** This type of fault is persistent until the faulty component is replaced or repaired. For such faults the circuit breakers are open during the period of fault. Example, breakdown of an overhead line caused by fallen tree on it. In order to give special attention during planning, operation and design stages to start to improve reliability, it good to identify which types of fault that occur on the distribution system affect the reliability of the system more.

CHAPTER THREE

DATA COLLECTION AND ANALYSIS

3.1 Introduction

This chapter briefly deals with the methodologies used for data collection and analysis for the existing system. Interviews with the respective professional workers at Alaba substations have been conducted. Previously historical outage data's have been gathered for detail assessment and investigation to come up with a clear solution to the problem at hand.

3.1.1 Data Collection

The thesis data collected by:-

- Site visit
- Interviewing experts and professionals at the substation.
- Recorded data and existing information's are collected.

3.1.2 Material Requires Data Analysis

General methodology for this research work includes the following:

- Field visiting of existing structure of Alaba electric power distribution system
- Power interruption data of 3 years from January, 2019 to December, 2021 have been gathered from Alaba distribution system records and other load centers.
- Gathering data from EEP, (Hawassa) to get relevant national standards and current updated information related to this research work.
- Monte-Carlo simulation technique used to analysis and simulate the overall behavior of the distribution system reliability indices.
- Whale optimization technique used to determine the optimal placement of sectionalizers switches with MATLAB software.
- ETAPS software has been used for modeling existing system.

3.2 Existing Structure of Alaba Power Distribution System

The distribution system of Alaba has distribution substation which has transformers, high voltage and low voltage buses, circuit breakers for high and low voltages and control room. The Alaba distribution system has 15kV primary distribution substation, and 132 kV/15kV substations power transformers of various ratings like 20 /12 /6.3/3MVA are installed to step down voltage to 15kV for feeding to Distribution Transformers. Mostly, 15kV overhead conductors are used for feeding distribution transformers on each 15kV feeder. Radial feeders originate at substations, serve groups of customers, and are not connected to any other feeder. Power flows along radial feeders from substations to customers along a single path, which, when interrupted, results in loss of power to the customers served by those feeders. The 15kV lines are usually used for nearby rural areas and mainly for town areas, for Alaba city, Alaba gater, Durame city and Durame water.

The primary distribution system voltage (15kV) is then further reduced by distribution transformers to 380 volts three-phase or 220 volts single-phase supply required by most users of the area. Secondary distribution system (SDS) is fed by the distribution transformer, which step-down the distribution system voltage level down to secondary distribution level. SDS is usually radial networks and route the power within a close proximity to the customers. The service drop in the SDS connects the energy meter of each customer with the utility supply.

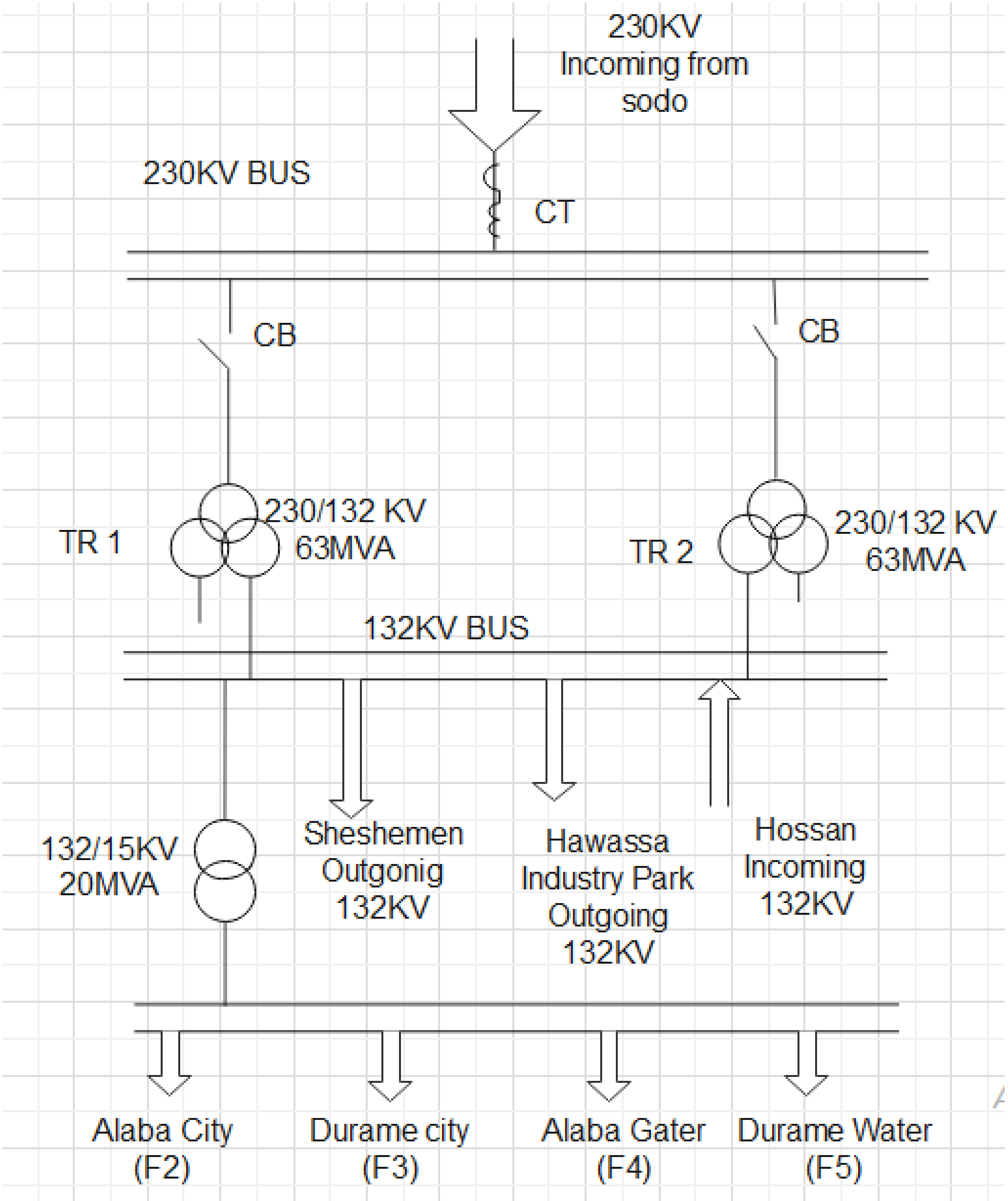

Figure 3.1 Alaba power distribution systems

3.3 Data Collected

Using the collected data from the distribution substation is summarized in table 3.1 below. The three years monthly power interruption frequencies and interruption durations are shown below using data from table 3.1, 3.2 and 3.3.

Table 3.1 Monthly Outage Frequencies and Durations of the four Feeders in 2019 G.C.

Feeder	Months	J	F	M	A	M	J	JU	A	S	O	N	D
Alaba city	F	25	28	20	27	27	22	24	23	21	23	19	17
	D	23.15	17.78	26.86	66.29	15.04	20.08	20.15	22.13	23.45	27.66	21.03	19.23
Durame city	F	23	26	25	24	27	24	35	33	20	16	22	25
	D	45.78	14.03	28.52	92.44	40.59	46.45	56.49	26.13	22.56	12.67	19.23	22.01
Alaba Gater	F	21	11	27	47	34	26	26	18	20	23	19	23
	D	34.08	8.79	15.64	75.65	15.33	13.17	13.17	16.20	22.07	19.45	22.03	19.02
Durame Water	F	8	19	19	18	8	15	15	12	12	19	18	16
	D	20.79	20.38	30.47	71.99	15.43	18.63	18.63	18.61	16.12	24.09	23.64	28.90

Table 3.2 Monthly Outage Frequencies and Durations of the four Feeders in 2020 G.C.

Feeder	Months	J	F	M	A	M	J	JU	A	S	O	N	D
Alaba city	F	26	22	48	12	26	19	17	21	15	24	16	20
	D	22.56	46.89	57.87	25.56	22.78	19.67	18.24	22.05	15.62	23.18	23.06	22.12
Durame city	F	22	27	47	37	22	56	32	27	29	33	24	28
	D	35.89	57.08	63.69	49.04	35.76	28.32	47.23	25.90	46.59	32.41	46.67	32.78
Alaba Gater	F	22	22	28	35	24	19	29	27	22	29	32	27
	D	42.78	48.08	82.34	35.78	19.06	22.62	35.62	16.17	16.78	33.85	35.84	38.23
Durame Water	F	19	22	16	26	15	13	12	28	14	23	12	18
	D	20.54	29.67	16.81	32.09	26.93	26.82	12.54	28.48	11.54	36.62	17.68	29.03

Table 3.3 Monthly Outage Frequencies and Durations of the four Feeders in 2021 G.C.

Feeder	Months	J	F	M	A	M	J	JU	A	S	O	N	D
Alaba city	F	9	14	10	10	14	19	21	24	19	23	25	18
	D	2.16	7.05	4.18	7.3	12.78	23.56	20.12	25.82	18.89	25.71	32.51	6.22
Durame city	F	5	18	11	21	23	19	18	23	54	60	69	58
	D	2.06	8.6	9.2	8.4	9.67	9.45	8.45	25.45	32.60	55.14	128.45	100.98
Alaba gater	F	12	11	9	7	25	25	40	58	34	49	69	42
	D	15.30	12.21	4.3	8.2	25.78	33.45	50.67	53.12	62.39	62.79	76.03	94.29
Durame Water	F	4	14	12	15	9	8	9	7	8	10	30	15
	D	6.08	10.11	7.09	10.4	12.67	10.56	6.65	8.56	12.72	13.60	33.54	9.21

Table 3.4 Total interruption value of consecutive three (2019-2021 G.C) years.

Feeders Name	Interruption Frequency(F) and Durations	2019 G.C	2020 G.C	2021 G.C
Alaba City	F	276	266	206
	D	304.85	319.33	165.98
Durame City	F	300	384	379
	D	426.9	501.27	390
Alaba Gater	F	295	286	381
	D	274.6	427.15	498.32
Durame Water	F	179	158	141
	D	297.65	232.13	140.68

In this thesis, a special emphasis is given only to feeder Durame city (15KV). This is because as per the data obtained from Alaba Distribution Substation and table 3.4 the mentioned Durame city feeder has frequent and more frequency and duration interruptions than the other feeders in the existing substation.

The table 3.4 shows the frequency and duration of interruptions highly increased from 2019G.C to 2020G.C because of the Government of Ethiopia did high expansion to electrify the rural kebele's without enough awareness the community about trimming the trees, animal contact from distribution line. As result, increases the interruptions but from 2020G.C to 2021G.C slightly decreased the interruptions because of certain amount worked on the trimming the trees and opened additional office in Shone and Adilo town that means increase the workers for operations/maintenance the line. Therefore, for this thesis 2020G.C Durame feeder data has been used as a base year.

3.4 Interruption Data from 2019 G.C to 2021G.C

Among the different kinds of power system faults, frequently occurring faults at Alaba substation contain permanent and transient earth fault, permanent and transient short circuit, and interruptions due to operation/maintenance.

