DISTRIBUTION SYSTEM RELIABILITY ENHANCEMENT BY ASSET MANAGEMENT STRATEGIES FOR NETWORK RECONFIGURATION (ACASE STUDY OF NEKEMTE CITY DISTRIBUTION NETWORK)

MSC.THESIS

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MASTER OF SCIENCE IN POWER SYSTEM AND ENERGY ENGINEERING

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IN

POWER SYSTEM AND ENERGY ENGINEERING

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EXAMINERS' APPROVAL SHEET

We, the undersigned, members of the Board of Examiners of the final Master's degree open defense, by Tadesse Garoma have read and evaluated his thesis entitled "Distribution System Reliability Enhancement by Asset Management Strategies For Network Reconfiguration (A Case Study of Nekemte City Distribution Network)" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering with Specialization in Power System and Energy Engineering.

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CANDIDATE'S DECLARATION

I hereby declare that the thesis "**Distribution System Reliability Enhancement by Asset Management Strategies for Network Reconfiguration (A Case Study of Nekemte City Distribution Network)**" is my own work conducted under the guidance of Dr. Baseem Khan, and Mr.Issaias Gidey, Department of Electrical Engineering, Institute of Technology, Hawassa University.

I further declare that to the best of my knowledge, the thesis does not contain any part of work that has been submitted for the award of any degree either in this university or any other university without proper citation.

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This is to certify that the statement made above by the candidate is true to the best of my knowledge.

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Advisor Name: Signature Date

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Co-advisor Name**:** Signature Date

CERTIFICATE

This is to certify that the work entitled "**Distribution System Reliability Enhancement By Asset Management Strategies For Network Reconfiguration (A Case Study Of Nekemte City Distribution Network)**" submitted by Tadesse Garoma, Id No: PGeng/011/08, Department of Electrical and Computer Engineering, Hawassa University Institute of Technology, Hawassa, Ethiopia is a record of a benefice research carried out by him under my supervision and guidance. The thesis work in my opinion, has reached the requisite fulfilling the requirement of Master of Science Degree. The results contained in the thesis have not been submitted in part or full to any other University or Institute for the award of any degree.

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ABSTRACT

Assets aging, corrosion, deterioration and slow replacement rate causes derating of the distribution system reliability and frequently damage and burn for the assets. They cause system power outage in radial distribution system in which a single power supplies the whole system. Thus, the objective of the study is to enhance the distribution system reliability by asset management strategies for network reconfiguration.

Nekemte city is located in western Ethiopia, Oromia Region, East Wollaga Zone at latitude $9°5'N$, and longitude of $36°33'E$. Nekemte city distribution network is selected as a case study area in order to collect and analysis asset management strategy (in appendix (A) and reliability data (Appendix (B). The study is limited to circuit breakers (15Kv), transformers (15/0.4Kv) and OH lines (15Kv) assets. Age and health condition data's of assets are collected to evaluate each asset's health index. Health index is used to decide the proper maintenance and replacement strategy for present and future. As the result of asset management strategy, two (2)circuit breakers, seventy seven(77) transformers and forty point one (40.1) km of distribution overhead line requires replacement strategy and five (5) transformers and point seven(0.7) Km of distribution overhead line requires preventive maintenances.

The placement and populations of automatic reclosers, sectionalizing switches and automation switches are optimized using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) for network reconfiguration. Since, GA is better for local optima solution and PSO is better for Global Optima solution, it is better if the results of both compared. In this thesis using PSO is better result than GA result. GA and (PSO) are developed in MATLAB R2016a software as shown in Appendix (C) and Appendix (D) respectively. PSO results five (5) sectionalizing switches, seven (7) Automations switches and eighteen (18) reclosers and their respective position in distribution line. DIgSILENT Power Factory 15.1.7 software is used to demonstrate and simulate distribution system to assess reliability Index.

Using Asset management strategy for network reconfiguration the distribution system, SAIFI is improve by 84.56 percentage from 87.2 to 13.461 per customer year, SAIDI is improved by 98.27 percentages from 5889.86 to 101.565 hours per customer year. ENS improved by 98.24 percentages from 119.407 to 3.913MWh per year, and EIC improved by 98.24 percentages from 11.942 to 0.21 and save 11.732 M$ in a year. These work have Payback period of 1.742, therefore it is economically feasible if implemented.