Table 3.5 shows the duration and frequency of these different types of faults such as permanent Earth Fault (PEF), Permanent Short circuit (PSC), Transient Earth fault (TEF) and Transient Short circuit (TSC) [18].

Table 3.5 Planned and Unplanned power interruption 2019-2021G.C.

Name of Feeder	TEF		PSC		TSC		PEF		OPR	
	F	D	F	D	F	D	F	D	F	D
Alaba city.	167	155.42	122	144.03	149	160.45	139	148.7	171	181.56
Durame city	208	257.56	192	255.03	205	253.79	219	279.42	239	272.37
Alaba Gater	167	213.85	179	194.56	202	249.74	203	266.12	211	275.8
Durame Water	94	127.09	76	94.2	104	152.25	98	149.53	106	147.39
Total	636	753.92	569	687.82	660	816.28	659	843.77	737	877.12

Table 3.6 Feeders Outgoing from Alaba distribution Substation in 2020 G.C.

No.	**Name of the feeder**	**Feeder Line Voltage(kV)**	**Feeder Load Current(A)**	**Average Load (MW)**
1	Alaba city	15	120	3.2
2	Durame city	15	120	4.44
3	Alaba Gater	15	120	2.8
4	Durame water	15	120	2.5

The above table 3.6 shows us Durame city feeder has high peak load (MW) than other feeders.

Table 3.7 Transformers rate.

Feeder Name			Transformer Capacity(kVA)								
	25	50	100	160	200	315	400	500	630	800	1250	TOTAL
Durame city	21	28	70	-	18	15	1	1	1	1	-	156

The table 3.7 indicates the type of transformer and their capacity of Durame city feeder

Table 3.8 Total number of customers served.

Alaba distribution substation Durame city feeder	2019 G.C	2020G.C	2021G.C	Total number of customer served from Alaba substation
Number of customers	12,645	14,784	14,884	33,833

The above table 3.8 shows us the feeder has residential, commercial and small industrial customers. The number of customers is increased yearly.

3.5 Customer Cost of Electric Service Interruptions

The main objective of modern electric power system is to provide an adequate electrical supply to its customers as economically as possible at a reasonable level of reliability. It is essential to recognize that reliability and economy must be preserved together in-order to perform objective cost benefit studies. That is to maximize the reliability, utility should balance their reinforcement cost for reliability improvement and the customer cost for poor reliability. Therefore, the optimal level of reliability is said to be achieved when the sum of utility cost and the customer cost are minimum. The total cost is the sum of the utility/investment cost and the customer cost as stated in chapter four below.

Purpose of outage cost is to understand the nature of faults and variety of customer impacts that would be resulted due to electric service interruption. The effect of interruption or outage cost can be generally classified into direct and indirect costs.

Direct costs are those arising directly from the electrical interruption and relate to such impacts as lost industrial production, spoiled food or raw materials, personnel leisure time, injury or loss of life. Indirect costs are related to impacts arising from response to the interruption, such as crime during blackouts (short term), business relocation (long term) and civil disobedience and looting during an extended blackout [19].

3.6 Feeder Single Line Diagram Using ETAP Software

The existing structure of Durame city feeder consists of IEEE-156 bus system is modeled using ETAP 16.0.0 in order to determine the application of whale optimization algorithm a case study is performed using 132/15KV Durame city distribution feeder. The number of switches and their locations are not optimized. The optimal location for placement of sectionalizer switches on the distribution feeder shown in Figure 4.5 is obtained with the help of whale optimization algorithm. The developed program based on whale optimization is implemented in MATLAB software. This feeder which has three sectionalizer switches with 156 load points is shown in Figure 3.3.

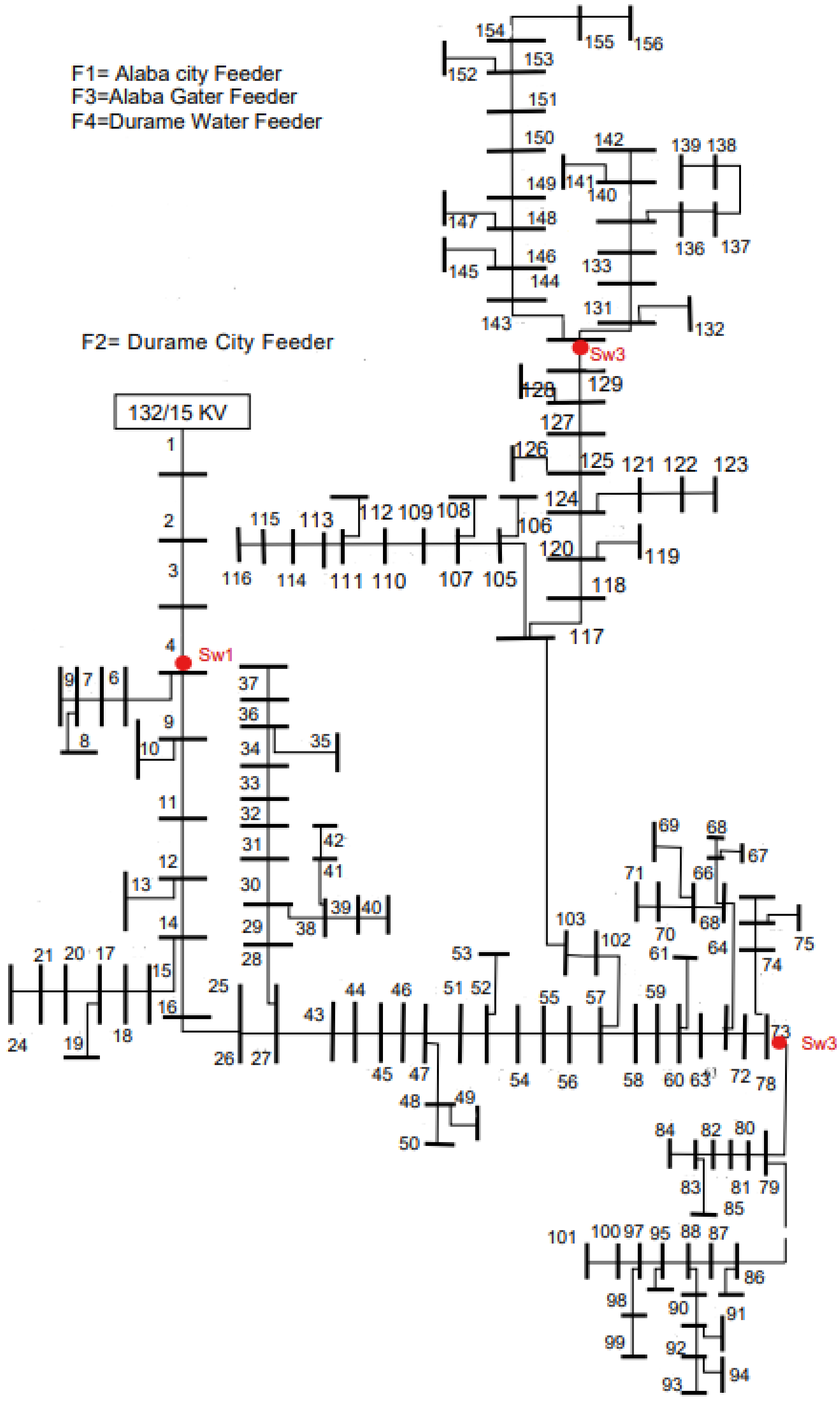

Figure 3.2 Single line networks Durame city feeder (bus-156).

3.7 Reliability Indices Evaluation Using Sequential Monte Carlo Simulation Method

Both expected values and probability distribution of the indices are analyzed using sequential Monte Carlo Simulation technique. The basic parameters needed to evaluate the indices are Average Failure rate (λ), Mean time to Repair (MTTR) and power of each load point. For this study 1000 iterations have been carried out in order to simulate load points and system indices. The below figure parameter found Appendix **A** and Appendix **B**. The following figures show the distribution of reliability indices of Durame city feeder.

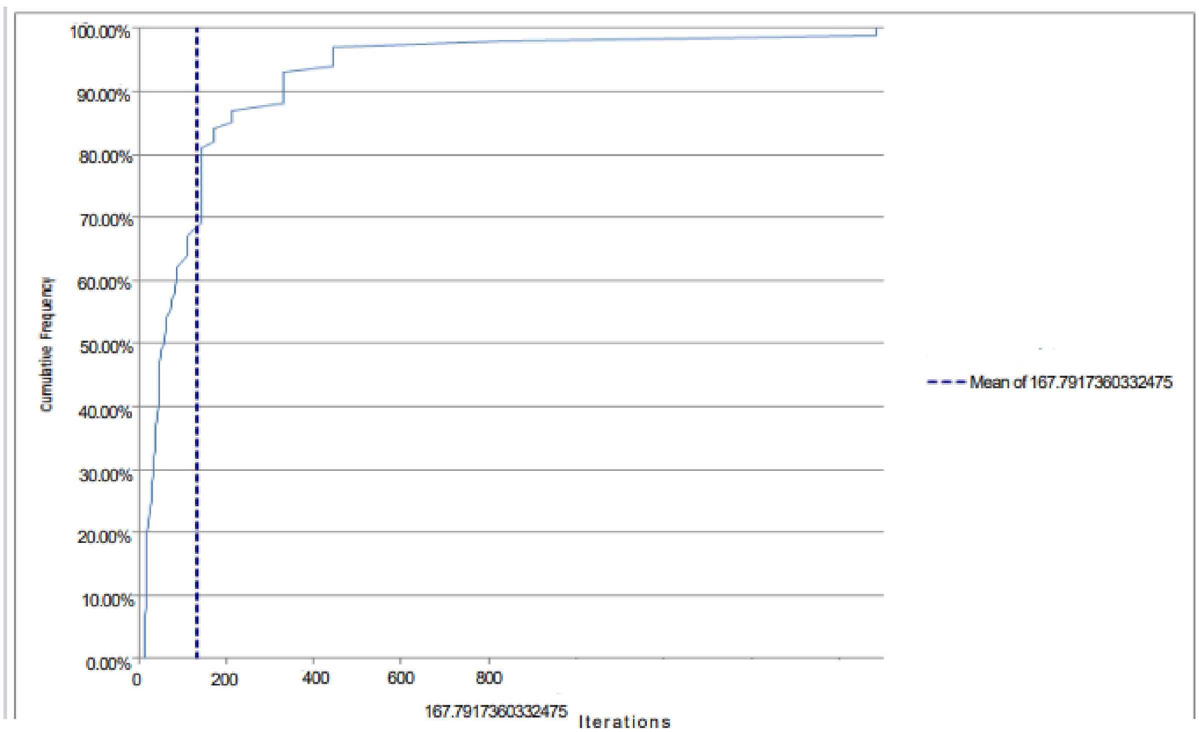

Figure 3.3 SAIFI value for Durame city feeder.

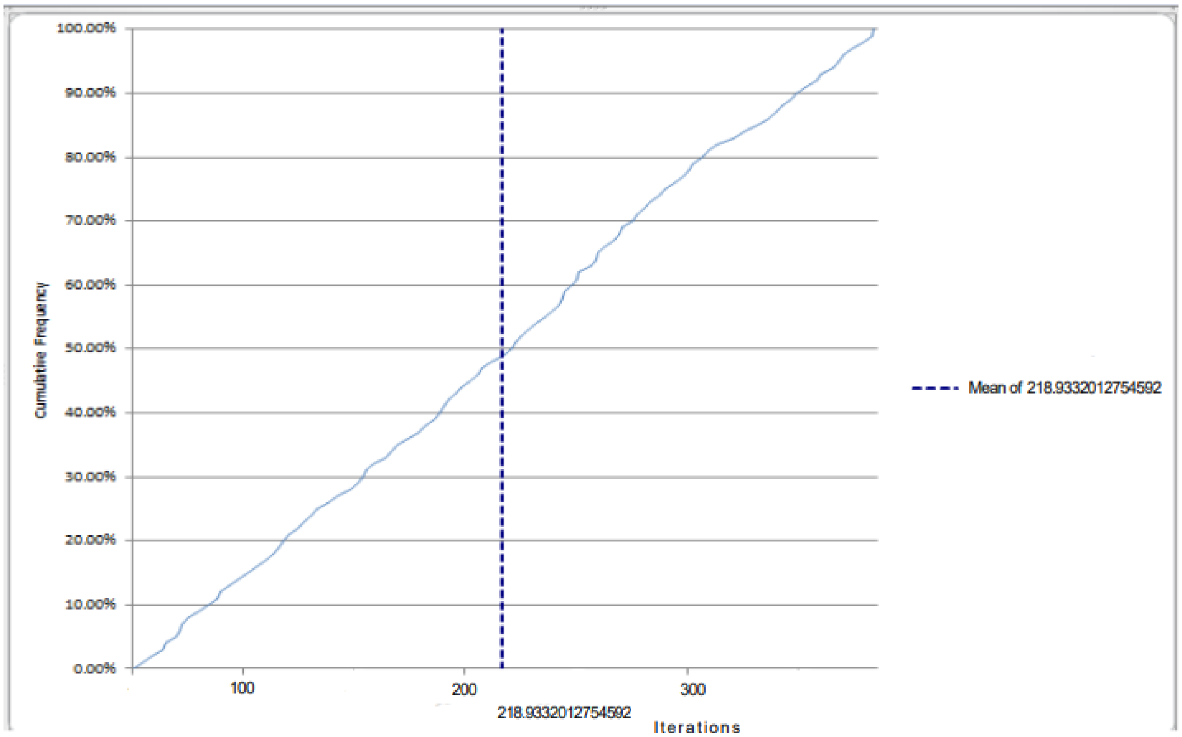

Figure 3.4 SAIDI value for Durame city feeder.

The above figure 3.3 and 3.4, show us the blue straight dot line indicate exact value of SAIFA and SAID respectively and accumulative probability.

3.8 Comparison of the Calculated Values of Reliability Indices with Benchmarks

In the Table 3.9 bellow, shows the calculated Reliability indices values of Durame city feeder (F2) compared with Ethiopia Electric Agency standard and other country benchmark values most commonly used reliability indices. This thesis also focuses on the customer oriented reliability indices and energy oriented indices.

Table 3.9 Comparisons of SAIFI and SAIDI values EEA and other country benchmarks.

Countries	**SAIFI (Int./Year/Customer)**	**SAIDI (Hr./Year/Customer)**
United States of America	1.5	4
Italy	2.2	0.967
France	1.0	1.03
Denmark	0.5	0.4
Australia	0.9	1.2
Spain	2.2	1.73
Canada	3.4	6.9
Netherland	0.3	0.55
United Kingdom	0.8	1.55
Germany	0.5	0.383
Ethiopia	20	25
Alaba (Durame City Feeder)	167.79	218.93

3.9 Data Analysis

Based on the data collected from Alaba distribution substation we can summarize the power reliability indices of the Durame city feeder in the following manner.

- System Average Interruption Frequency Index (SAIFI) of the overall system as shown in Table 3.9 is 167.79 Int. /yr. As per Ethiopian Electrical Agency's (EEA‟s) standard, SAIFI should not exceed 20 interruptions per customer per year, which indicates that the current value is above the acceptable value by a large margin and also, when we compare the calculated SAIFI value with Denmark standard, it is much greater than the maximum limit [20]. Above mentioned value clearly indicates that there is serious reliability problem in the existing Durame city feeder.

- System Average Interruption Duration Index (SAIDI) of the overall system from Table 3.9 is 218.93 hours per customer per year. This indicates that there is great reliability problem in the existing Durame city feeder. As per the Ethiopian Electrical Agency's

(EEA), the SAIDI value should not exceed 25 hours per customer per year [20]. The permissible SAIDI value in Denmark is 0.4 hours per customer per year [20].

Lastly, based on the data analysis the following conciliations have derived.

- The power reliability of the Durame City feeder, F2 does not meet the standards set by the Ethiopian Electric Agency (EEA).
- In the study area of city feeder line, F2 has high Unreliability power service.
- The effect of planned and unplanned outages in the existing power grid of Durame city feeder line, F2 has more loss of Unsupplied Energy.

3.10 Electric Tariff

Table 3.10 Electricity tariff Ethiopian Electric Power (EEP)

Customers	Monthly consumption (kWh)	Price Rate (Birr/kWh)
Residential	0-50	0.2730
	51-100	0.7670
	101-200	1.6250
	201-300	2.0000
	301-400	2.2000
	401-500	2.4050
	Above 500	2.4810
General Tariff		
Flat Rate		2.1240
Low Voltage Industry Tariff		
Flat Rate		1.5310

The cost of energy that is not provided to the customers is given by the following equation:

$$\text{EENS} = \text{Average Peak load} * \text{Annual outage time} \quad (3.1)$$

$$\text{Cost of EENS} = \text{Average Peak load} * \text{Annual outage time} * \text{cost/KWh} \quad (3.2)$$

Where ,

EENS = Expected Energy Not Served

Peak load = Average peak load per year

Time of outage = total time of power interruption per year

From above electric tariff table taking an average price of 2 ETB per KWh for the electricity according to EEP [21], the average energy not supplied and average cost of energy not supplied due to power interruption per year for each outgoing feeder of Alaba distribution system (ADS) of Durame feeder (15KV) are calculated using the above equations (3.1) and (3.2) and tabulated in table below.

Table 3.11 Average and Peak Load of the Substation Durame city feeder in 2020 G.C

Name of feeder	Peak Load (MW) 2020 G.C		
Durame City Peak load(MW)	Min.	Max.	Average Peak load(MW)
	3.08	5.8	4.44

In this thesis work using values in table 3.12 we can get the values of EENS and Cost of EENS for Feeder per year as shown in table below.

EENS=Average peak load*Annual outage hour per year

$$\text{Failure rate } (\lambda) \text{ per km} = \frac{\text{Number of interruption}}{(\text{Total feeder length}) * (\text{Number of interruptio year})}$$

$$= \frac{384}{45.5\ km * 1 year} = 8.439 \frac{\text{f}}{km/year}$$

MTTR=$\frac{\text{Total duration of outage}}{\text{Total number of outage}} = \frac{501.27}{384} =$1.305 $\frac{\text{hrs}}{f}$

Average Annual outage time (u) = ($\lambda * $ MTTR)

= ((8.439 * 45.5) * 1.305) = (383.97 * 1.305) = 501.08 h/year.

EENS=4.44MW*501.08h/year

EENS=2,224.79MWh/year

Cost of ENNS=2,224.79 *1000KWh/year *2 ETB

Cost of ENNS=4,449,590.4 ETB

Table 3.12 Expected energy and cost due to EENS.

Feeder	EENS (MWh/year)	Cost of EENS (KW/Birr/year)
Durame city (2020 GC)	2,224.79	4,449,590.4

3.11 Power Flow Equation

Using whale optimization algorithm searching best fitness performed by the switching of the existing sectionlazer switches. While performing WOA the main focus is done to choose the optimally best allocation of the sectionalizer switches. It helps to obtain maximum loss reduction for the network. The determination of the loss reduction before and after using proposed method can be easily achieved by the load flow study. Consider the one line diagram of a radial system as shown in figure 3.6.

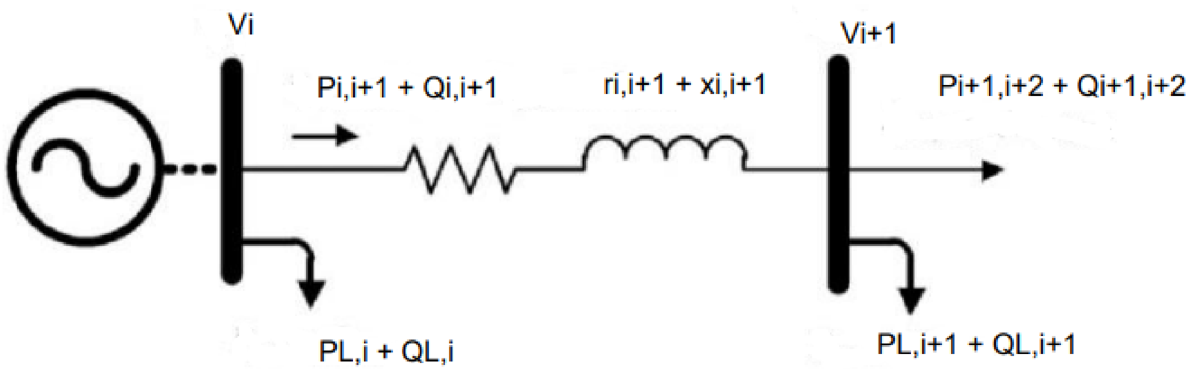

Figure 3.5 Single line diagram of radial system

The power flow equation is calculated by:-

$$Pi = Pi{+}1 + PLi{+}1 + ri\,\frac{Pi^2+Qi^2}{|Vi|^2} \tag{3.3}$$

$$Qi = Qi{+}1 + QLi{+}1 + Xi\frac{Pi^2+Qi^2}{|Vi|^2} \tag{3.4}$$

$$|Vi|^2 = |\mathbf{V}i{+}1|^2 + 2(riPi + xiQi) - (ri^2 + xi^2)\frac{Pi^2+Qi^2}{|Vi|^2} \tag{3.5}$$

Where **P**i and **Q**i indicates the active and reactive power of the source end bus i, **P**Li and **Q**Li is the real and reactive load power for bus i, **V**i is bus i voltage, **r**i and **x**i is the resistance and reactance. |**Vi+1**|² represent voltage magnitude at $\mathbf{i+1^{th}}$ bus.

3.11.1 Problem Formulation

The formulation is done in such a way that it can lessen the active power loss and to maintain a healthy profile of the system voltage. This can be achieved by optimally selecting the location and the combination of the switches.

$$\text{Min}\mathbf{P}\text{ower losses} = \sum_{i=1}^{n}(Ii^2)Ri \tag{3.6}$$

Where,

N = the total branch number,

$\mathbf{I}i$ = indicates branch current at $\boldsymbol{i^{th}}$ node, and

$\mathbf{R}i$ = the branch resistance.