Key words: - Asset management strategy, network reconfiguration, reliability enhancement

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NOMENCLATURE

ASAI	Average system Availability Index
ASU	Average system Un Availability Index
BPSO	Binary Particle Swarm Optimization
CAIDI	Customer Average Interruption Duration Index
CBM	Condition Based Maintenance
DNR	Distribution Network Reconfiguration
DSM	Demand Side Management
DOF	Degree of member function determination
EEA	Ethiopian Electric Agency
EIC	Expected Interruption Cost
ENS	Energy Not Supplied
GA	Genetic Algorithm
IAM	Institute of Asset Management
IEEE	Institute Electrical and Electronics Engineering
Km	Kilo meter
KW	Kilo watt
MW	Mega Watt
MWh	Mega Watt hour
OHL	Overhead line
PSO	Particle Swarm Optimization
POF	Probability of Failure
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
$\beta 1$	Initial Ageing Rate
H_{new}	Health score of a new asset
λ_i,	Average failure rate at load point i
r_i,	Average annual outage time at load point i
U_i	Annual unavailability at load point i

CHAPTER ONE

INTRODUCTION

1.1.Background

The electric power distribution system is the last stage of the power system that links electric utilities to consumers [1]. Providing electric power to the customers in a reliable and economical way is one of the major purposes of electric power distribution system. Reliable electric power helps the electric utilities to generate and deliver electric power in effective way and with low economic cost. This also helps customers to get reliable and secure electric power with low costs for their daily activities. However, due to aging, deterioration, corrosion, lightening, overloading, excavating of assets, the distribution system, experiences the random temporary/sustained failures in a period of the network lifetime [2]. This stochastic nature of the failure makes a difficult task in distribution system to predict and control of power interruption assets and causes the derating reliability in distribution system. Therefore it is necessary to consider the implication distribution system reliability enhancement techniques.

This thesis studies the distribution network reliability enhancement using asset management strategies and distribution network reconfiguration techniques. Asset management strategy is a systematic process of operating, maintaining, upgrading, and disposing of assets in the most cost-effective way and it help distribution utilities and services to save money, reduce risk, and to improve reliability of their critical assets. Asset management strategy of develops maintenance, replacement and intervention strategy to enhance reliability of distribution network by assessing the health condition of each asset. The maintenance and replacement strategy enhances asset reliability by, transferring its failure state to healthy state. This reduces the frequency or the duration of power supply interruptions [3].

In radial electrical distribution network each consumer has a single source of supply and an asset failure will cause the distribution system feeder power outage. Therefore Network reconfiguration is necessary to reduce the distribution system power outage in radial system. Distribution network reconfiguration problem is an optimization problem that needs a suitable algorithm. The method used for this optimization problem is Genetic Algorithm (GA) optimization and Particle Swarm Optimization [4].

Nekemte city is located in western Ethiopia, Oromia Region, East Wollaga Zone at latitude $9°5'$N, and longitude of $36°33'$E . Nekemte city distribution network is selected as a case study area to collect and analysis asset management strategy (in appendix (A) and reliability data (Appendix (B) and to simulate distribution system reliability enhancement by asset management strategy for network reconfiguration.

1.2. Statement of the problem

Nekemte city electrical distribution system is a complex system that consist a huge number and old aged of electrical assets that requires secure operation, management strategy and secure management policy. A decision regarding maintenance, replacement of disparate, complex and distributed assets is one of the main challenges facing Nekemte city distribution network.

Gradually asset's aging, corrosion, dusts, deterioration, and slow maintenance and replacement rate of Nekemte city distribution network causes for assets damage, explosion and system power outage. These challenges have very significant on distribution network unreliability and cost. The system experiences average interruption frequency index (SAIFI) of 87.2 per customer annual and Expected Interruption cost (EIC) of 11.942 million dollars per year. Comparing Nekemte city distribution system with average interruption frequency index (SAIFI) with that of Ethiopian Electric Agency (EEA) reliability index standards, the system performances below Ethiopian Electric Agency (EEA) reliability [13]. Hence it needs reliability improvement.