The limitations of the network are:

1. Voltage limit

$$Vmin \leq Vbus \leq Vmax \tag{3.7}$$

2. Power flow limit

The line power flow (**PFl**) should be always less than the maximum limit of power flow $\boldsymbol{PFl^{max}}$ as:

$$\boldsymbol{PFl} < \boldsymbol{PFl^{max}} \tag{3.8}$$

3.12 Rating of Sectionalizer Switch

The following factors should be considered when (technically) selecting a sectionalizer:

1. The nominal voltage and current of a sectionalizer switch should be equal to or greater than the maximum value of voltage or load at the point of installation.

2. The short-circuit capacity (momentary rating) of a sectionalizer switch should be equal to or greater than the fault level at the point of installation. The maximum clearance time of the associated interrupter should not be permitted to exceed the short-circuit rating of the sectionalizer switch.

3. Coordination factors that need to be taken in to account include the starting current setting and the number of operations of the associated interrupter before opening.

2.13 Operating Mechanism of Sectionalizers

Sectionalizer switches are constructed in single-or three-phase arrangements with hydraulic or electronic operating mechanisms

2.13.1 Hydraulic Operating Mechanisms

Sectionalizer with hydraulic operating mechanisms has a working coil in series with the line. Each time an overcurrent occurs, the coil drives a piston that activates a counting mechanism when the circuit is opened and the current is zero by the displacement of oil across the chambers of the Sectionalizer switch. After a pre-arranged number of circuit openings, the sectionalizer switch contactor is opened by means of pre-tensioned springs. This type of sectionalizer switch can be closed manually.

2.13.2 Electronics Operating Mechanisms

Sectionalizer switches with electronics operating mechanisms is more flexible in operation and easier to set. The load current is measured by means of CTs, and the secondary current is served to a control circuit that counts the number of the recloser or the related interrupter and then sends a tripping signal to the opening mechanism. This type of sectionalizer is constructed with manual or motor closing.

The electronic controlled mechanisms are more flexible and easier to set compared to the hydraulic mechanism. The have both manual and automatic motor controlled opening and closing options.

2.13.3 Sectionalizer Switches Advantages

1. Solution in areas where fuse coordination is difficult due to large available short circuit current (i.e. close to substation).
2. Less specification to consider: Sectionalizer switches do not have an interrupting rating.
3. Less system coordination studies needed: Sectionalizer switches do not have time-current characteristics.
4. Afford an additional point to monitor currents and voltages on the system.
5. Can be functional in distribution automation schemes such as Fault Location, Isolation and Service Restoration.
6. Improve reliability breaking down circuits into smaller sections to reconfigure.
7. More economical than recloser

CHAPTER FOUR

SIMULATIONS, RESULTS AND DISCUSSION

4.1 The Simulation Result of Durame City Feeder

The simulation results for proposed system two different cases are considered for the implementation of the stated algorithm as explained below:-

Case: -I Network with three sectionalizer switches (existing case)

Case: - II Network after optimal allocation and sizes sectionalizer Switches installed**.**

4.1.1 Case:-I Network with Three Sectionalizer Switches (Existing Case)

In Table 4.1 shows that the existing case SAIFI, SAIDI, EENS and EENS cost of Durame feeder. The SAIFI, SAIDI, EENS and EENS cost of the feeder are 167.79 int/cust/yr., 218.93hr/cust/yr., 2,224.79MWhr/yr., 4,449,590.4 Birr/yr., respectively.

Table 4.1 Existing case reliability indices

Reliability index	SAIFI (int/cust/yr.)	SAIDI (hr./cust/yr.)	EENS (MWh/year)	Cost of EENS (KW/Birr/year)
Value	167.79	218.93	2,224.79	4,449,590.4

From the above table 4.1 the data is obtained by simulating the single line diagram of the distribution substations of Durame city which is existing system data but the power loss is obtained by calculating the total loss of the feeder from energy not supplied data.

4.1.2 Case: - II Network After Optimal Allocation and Sizes Sectionalizer Switches Installed.

The better understanding and the association of the natural hunting behavior of the whale with the real-time distribution system plays an important character. The prey location specifies the weak bus in a given test system. The best defined agent mentions to the optimally determined switch combination. Additional, the update of their location is done as per the best search agent, which connects the distribution system as the update for the selected switch combination for the operation to be achieved. The basic parameters needed to evaluate section length, length from distribution, Installed load value of KVA, Average failure rate (λ) and number of load. For this study 1000 iterations have been carried out in order to search the best fitness value. The following figures show the best fitness value of proposed case system to determine the optimal place and size of sectionilazer Switches. The figures parameters value are found at appendix **A** and appendix **C**.

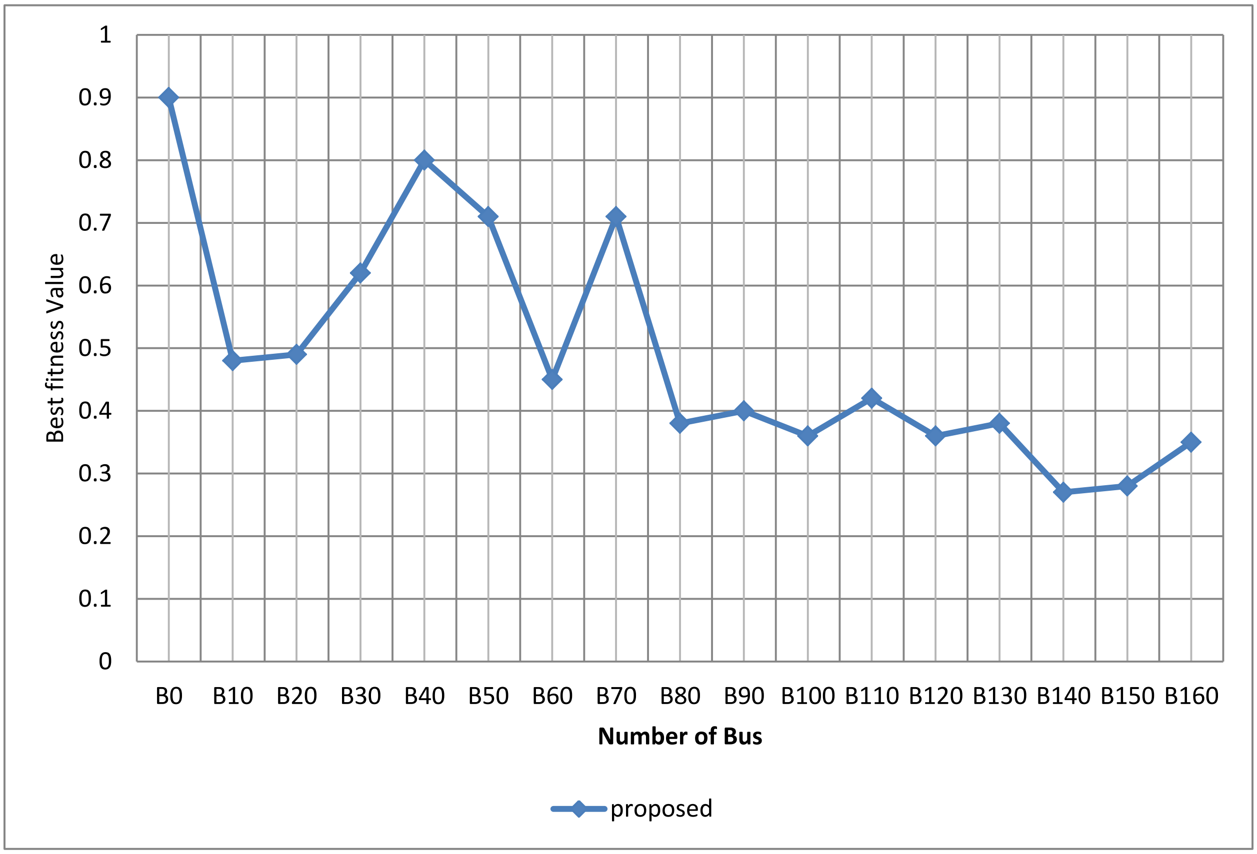

Figure 4.1 Show the best fitness value of the network the proposed case system.

This result in Figure 4.1 show us ten best optimization fitness value in otherwise the optimal number of sectionilazer switches have been optimized to ten that means seven additional switches are important to the given test feeder. These are found between on bus B3-4,B12-14,,B29-30,B46-47,B64-66,B73-79,B87-88,B103-117,B129-130,B149-150 and the existing network sectionilazer switches are found between on bus B3-4,B129-130,B73-79.

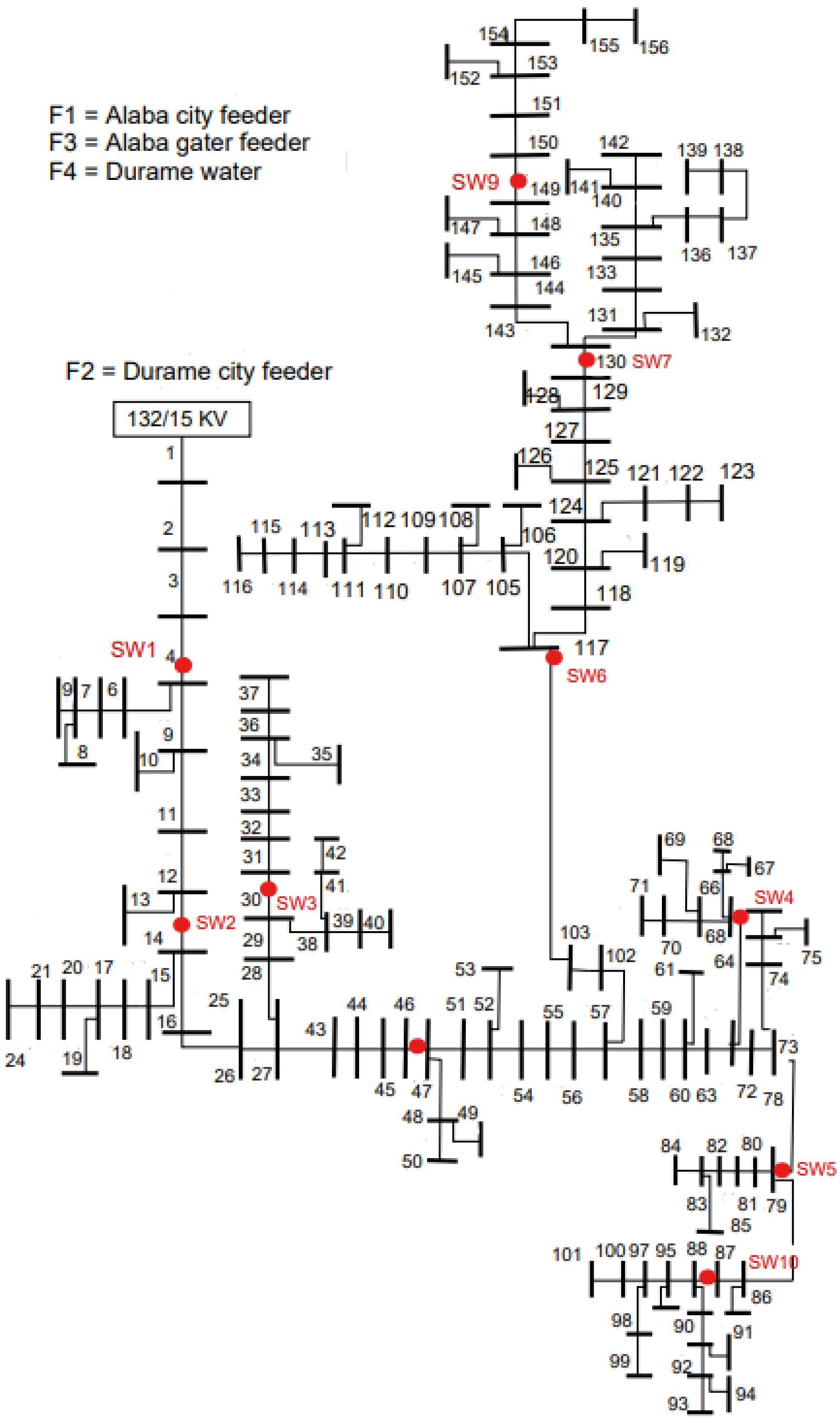

Figure 4.2 Durame city feeder after optimization.