Therefore Nekemte city distribution network requires reliability enhancement techniques to satisfy customer's power need. Hence, this thesis implies asset management strategies for network reconfiguration to enhance the distribution system reliability.

1.3. Objective

1.3.1. General Objective

The main aim of this thesis is to enhance distribution system reliability by asset management strategy for network reconfiguration.

1.3.2. Specific Objectives

- To model asset management strategy
- To model distribution network reconfiguration
- To assess the age, health condition, health score and probability failure of assets
- To evaluate distribution system reliability index using asset management strategy and network reconfiguration
- To draw relevant conclusions and recommendations that can be of use for the performance improvement of the Nekemte city distribution system.

1.4. Scope and limitations

The thesis focuses on distribution system reliability enhancement by asset management strategies for network reconfiguration. In electrical distribution network asset management strategy is bulky technique; however this thesis is limited to asset maintenance strategies and replacement strategies. Distribution system also consist different types of electrical assets such as poles, resisters, fuses , transformers, circuit breakers, OH lines and extra, however this thesis is limited to distribution transformers(15/0.4Kv), circuit breakers (132Kv) and OH lines(15Kv) assets which are critical in reliability and cost.

Distribution system consist medium voltage (15Kv) and low voltage (0.4Kv) OH distribution line. In this reliability and asset management data's related to low Voltage (0.4Kv) is not considered in order to limit scope of this thesis.

Assets in distribution systems are the products of different countries such Italy, Ethiopia (METEC), Indian and Chinese, therefore they have different management and reliability performance. Such performance factors are not considered in reliability and asset management evaluations, since there is no limited standard.

The Expected Life of an asset is affected by the environment, altitude, distance from coast in which the asset is installed. For example, assets exposed to higher levels of moisture or pollution may be expected to degrade quicker than assets of the same type exposed to lower levels of moisture or pollution. The levels of exposure will depend on the location of the asset and also whether or not it is installed within an enclosure that affords protection from the weather. This effect of location factor is not considered.

OH and the network reconfiguration techniques of improving distribution system reliability. The study assesses asset health condition and failure rate to evaluate the reliability performance of distribution system.

The thesis is limited to the circuit breaker; transformer and distribution overhead line asset age, corrosion; deterioration data in order assess the management strategies for network reconfiguration to enhance performance of distribution system reliability.

CHAPTER TWO

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1. Asset Management Strategy

Now a day, electrical distribution system become a huge and complex system that consist huge number and old aged of electrical assets that requires secure operation, management strategy and secure management policy [5]. The management of disparate, complex and distributed assets is one of the main challenges facing the electricity distribution network such as problem decisions regarding equipment maintenance, replacement of distribution assets. Therefore asset management strategy is needed to overcome these problems in distribution system.

Asset management strategy is systematic process of cost effectively operating, maintaining and upgrading of electrical assets by combining engineering practices and economic analysis with sound business practice. Asset management is a disciplined, deliberate, and systematic approach to making informed decisions about assets maintenance, repair or replacement strategies.

In general asset management strategy is a prospective of how to develop the best maintenance strategy, how to develop the best replacement strategy, how to maximize the use of the existing assets, how to operate with a risk management vision [6].

2.1.1. Modeling of Asset Management Strategy

Asset management strategy is modeled by its health index to know how to prioritize the maintenance and replacement in distribution network asset. Health index is a combination of all current information about an asset and it provides a single quantitative index that represents its overall health. Health index used for an asset management decision support; end of life estimation and to plan maintenance strategies. It also represents the level of long-term degradation, a condition not easily determined by routine inspection.

The Health Index (HI) is derived from the health score and probability of failure (POF). The POF of an asset is a function of the asset's health score, with the health score being a function of normal expected life, location factor, duty factor, reliability, observed condition and measured condition.

I. Expected Life

Expected life is derived from normal expected life, taking into account two degradation factors, location factor and duty factor.

The normal expected life is defined as the time (in years) in an asset's life when the first significant signs of deterioration would be expected. Location factor represents the effects of the surrounding environment on the asset and duty factor represents any additional ageing due to the way in which the asset is being used. Considering unity location and duty factor the expected life of an asset is the same as its normal expected life [8].

II. Initial Ageing Rate(β1)

Initial aging rate is the rate of change of health of a distribution asset as it involved to deterioration processes, example corrosion, oil oxidation, insulation breakdown, etc. and it is accelerated by the products of the deterioration process. The ageing rate of the asset is determined from the natural logarithm of the assets health score when new and the health score that corresponds to the expected life of the asset , as expressed in equation 2.1 .

$$\beta_1 = \frac{\ln\left(\frac{H_{Expected\ Life}}{\mathrm{H_{New}}}\right)}{\text{Expected Life}} \tag{2.1}$$

Where: H_{new} is the Health Score of a new asset;

$H_{\text{Expected Life}}$ is the Health Score of the asset when it reaches its expected life.

III. Initial Health Score

The initial health score is obtained using the generic relationship between asset health and age as expressed using equation (2.2).

$$\text{Health Score}=\mathrm{H_{New}}\ e^{(\beta_1+\text{age})} \tag{2.2}$$

Where:-H_{new} is the health score of a new asset, *age* is the current age of the asset in year

β_1 is the initial ageing rate.

IV. Current Health Score

Current health score is the modification of initial health score based on observed condition and measurement data of an asset. It also based on health score and reliability factor if available and appropriate. Current health score is expressed using equation (2.3).

$$\text{Health Score} = \mathrm{H_{New}}\ e^{(\beta_1+\text{age})}\ \ \text{Health score Factor} \tag{2.3}$$

Where:-H_{new} is new health score, *age* is the current age of the asset in year, β_1 is the initial ageing rate

Using recommended limits of electric distribution accepted various international standards institute of Electrical and Electronic Engineering (IEEE), International Electro technical Commission (IEC), Health score is assigned to all assets, which is between 0.5 and 10 to determine health index [9]. Health index is categorized into five bands (HI1-HI5) based on their health score. Health index band (HI-1) indicates the asset as new, which have health score between (0.5-4.5), health index band (HI-2) indicates the asset as good or serviceable condition, which having health score between (4-5.5), health index band (HI-3) indicates the asset as deterioration requires assessment and monitoring, which have health score between (5-6.5), health index band (HI-4) indicates the asset as material deterioration, intervention requires consideration, which have health score between (6-8), and health index band (HI-5) indicates the asset as end of serviceable life, intervention required, which have health score between (7.5-10). With this information, utilities can determine which assets need immediate major capital expenditures, which will need refurbishment or replacement in the near future but not immediately and which are in good condition and do not need any action.

2.1.2. Asset Failure Rate Modeling

The asset failure rate is a measure of the rate at which outage will occur in a given period of time. The number of components exposed to failure due to ageing, visual inspection factor and other causes of failure is considered to estimate the asset failure rate.

Asset health based failure rate per year shall be calculated based on the first three terms of the Taylor series for an exponential function. This implementation has the benefit of being able to describe a situation where the probability of failure rises more rapidly as asset health degrades, but at a more controlled rate than a full exponential function. It is described in equation (2.4).

$$\text{Failure Rate} = K[1 + (CH) + \frac{(CH)^2}{2!} + \frac{(CH)^3}{3!}] \tag{2.4}$$

Where: H is a variable equal to health score (current or future), K and C are constants parameters.

The constant value of C, defines the shape of the curve and the constant value of K, defines the scales of probability of failure.

2.2. Distribution System Reliability Modeling

Distribution system performance is modeled using reliability indices. Distribution system reliability indices are a measure of the reliability and availability of supply of the network and the interruptions experienced by the customers in distribution network. Reliability indices quantify the loss of supply in terms of the frequency, duration, the amount of installed plant (transformers) affected and the number of customers affected by the events occurring on the network.

2.2.1. Load Point Reliability Indices

Usually, the three basic reliability parameters used to measure distribution system reliability are, average failure rate λ_i, average outage time r_i, and annual unavailability (U).