Table 4.2 Sectionalizer switches optimal place and numbers.

Optimization Method	Number of Switches	Sectionalizer Switches	Sectionalizer Switch Location	Additional Switches
Existing	3	Sw1,Sw2,Sw3	B21-24,B73-79, B129-130	-
WOA	10	Sw1,Sw2,Sw3,Sw4,Sw,5Sw6,Sw7,Sw8,Sw9,Sw10	B3-4,B12-14,,B29-30,B46-47,B64-66,B73-79,B87-88,B103-117,B129-130,B149-150	7
PSO	10	Sw1,Sw2,Sw3,Sw4,Sw,5Sw6,Sw7,Sw8,Sw9,Sw10	B3-4,B23-43,,B56-57,B73-74, B87-88 ,B105-106,B93-117,B129-130, B135,136,B149-150,	7

Table 4.2 shows the best placement obtained when taking into account an increasing number of switches. Clearly, the larger the number of switches, the better the SAIFI and SAIDI results (in terms of improvements with respect to the case I). The improvement on SAIFI and SAIDI given by an increasing number of switches can be used as basis to perform a cost/benefits analysis to establish the optimal number and location of switches to be installed, taking into account the switch installation and maintenance costs and the resulting return of investment.

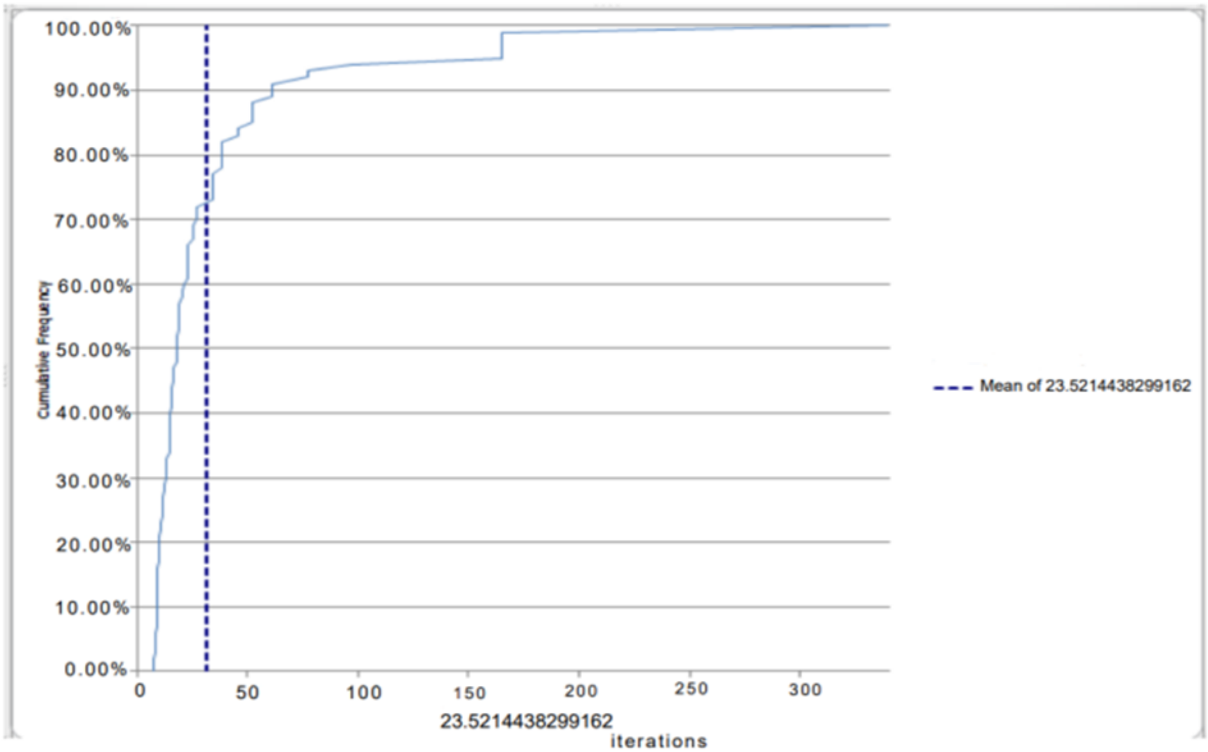

Figure 4.3 After Optimization SAIFI value for Durame city feeder.

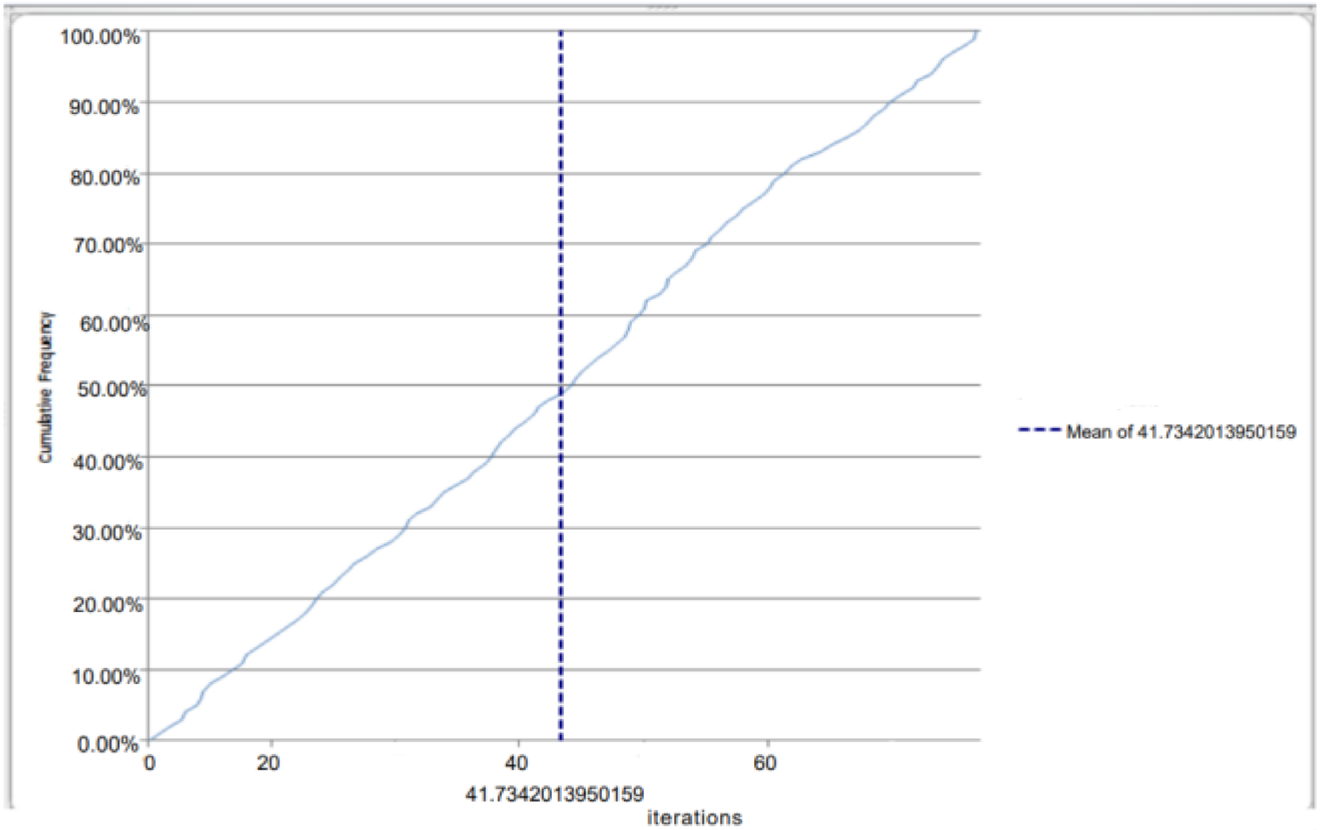

Figure 4.4 After optimization SAIDI value for Durame city feeder

The above figure 4.3 and 4.4, shows us the blue straight dot line indicate existing line exact value of SAIFA and SAID respectively and accumulative probability.

Table 4.3 Whale optimization algorithm system reliability indexes.

Reliability index	SAIFI (int/cust/yr.)	SAIDI (hr./cust/yr.)	EENS (MWhr/yr.)	Cost of EENS (birr/yr.)
Value	23.52	41.73	734.199	1,468,398

4.2 Comparison Result between Existing Case with PSO and WOA.

Table 4.4 Comparisons reliability indices of existing case with PSO and WOA.