I. Failure Rates (λ)

Distribution network consist lines, transformers, circuit breakers components. Failure rate at taken load point is the sum failure rates of each component connected in series as described in equation (2.5) [10].

$$\lambda_i = \sum_{j=1}^{n} \lambda_j \qquad (2.5)$$

Where, n is the total number of components which affect load point i, λ_j is average failure rate of element j, $\boldsymbol{\lambda_i}$ failure rate at load point i, $\boldsymbol{\lambda_j}$ failure rate components j in series circuit

II. Unavailability (U)

Availability is the probability of distribution network being energized. It is the most basic aspect of reliability and is typically measured in percent or per-unit. Unavailability described as in equation (2.6).

$$U_i = \sum_{j=1}^{n} \lambda_j \; r_j \qquad (2.6)$$

Where n is the total number of components which affect load point i, λ_j is average failure rate of element j, r_j is average repair rate of element j

III. Mean Repair Time (r)

Mean repair time is directly related to duration of supply interruptions. It is a measure of how the distribution system faces to failures. Average restoration time at a given load point is described in terms of unavailability and failure rate as shown in equation (2.7).

$$r_i = \frac{U_i}{\lambda_i} \qquad (2.7)$$

Where λ_i is average failure rate at load point i

r_i Average restoration time to restore load point i and

U_i Unavailability at load point i

These load point reliability indices do not give full information in terms of customer. In order to reflect the severity or significance of system outage in terms of customer and energy, additional reliability indices such as customer oriented indices and load oriented indices are needed.

2.2.2. Customer Oriented Reliability Indices

Customer oriented reliability indices expresses distribution system reliability in terms of customers in the system.

I. System Average Interruption Frequency Index (SAIFI)

The SAIFI of a network indicates how often the average customer connected would experience sustained interruption per year excluding re-interruptions [10]. It can be mathematically expressed (2.8)

$$SAIFI = \frac{Total\ Number\ of\ Customers\ Interruption}{Total\ Numbers\ of\ customers\ served} = \frac{\sum \lambda i Ni}{\sum Ni} \tag{2.8}$$

Where λ_i is the failure rate and N_i is the number of customers at load point i

SAIFI is a measure of how many sustained interruptions an average customer will experience annually. For a fixed number of customers, the only way to improve SAIFI is to decrease the number of sustained interruptions experienced by customers.

II. System Average Interruption Duration Index (SAIDI)

The SAIDI of a network indicates the duration of a sustained interruption the average customer would experience over the year. It is usually measured in customer minutes or customer hours of interruption. Mathematically SAIDI can be expressed as (2.9):

$$SAIDI = \frac{Sum\ of\ Customers\ Interruption}{Total\ Numbers\ of\ customers} = \frac{\sum UiNi}{\sum Ni} \tag{2.9}$$

Where U_i is annual outage time and N_i is the number of customers at load point i

III. Customer average interruption duration index (CAIDI)

The CAIDI of a network shows the average duration of a sustained interruption that only the customers affected would experience annually. It is normally measured in customer minutes or customer hours of interruption. CAIDI is the ratio of SAIDI and SAIFI and mathematically expressed as equation (2.10)

$$CAIDI = \frac{Sum\ of\ Customers\ Interruption}{Total\ Numbers\ of\ customers\ Interruption} = \frac{\sum UiNi}{\sum Ni\lambda i} \tag{2.10}$$

Where λ_i is the failure rate, U_i is annual outage time and N_i is the number of customers at load point i.

CAIDI is a measure of how long an average interruption lasts, and is used as a measure of utility response time to system contingencies.

IV. **Average service availability (unavailability) index, ASAI(ASUI)**

The ASAI represents the fraction of time (often expressed as a percentage) that a customer has received supply during one year. ASAI is a useful for measuring the availability of customers with firm supplies [9]. Mathematically ASAI can be expressed as (2.11).

$$\text{ASAI} = \frac{\textit{Customers hours of avialabile Service}}{\textit{Customers hours demand}} = \frac{\sum Ni * 8760 - \sum NiUi}{\sum Ni * 8760} \qquad (2.11)$$

$$\text{ASUI} = 1 - \text{ASAI} = 1 - \frac{\sum Ni * 8760 - \sum NiUi}{\sum Ni * 8760} \qquad (2.12)$$

Where 8760 is the number of hours in a calendar year

2.2.3. Load and Energy oriented Indices

I. Energy not supplied index (ENS)

$$\text{ENS} = \text{total energy not supplied by the system} = \sum La(i)Ui \qquad (2.13)$$