Reliability index	Existing	PSO	WOA
SAIFI (int/cust/yr.))	167.79	28.45	23.52
SAIDI (hr./cust/yr.)	218.93	53.12	41.73
EENS (MWhr/yr.)	2,224.79	808.67	734.199
Cost of EENS (Birr/year)	4,449,590.4	1,617,340	1,468,398

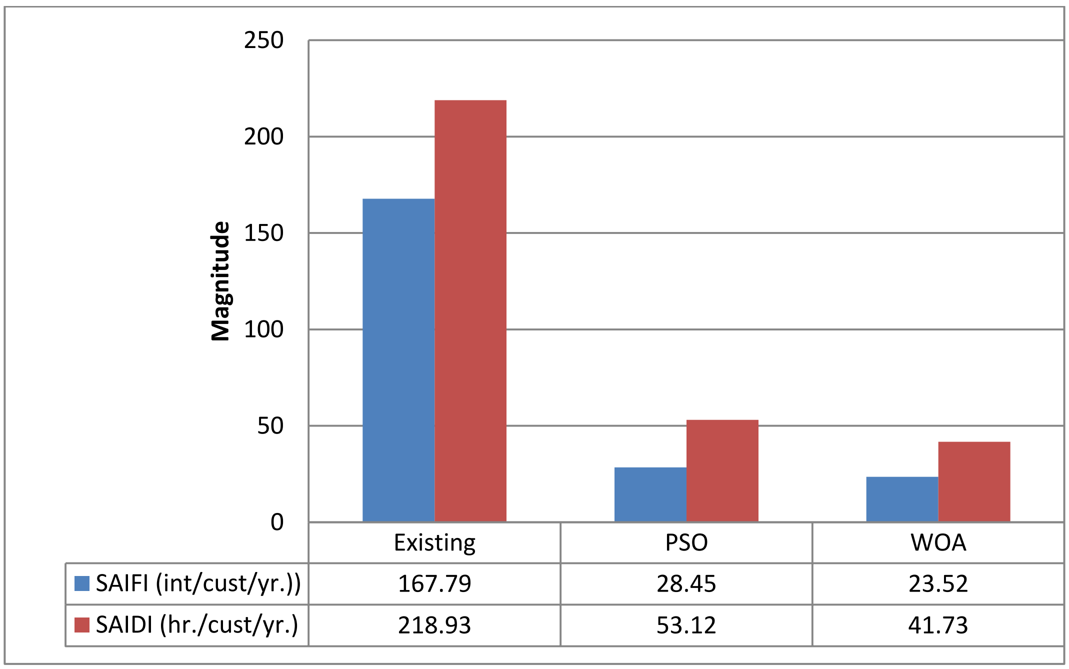

Figure 4.5 Comparison SAIFI and SAIDI of existing with PSO and WOA

Table 4.5 Comparison EENS of existing case with PSO and WOA

Case	EENS (MWhr/yr.)
Existing	2,224.79
PSO	808.67
WOA	734.199

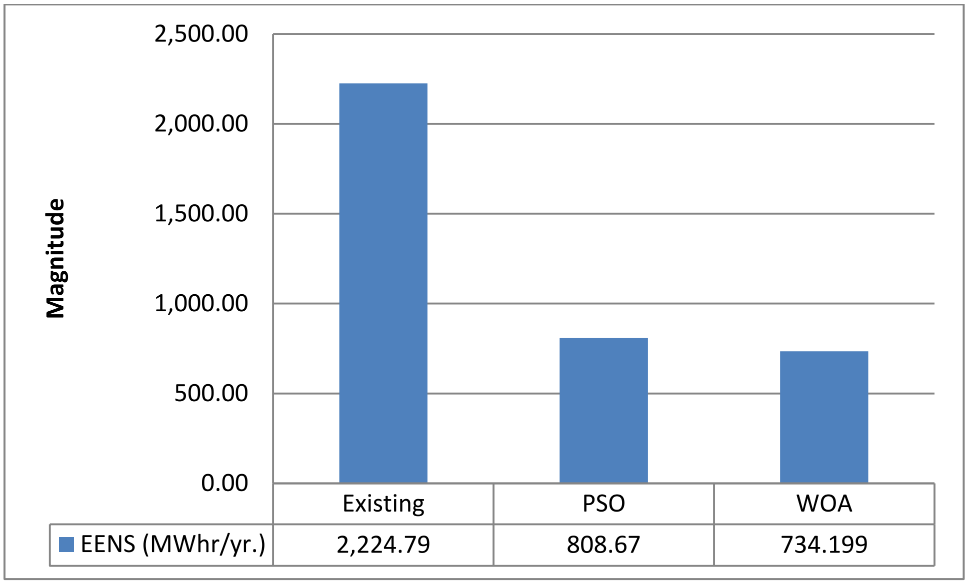

Figure 4.6 Comparison EENS of Existing Cases with PSO and WOA.

Table 4.6 Comparison Cost of EENS of existing Cases with PSO and WOA.

Case	Cost of EENS (Birr/yr.)
Existing	4,449,590.4
PSO	1,617,340
WOA	1,468,398

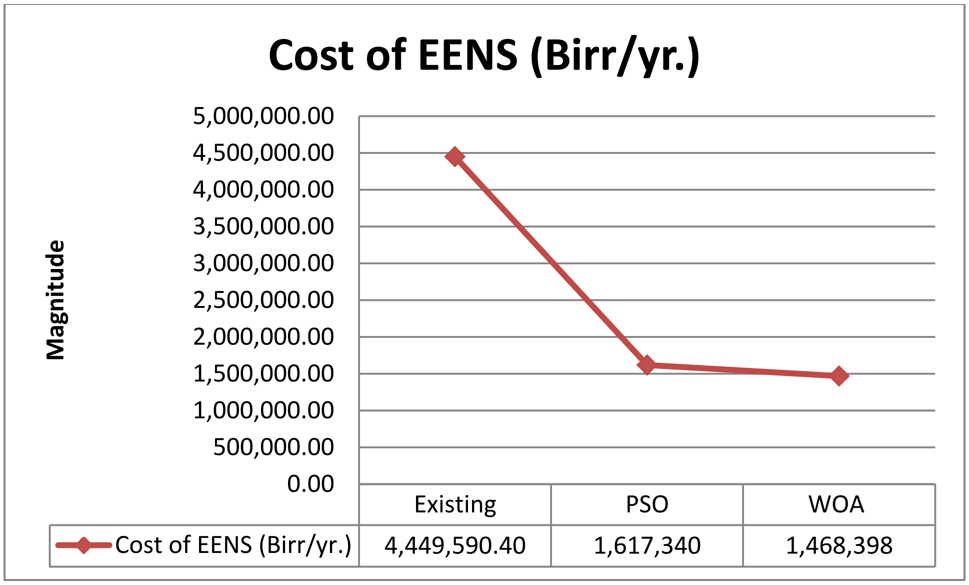

Figure 4.7 Comparisons Cost of EENS of Existing with POS and WOA.