Where $\mathrm{U_i}$ is annual outage time, $L_{a(i)}$ is the average load connected to load point i

II. Average energy not supplied index (AENS)

$$\text{AENS} = \frac{\textit{Energy not}\ \text{supplied}}{\textit{Total Numbers of Customers}} = \frac{\sum \mathrm{L_{a(i)}U_i}}{\sum \mathrm{N_i}} \qquad (2.15)$$

Where $\mathrm{U_i}$ is annual outage time, $L_{a(i)}$ is the average load connected to load point i.

There is a variety of power system reliability indices evaluation techniques. The two main approaches are analytical and simulation techniques. Simulation methods estimate the reliability indices by simulating the actual process and random behavior of the system. The method therefore treats the problem as a series of real experiments. The simulation process can flow either random or sequential simulation.

2.3.Distribution Network Reconfiguration

Distribution network reconfiguration is the process of changing the topological structure of distribution feeders by adding and updating the open/close status of the network sectionalizes and tie switches. Reconfiguration is an effective way to improve the performance of power distribution networks. Sectionalizing and tie switch system option create power path searching alternative with the existing laterals. This improves supply reliability and power availability. .

2.3.1. **Distribution Network Reconfiguration Problem Modeling**

Finding a radial operating structure that maximizes the system reliability and minimize the total cost of sectionalizing switches, reclosers and automation is a problem in distribution network reconfiguration. Therefore distribution network reconfiguration problem is modeled by cost optimization [11] under reliability constraints. Cost optimization is the objective problems as expressed in equation (2.15) and system reliability indices is constraint problems as expressed in equation (2.16) and equation (2.17).

Objective problem: -

$$Minimize\ Total\ Cost\ C = csNs + crNr + caNa \qquad (2.15)$$

Subjected to constraint problems:-

$$\text{SAIFI} \leq 20 \text{ Interruption./customer/annual} \qquad (2.16)$$

$$\text{SAIDI} \leq 25 \text{ hr./customer./annual} \qquad (2.17)$$

Where, Ns-Numbers of sectionalizing switches, cs cost of a sectionalizing switch

N_r-numbers of recloser c_r cost of a recloser

Na-numbers of automation ca cost of automation

C- Total costs of reclosers, automations and sectionalizing switches

The distribution system average interruption frequency SAIFI and system average interruption duration (SAIDI) is taken in reference to Ethiopian reliability index standard [12].

Distribution network reconfiguration problem is characterized with a complex, nonlinear and constrained mixed-integer optimization problem where integer variables represent the system switches and continuous variables represent the distribution network. The complex nature of the distribution network reconfiguration problem, makes it prohibitive to adopt most of the exact optimization methods to solve it [13]. On the other hand, Evolutionary techniques such as Genetic Algorithm(GA) and Particle swarm Optimization(PSO) are particularly suitable to handle the complex optimization problem of distribution system reconfiguration.

2.3.2. Genetic Algorithm Optimization

Genetic algorithms have become very popular as a method of finding global optimums and it is a technique of optimization based on natural selection of Darwin’s theory of evolution [14]. The theory lies in that selected initial population with member individuals (chromosomes) can give new population with better fitness and selectivity. These individuals (chromosomes) are represented either in double vector or binary string with single binary digit (gene) of chromosome.

Genetic algorithms are most attractive for parallel processing environments, and when each child can be evaluated quickly. The cross breeding and mutation algorithms must be custom designed and tested for each application. Parameters such as the number of crossbreeding per generation, mutation probability, number of generations, population size, and percentage of population reseeded must all be determined by testing. There are five basic genetic algorithms operator, Population, Fitness function, Selection, Crossover and mutation [15].

I. Population

The process begins with a set of individuals which is called a Population. Each individual is a solution to the problem to be solved. An individual is characterized by a set of parameters (variables) known as Genes. Genes are joined into a string to form a Chromosome (solution). In a genetic algorithm, the set of genes of an individual is represented using a string of binary values (1s and 0s).