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

4.2.1 State of Convergence of Existing, PSO and WOA.

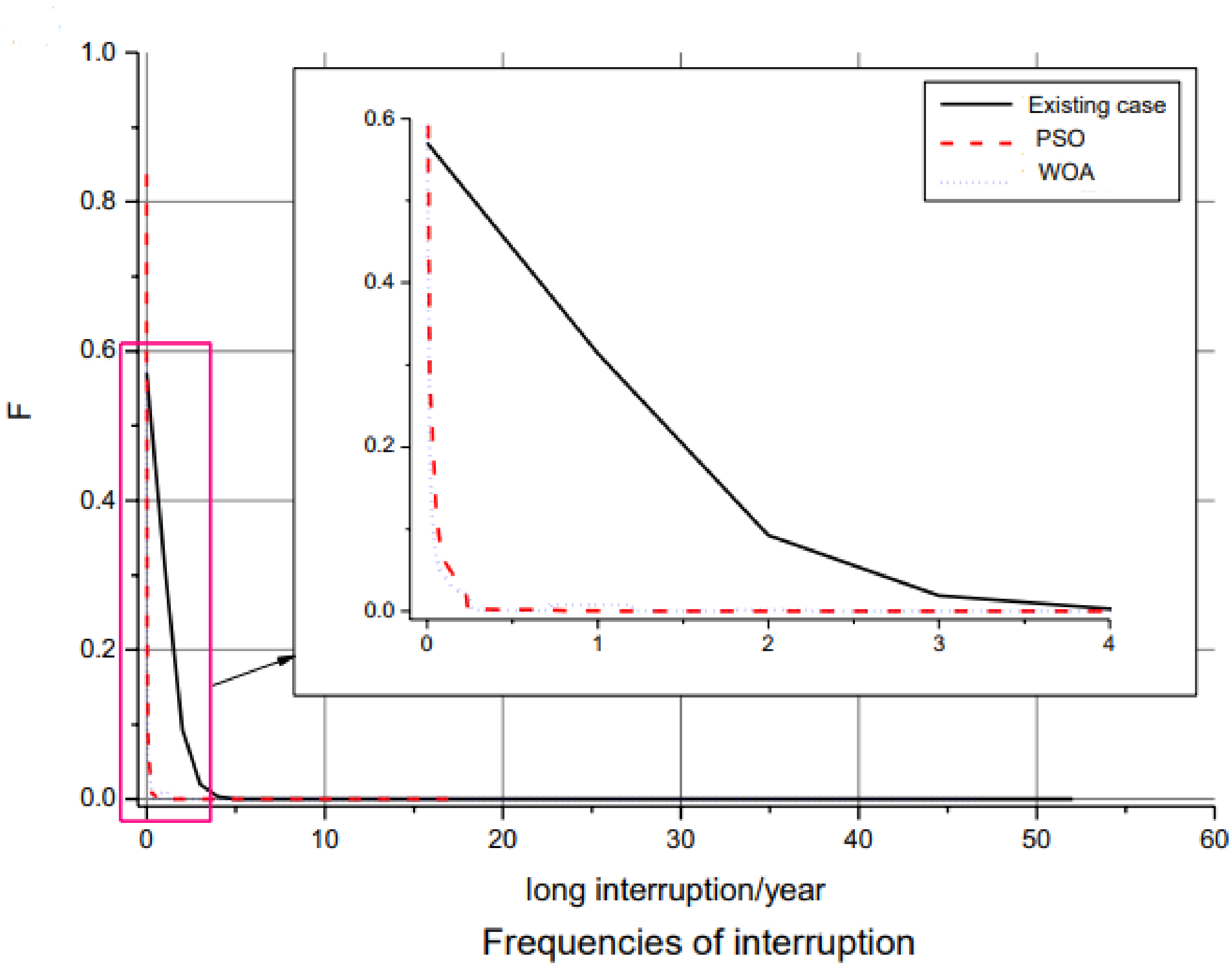

Figure 4.8 State of Convergence the frequencies of Existing case,PSO and WOA

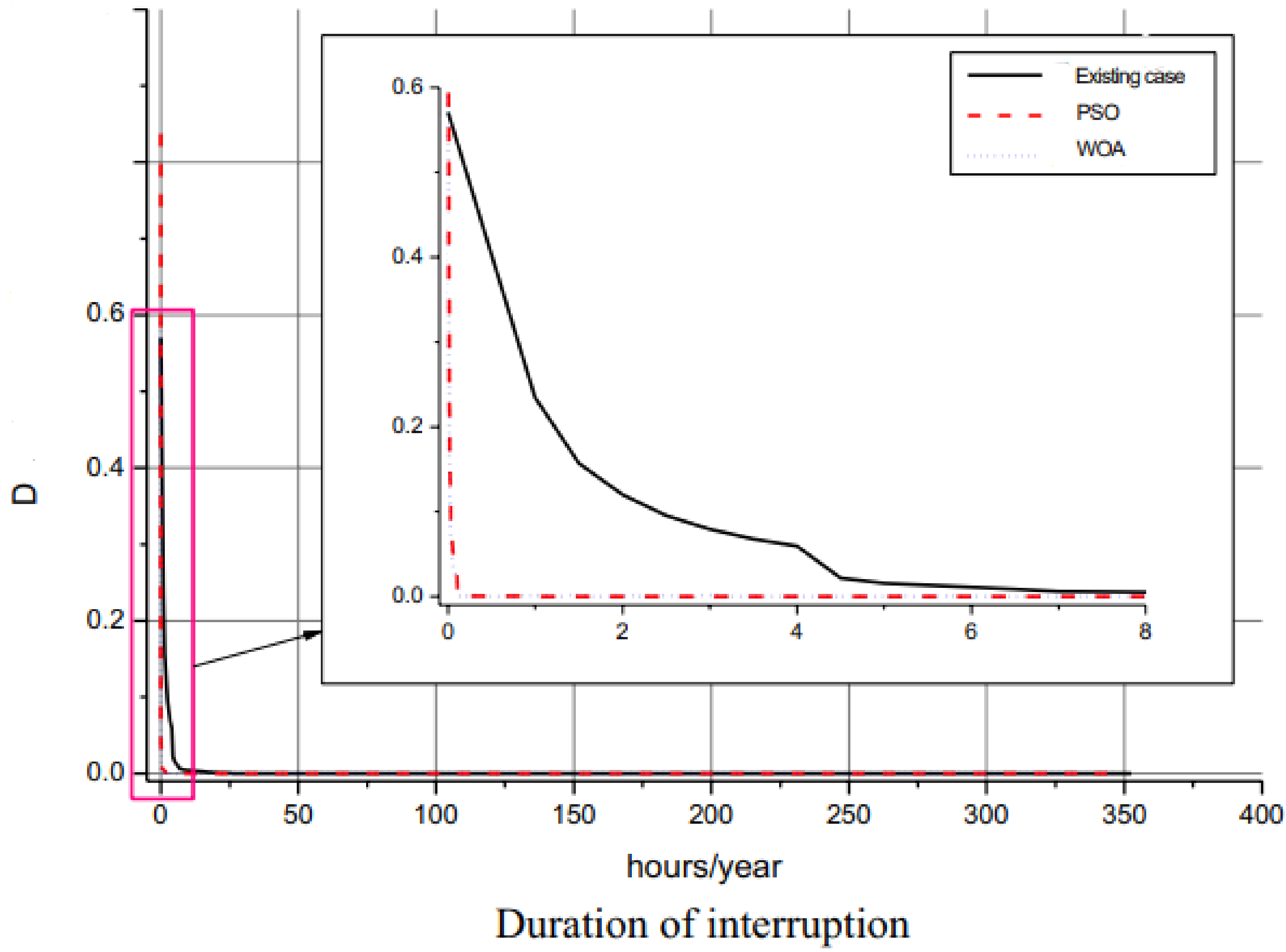

Figure 4.9 State of Convergence the interruption duration of Existing case, PSO and WOA

The above figure 4.8 and 4.9 shows in the case of WOA with small iteration it convergence to optimal solution than existing case and PSO.

4.3 Advantages of the Whale Optimization Algorithm

- ✓ WOA has an ability to avoid local optima and get a global optimal solution**.**
- ✓ WOA has simple structure, few control parameters and considerable avoiding local optimum**.**

- ✓ WOA is based on the intelligence. It can be applied into both scientific research and engineering use.

4.3.1 Comparison of Whale Optimization Algorithms with Others Algorithms

WOA has high local optima avoidance and convergence speed simultaneously during the path of iterations. But, PSO (particle Swarm optimization) and GSA do not have operators to devote specific iterations to exploration or exploitation. In other words, PSO and GSA (and any other similar algorithms) utilize one formula to update the position of search agents, which increase the likeliness of stagnation in local optima.

4.4 Cost of Implementation of Proposed Method of Reliability Improvement

Power interruption costs in both the customer sides and the utility. The magnitude of the economic loss due to interruptions depends commonly on the composition of the customers that experience interruptions. Customers in Durame city utility are roughly divided into three categories:-

- ✓ Residential
- ✓ Commercial and
- ✓ Small industrial customers.

For small industries, electricity supply interruption costs are strongly related to production losses and to costs involved in restoring production. In addition, interruptions also cause property damages and revenue loses for industries, commercial customers and for private individuals. It is difficult to estimate the exact value of interruption costs and economical loses, since the properties of each customer are different and difficult to found important data.

Table 4.7 Show improvement of existing case by used WOA

Reliability index	Existing	WOA	Improvement (%)
SAIFI (int/cust/yr.))	167.79	23.52	85.98
SAIDI (hr./cust/yr.)	218.93	41.73	80.93
EENS (MWhr/yr.)	2,224.79	734.199	67
Cost of EENS (Birr/year)	4,449,590.4	1,468,398	66.44

The above tables 4.7 represent how much percent improved the existing case of SAIFI, SAIDI, EENS and Cost of EENS after the proposed method has been used.

4.4.1 Expected Energy Not Supplied

In this thesis, an economical cost analysis has been done based on the interruption cost only related to the utility side by using Expected Energy Not Supplied (EENS). Annual average unsold energy is reduced from 2,224.79 to 734.199MWh per year as shown in Table 4.7 Therefore; the revenue saved due to reliability improvement can be estimated as follows.

The cost of energy that is not provided to the customers is given by the following equation:

EENS = Average Peak load * Annual Outage time

Cost of EENS = Peak load *time*cost/KWh

Where EENS = Expected Energy Not Served

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

Case 1: Network with three sectionalizer switches (existing)

The Revenue loss before improvement due to unsold energy is:

=2,224.79 X 1000 KWh/year X 2birr

Financial loss =4,449,590.4 ETB.

Case 2: After determination and allocation optimal number of sectionalizer switches by WOA.

After improvement due to unsold energy is:

=734.199 X 1000 KWh/year X 2 birr

Financial loss= 1,468,398 ETB.

The total annual economic saving cost= cost of saving from EENS (before optimization) - cost of saving from EENS (after optimization)

=4,449,590.4 ETB - 1,468,398 ETB.

=2,981,192.4 ETB.

4.4.2 Investment and Payback

Currently, the Average cost of pole mounted drop out ,Rockwill Auto link electronics sectionalizer switch voltage 15 KV and 200A rating is $5500 (USD) (Based on the currency exchange rate found from Commercial Bank of Ethiopia on Saturday 6 In, May 2023 One US Dollar (USD) is sold by 54.02 Ethiopian Birr (ETB)

Total cost of sectionalizing switches=7* 5500$=38,500$

Wooden pole =5x8000ETB=40,000ETB=754$

Electrical AAC Conductor=1rollx239$=239$

Investment cost Sectionalizer Switches= Total cost of (Switches, pole and AAC) +Installation Cost + Maintenance Cost.

= Total cost of Switch + 10% Total cost of Switch+2% Total cost of Switch

= 39493$+3949.3$ +679.86$

= 44122.16$ = 2,383,479.08ETB

Based on investment and benefit cost of payback is calculated. Therefore, payback period is the period or length of time required to regain the cost expended in an investment. It is the ratio of the cost of investment to the yearly saving at Durame city feeder by using that investment.

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

$$\text{Payback period} = \frac{\text{Investment cost}}{\text{Economic saving cost}} \tag{4.1}$$

$$= \frac{2{,}383{,}479.08 \text{ ETB}}{2{,}981{,}192.4 \text{ ETB}}$$

$$= 0.79 \text{ year}$$

$$=9.48 \text{ month}$$

Therefore, the payback period is only nine month and fifteen a days. Generally, by determination and allocation optimal number of sectionalizing switches, the number of interruption in distribution system (Durame city F2) is reduced.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this thesis work, the assessment of the distribution reliability for Durame city feeder done by Monte Carlo Simulation approaches. The data collected from the study area was analyzed to evaluate the reliability indices. Using the data the distribution reliability indices such as SAIF, SAIDI and EENS were calculated the 2020G.C of Durame City feeder and reported in this thesis. The results of the indices were also compared with the bench mark values. From the comparison, it is concluded that the Durame city feeder is not reliable. This thesis, simulation and system modeling studies are carried out on 15KV Durame city feeder to evaluate the reliability performance for the existing feeder and also forecasting the reliability performance by whale optimization algorithm enhancement techniques. By implementing whale optimization algorithm techniques the overall reliability of Durame city feeder indices SAIFI by 85.98%, SAIDI by 80.93%, EENS by 67 %, and Cost of EENS by 66.44% has been improved as compared with the existing system. The proposed solution has potential saved around 2,981,192.4 ETB per year from the unsold energy of one feeder only with around nine month and fifteen a day's payback period investment which show us the proposed reliability assessment and enhancement of power distribution network by optimal placement of sectionalizer techniques is the most effective for reliability improvement and enhancement of power for Alaba Distribution Substations.

5.2 Recommendation

The following recommendations are given for further work for improving the Alaba distribution reliability based on this thesis work.

- ❖ Alaba distribution substation should increase number sectionalizer switches on optimum place to make distribution system more sustainable and reliable.
- ❖ Strongly recommended the EEU improve the workers experience in the data collections and documentation because of Alaba distribution workers have little experience in the documentation of the performance data for outgoing feeders.

- It is essential to give due attention for preventive maintenance to improve random power interruptions, sustainability of equipment and to deliver power to the customer.

- Finally, creating awareness to the rural people of the Kebeles and the people around the towns about the use and risk related with electric lines and pole.

5.3 Future Work

- As this thesis is conducted on one feeder, future researcher should do reliability improvement and enhancement of power in the whole part of the feeders.

- Future researcher should do reliability assessment and power enhancement by optimal placement of sectionalizers switches in the whole feeders of Alaba distribution Substation.

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APPENDIX

APPENDIX A

Load point	Installed load (KVA)	Length (Km)	Failure Rate (F/year)	Load point	Installed load(KVA	Length (Km)	Failure Rate (F/year)	Load point	Installed load(KVA	Length (Km)	Failure Rate (F/year)
L1	25	21	0.09	L53	100	28	0.06	L105	315	32.5	0.045
L2	25	21.1	0.07	L54	50	29.	0023	L106	100	33.5	0.07
L3	50	21.3	0.08	L55	630	29.42	0067	L107	50	33	0.0
L4	200	22	0.04	L56	200	29.43	0.090	L108	100	33	0.04
L5	400	23.4	0.007	L57	100	29.44	0.0067	L109	200	33	0.06
L6	315	23	0.15	L58	100	29.67	0.098	L110	100	33.45	0.032
L7	50	24	0.05	L59	50	29.78	0.03	L111	50	33.22	0.089
L8	400	23	0.008	L60	100	30.8	0.09	L112	50	3308	0.004
L9	200	21.5	0.06	L61	315	30.90	0.012	L113	100	33.53	0.06
L10	100	22.1	0.024	L62	800	34.50	0.073	L114	100	33	0.021
L11	315	22.5	0.06	L63	100	28.78	0.07	L115	100	34.8	0.054
L12	50	23	0.06	L64	50	32	0.08	L116	25	34.43	0.09
L13	315	25.	0.0091	L65	100	30.23.	0.033	L117	100	34.4	0.07
L14	25	25.45	0.0076	L66	100	30.90	0.042	L118	100	35.55	0.02
L15	200	4	0.074	L67	50	29.22	0.0014	L119	315	36	0.0082
L16	100	25.51	0.078	L68	100	30	0.067	L120	100	36	0.05
L18	100	28	0.05	L69	200	39.65	0.009	L121	100	38.56	0.0203
L19	25	24	0.02	L70	100	32.78	0.032	L122	100	34.13	0.04
L20	25	24.5	0.009	L71	50	36	0.064	L123	100	37	0.07
L21	25	24	0.056	L72	25	39.15	0.072	L124	25	39.1	0.0025
L21	315	24.9	0.056	L73	25	37.8	0.081	L125	100	40.2	0.08
L22	100	24.6	0.067	L74	100	33.67	0.033	L126	200	45	0.005
L23	200	27	0.097	L75	25	29	0.092	L127	100	45.2	0.016
L24	100	29.32	0.083	L76	25	28.6	0.051	L128	100	33.23	0.074
L25	315	23.35	0.091	L77	25	28	0.059	L129	50	34.67	0.06
L26	100	30	0.006	L78	50	32.4	0.0134	L130	100	33.52	0.02
L27	50	30	0.097	L79	100	37.9	0.0001	L132	315	34.99	0.05
L28	200	27.67	0.056	L80	50	33	0.05	L133	100	42.2	0.04
L29	100	31	0.07	L81	100	29.89	0.034	L134	200	42.43	0.021
L30	315	32	0.032	L82	315	39.78	0.078	L135	100	42.5	0.06
L31	100	34.25	0.006	L83	25	32	0.04	L136	100	42.2	0.08
L32	25	32	0.07	L84	25	41.00	0.09	L137	25	42.6	0.02
L33	100	34.78	0.03	L85	25	32.5	0.0024	L138	315	42.7	0.007
L34	25	31.19	0.04	L86	25	32.45	0.09	L139	100	42.33	0.075