II. Fitness Function

The fitness function determines how fit an individual is the ability of an individual to compete with other individuals. It gives a fitness value to each individual. The probability that an individual will be selected for reproduction is based on its fitness value.

III. Selection

The idea of selection phase is to select the fittest individuals and let them pass their genes to the next generation. Two pairs of individuals (parents) are selected based on their fitness values. Individuals with high fitness have more chance to be selected for reproduction. Selection is the process of determining the number of times a particular individual is chosen for reproduction and, thus, the number of offspring that an individual will produce. The principle of genetic algorithms is essentially Darwinian natural selection. Selection provides the driving force in genetic algorithms.

IV. Crossover

Crossover is the most significant phase in a genetic algorithm. For each pair of parents to be mated, a crossover point is chosen at random from within the genes. Offspring are created by exchanging the genes of parents among themselves until the crossover point is reached.

V. Mutation

Mutation rate determines the probability that a mutation will occur. Mutation is employed to give new information about the population (uncover new chromosomes).It also prevents the population of becoming saturated with similar chromosomes, simply said to avoid premature convergence.

Large mutation rates increase the probability that good schemata will be destroyed, but increase population diversity. The best mutation rate is application dependent. For most applications [15], mutation rate is between 0.001 and 0.1. In certain new offspring formed, some of their genes can be subjected to a mutation with a low random probability.

i. Single Point Mutation

Single gene (chromosome or even individual) is randomly selected to be mutated and its value is changed depending on the encoding type used.

ii. Multi Point Mutation

Multi genes (chromosomes or even individuals) are randomly selected to be mutated and there values are changed depending on the encoding type used.

In general Genetic Algorithm (GA) maintains a population of individuals in which each individual represents a potential solution to the problem. Each individual is evaluated to give some measure of its fitness. Some individuals undergo stochastic transformations by means of genetic operations to form new individuals.

The two types of transformation mutation, which creates new individuals by making changes in a single individual and crossover, which creates new individuals by combining parts from two individuals are used in new individual evolution. The new individuals, called offspring, are then evaluated. A new population is formed by selecting the more fit individuals from the parent population and offspring population. After several generations, genetic algorithm converges to the best individual, which hopefully represents an optimal or suboptimal solution to the problem.

2.3.3. Particle Swarm Optimization

The Particle Swarm Optimization (PSO) is a relatively new and powerful intelligence evolution method for solving optimization problems. It is a population based optimization algorithm which was first proposed by Kennedy and Eberhart in 1995 [16]. It is inspired by the social behavior of bird flocking or fish schooling. PSO is a derivative algorithm of Genetic Algorithm (GA). Unlike GA, PSO has no evolution operators such as crossover and mutation. Therefore, it will save much computational time.

In PSO, each solution is a bird in the flock and is referred to as a particle. A particle is analogous to a chromosome in GAs. As opposed to GAs, the evolutionary process in the PSO does not create new birds from parent ones. Rather, the birds in the population only evolve their social behavior and accordingly their movement towards a destination.

Each bird looks in a specific direction, and then when communicates together, they identify the bird that is in the best location. Accordingly, they speed towards the best bird using a velocity that depends on its current position. Each bird, then investigates the search space from its new local position, and the process repeats until the flock reaches a desired destination. PSO consist parameters such as particle swarm, inertia weight, current position, global position and acceleration coefficients [17].

I. Particle swarm

In PSO particles are the population array of random solutions which are placed in the search space. The collection of these particles is called particle swarm. Each individual particle is composed of three d dimensional vectors, where d is the dimensionality of the search space. These three vectors are the current position ($X_{i)}$), the velocity ($V_{i)}$) and the previous personal best position (P_i).

II. Current Position(X_i)

The current position X_i of a particle is a set of coordinates describing a point in the search space, which is representing the information of a potential solution.

III. Velocity(V_i)

The velocity ($V_{i)}$) indicates the rate of the position change for particle i. vi is restrict within a limit $|V_i| \leq$ Vmax. Vmax determines which region is searched between the current position and the target position.

IV. Personal best position (P_i)

The personal best position pi indicates the best position which the particle i has reached so far.

It will be the reference of particle update. In the initialization it is equal to the current position (X_i).