L35	50	31.37	0.01	L87	315	33.78	0.01	L140	25	42.09	0.063
L36	50	38	0..0049	L88	50	33.05	0.005	L141	100	42.23	0.008
L37	100	42.45	0.07	L89	50	34	0.023	L142	200	42.01	0.002
L38	25	34.65	0.05	L90	315	34.57	0.045	L143	100	42.4	0.00019
L39	200	33	0.0066	L91	100	34	0.06	L144	50	43	0.03
L40	100	27.87	0.076	L92	25	35.67	0.04	L145	200	42.5	0.002
L41	25	28	0.09	L93	25	36	0.03	L146	100	43	0.0045
L42	100	29.78	0.78	L94	100	36.72	0.006	L147	50	42.1	0.04
L43	100	29	0.081	L95	315	37	0.02	L148	315	45	0.07
L44	200	33	0.072	L96	100	38.72	0.009	L148	25	46	0.05
L45	100	38.08	0.09	L97	50	37.71	0.011	L149	50	42.6	0.09
L46	100	42.76	0.003	L98	100	33.63	0.07	L150	100	43.5	0.02
L47	100	31.63	0.02	L99	50	33.99	0.02	L151	50	43.32	0.05
L48	100	46.78	0.05	L100	100	34.67	0.099	L152	200	43	0.012
L49	100	29	0.0078	L101	200	35.01	0.001	L153	100	43	0.034
L50	25	26	0.092	L102	315	35.45	0.07	L154	50	48.3	0.089
L51	100	28	0.06	L103	100	35.	0.034	L155	100	45	0.072
L52	100	32.03	0.043	L104	200	36.67	0.042	L156	25	45.5	0.033

APPENDIX B

Load point	Mean time to repair (MTTR)	Number of customers	Load point	Mean time to repair (MTTR)	Number of customers	Load point	Mean time to repair (MTTR)	Number of Customers
L1	0.3546	63	L53	0.3129	88	L105	0.2239	215
L2	0.6970	51	L54	0.0704	69	L106	0.5191	121
L3	0.8490	63	L55	0.3979	356	L107	0.6110	72
L4	0.8724	73	L56	0.8555	79	L108	0.5703	78
L5	0.6411	131	L57	0.6809	73	L109	0.7821	93
L6	0.2098	61	L58	0.7233	63	L110	0.8035	96
L7	0.7382	89	L59	0.7634	70	L111	0.7539	90
L8	0.7831	76	L60	0.8720	95	L112	0.1322	118
L9	0.1978	56	L61	0.4359	86	L113	0.8815	72
L10	0.4534	43	L62	0.5525	489	L114	0.1673	91

L11	0.2299	94	L63	0.7645	92	L115	0.6222	83
L12	0.3979	66	L64	0.3285	81	L116	0.9168	1
L13	0.3418	73	L65	0.2054	42	L117	0.2713	62
L14	0.6176	1	L66	0.2174	90	L118	0.1686	60
L15	0.2379	236	L67	0.7846	112	L119	0.0082	245
L16	0.8011	64	L68	0.2554	78	L120	0.4929	94
L18	0.8555	51	L69	0.6597	200	L121	0.1072	90
L19	0.6809	93	L70	0.8466	63	L122	0.1038	96
L20	0.2965	82	L71	0.6712	47	L123	0.1655	97
L21	0.2238	271	L72	0.7321	92	L124	0.4942	84
L21	0.3166	87	L73	0.8142	73	L125	0.4514	87
L22	0.0684	60	L74	0.7812	50	L126	0.6205	164
L23	0.4306	84	L75	0.3210	74	L127	0.3517	1
L24	0.8155	47	L76	0.7519	91	L128	0.1892	1
L25	0.4106	222	L77	0.059	70	L129	0.2238	2
L26	0.8101	29	L78	0.0134	229	L130	0.6768	56
L27	0.3719	**77**	L79	0.3499	56	L132	0.0684	226
L28	0.1656	96	L80	0.1704	81	L133	0.4306	247
L29	0.9914	71	L81	0.3979	55	L134	0.4249	85
L30	0.8682	211	L82	0.3545	193	L135	0.7341	88
L31	0.1376	56	L83	0.2807	56	L136	0.4320	90
L32	0.4581	98	L84	0.4416	56	L137	0.4120	87
L33	0.3379	41	L85	0.3225	201	L138	0.1851	273
L34	0.5807	55	L86	0.5729	75	L139	0.6296	78
L35	0.3704	27	L87	0.6204	54	L140	0.5102	99
L36	0.1828	119	L88	0.7565	65	L141	0.8561	70
L37	0.3719	64	L89	0.5051	2	L142	0.7306	56
L38	0.3719	45	L90	0.2812	152	L143	0.2642	49
L39	0.6165	207	L91	0.3116	91	L144	0.5413	63
L40	0.3810	1	L92	0.4510	92	L145	0.7382	142

L41	0.5891	74	L93	0.4513	81	L146	0.3379	96
L42	0.7205	84	L94	0.6686	62	L147	0.3978	94
L43	0.2560	31	L95	0.3379	283	L148	0.2150	231
L44	0.8927	47	L96	0.0074	1	L148	0.5032	78
L45	0.2954	1	L97	0.7846	1	L149	0.4291	111
L46	0.8536	56	L98	0.2554	1	L150	0.2965	90
L47	0.0558	1	L99	0.6417	1	L151	0.6766	79
L48	0.2405	99	L100	0.8496	76	L152	0.2684	162
L49	0.4578	85	L101	0.5126	86	L153	0.453	99
L50	0.3512	67	L102	0.6712	220	L154	0.5592	66
L51	0.7426	63	L103	0.7849	98	L155	0.5019	106
L52	0.5543	57	L104	0.6571	152	L156	0.4306	42

APPENDIX C

```
clear all
    clc
    clc;
    Average failure rate=l; % for each load point
l = [0.09; 0.07; 0.08; 0.04;….
0.033];
Mean time to repair =MTTR; % for each load point
MTTR   = [0.3546; 0.6970; 0.8490; 0.8724; 0.6411;...

. 0.4306];
Power = [25;25;50;200;…
25];
Users = ceil (power/2)-1;
%% failure history
duration = 1; % years
interruption = 0 ;
outage_time = 0;
```

```
maxT = 0;
for i = 1:N ;
[downT{i},upT{i}] = ((i),MTTR(i),duration);
cur = max(upT{i}(1:end));
if (maxT < cur)
maxT = cur;
end
interuption = interruption + length(downT{i})-1;
outage_time = outage_time + sum(upT{i}-downT{i});
%     figure;
      line(1:length(downT{i}),downT{i});
      line(1:length(downT{i}),upT{i},’’color’’,’’r’’,’’Marker’’,’’.’’);
end
% indexes calculation
average_interruption = interruption/duration;
average_outage_time = outage_time/duration;
customers_num = sum(users);
total_power = sum(power);
SAIFI= average_interruption* customers_num/customers_num;
SAIDI= average_outage_time*customers_num/customers_num(customers_num*8760);
disp(“----------------”);
disp(“Step 1”);
disp((“SAIFI ’’ num2str(SAIFI)));
disp([“SAIDI”num2str(SAIDI)));
```

APPENDIX D

```
clear all
clc
clc
Xbest = (0 .0 range(dim);
Fbest = sys_float_info.max;
```

```
% Number of search agents
Search Agents_no= B1;B2;B3;……B156;
% Maximum numbef of iterations
Max_iteration=1000;
% check each whale
for i in range(n);
if whale Population(i).fitness < Fbest;
Fbest = whalePopulation(i).fitness;
Xbest = copy.copy(whalePopulation(i).position);

% main loop of woa
Iter = 0;
while Iter < max_iter;

% after every 10 iterations
% print iteration number and best fitness value so far
if Iter % 10 == 0 and Iter > 1;
print(Iter =  + str(Iter) +  best fitness = %.3f); % Fbest)

% linearly decreased from 2 to 0
a = 2 * (1 - Iter / max_iter);
a2=-1+Iter*((-1)/max_iter);

for i in range(n)
A = 2 * a * rnd.random() - a;
C = 2 * rnd.random();
b = 1;
l = (a2-1)*rnd.random()+1;
p = rnd.random();

D = (0.0 for i in range(dim));
```

```
D1 = (0.0 for i in range(dim));
Xnew = (0.0 for i in range(dim);
Xrand = (0.0 for i in range(dim);
if p < 0.5;
if abs(A) > 1;
for j in range(dim);
D(j) = abs(C * Xbest(j) – whalePopulation(i).position(j));
Xnew(j) = Xbest(j) - A * D(j);
else
p = random.randint(0, n - 1);
while (p == i);
p = random.randint(0, n - 1);
Xrand = whalePopulation(p).position


for j in range(dim)
D(j) = abs(C * Xrand(j) – whalePopulation(i).position(j))
Xnew(j) = Xrand(j) - A * D(j)
else:
for j in range(dim)
D1(j) = abs(Xbest(j) – whalePopulation(i).position(j));
Xnew(j) = D1(j) * math.exp(b * l) * math.cos(2 * math.pi * l) + Xbest(j);

for j in range(dim)
whalePopulation(i).position(j) = Xnew(j);

for i in range(n)
% if Xnew < minx OR Xnew > maxx
% then clip it
for j in range(dim)
whalePopulation(i).position(j) = max(whale Population(i).position(j), minx);
```

```
whalePopulation(i).position(j) = min(whale Population(i).position(j), maxx);

whalePopulation(i0.fitness = fitness(whalePopulation(i).position);

if (whalePopulation(i).fitness < Fbest);
Xbest = copy.copy(whalePopulation(i).position);
Fbest = whalePopulation(i).fitness;

Iter += 1
% end-while

% returning the best solution
return Xbest));
```