V. Global best position(Pg)

The global best position (P_{gi}) indicates the best position which the particle i has reached so far in reference to other particles.

VI. Inertia Weight

The inertia weight governs how much of the previous velocity should be retained from the previous time step. The best performance, however, was obtained by using an inertia weight that decreases from 0.9 to 0.4 [18].It is expressed as in equation (2.18).   .

$$W(i) = \left(\frac{W_{\min-}W_{max}}{Iter_{max}-1}\right)(i-1) + W_{max} \tag{2.18}$$

Where: -W (i): The inertia weight at iteration i W_{min} : The minimum inertia weight (final), default = 0.4

W_{max} : Maximum inertia weight (initial), default = 0.9

$Iter_{max}$: Iteration by which inertial weight should be at final value [18]

VII. Acceleration coefficients

The constants (c_1), express how much confidence a particle has on itself, while constant (c_2), and express how much confidence a particle has in its neighbors. With c1=c2=0, particles keep flying at their current speed until they hit a boundary of search space (assuming no inertia). If c1>0 andc2=0, all particles are independent, and if c1=0 and c2>0, each particles find the best position in its neighborhood by replacing the current best positions if the new position is better, on other hand the entire swarm is attracted to a single point. Therefore PSO is modeled mathematically using equation (2.20) [18].

$$\boldsymbol{V_{id}(t+1) = V_{id}(t) + C_1 * rand(.) * [P_{id}(t) - X_{id}(t)] + C_2 * rand(.) * [P_{gd}(t) - X_{id}(t)]} \quad (2.19)$$

$$\boldsymbol{X_{id}(t+1) = X_{id}(t) + V_{id}(t+1)} \quad (2.20)$$

Where: c1, c2 are acceleration coefficients,

rand () is a vector of random numbers generated uniformly from [0, 1].

P_{gd} , global best position,

P_{id} , current best position.

The acceleration coefficients c1 and c2 represents the weighting of the random acceleration terms that pull each particle towards pi and pg. They are commonly set to 2.0 for almost all applications [18].

Equation (2.19) indicates. V_{id} Pushes the particle in the direction it has moved so far. $C_1 * rand(.) * [P_{id}(t) - X_{id}(t)]$, pushes the particle return to the personal best position it has already reached so far. $C_2 * rand(.) * [P_{gd}(t) - X_{id}(t)]$, equation pushes the particle return to the global best position of the particles in the swarm.

2.4.Literature Review

The research publications which are related to asset management strategies and distribution reconfiguration for reliability enhancements are discussed in this section.

Tor Mohammed and Osman Bulent[19] studies asset management strategies in power distribution systems. It classifies asset mamangement strategies into short-term, mid-term and long-term based on time scales and emphasizes the central role of Information Technologies (IT) in asset management with supportive examples. Short-term asset management is related with the operational issues of the network, mid-term asset management is associated with the maintenance of system assets and long-term asset management is concerned with the strategically planning of distribution systems. The advantage of this paper is it describes the application of asset management strategies in power system distribution reliability enhancement and it also explains the central role of IT in asset management.

The disadvantage of this paper is it does not explain how asset management strategies and planning in distribution system is prioritized and how automation and maintenance strategies are related to the reliability of the system.

L.Bertling and A. Lina [20] proposed a method for comparing the effect of different maintenance strategies on system reliability and cost. This method relates reliability theory with the experience gained from statistics and practical knowledge of component failures and maintenance measures. In particular, a functional relationship between failure rate and maintenance measures has been developed for a cable component. The results show the value of using a systematic quantitative approach for investigating the effect of different maintenance strategies.

An advantage of this study is it relates reliability theory with maintenance strategies and develops a functional relationship between failure rate and maintenance measures. However its disadvantage is does not also consider the ageing and deterioration effect on health condition of assets, on maintenance and reliability in power distribution system.

Sugier Jarosław [21] discusses an approach in which a system with scheduled inspections and possible repair activities is described by the discrete state-transition deterioration model. The model can be translated into a semi-Markov process, which after solving, yields numerous reliability characteristics including average equipment life, its deterioration rate represented by the so-called life curve, probability of failure within given time horizon, etc.

It also presents briefly the methodology behind model creation and concentrate on its one specific aspect automatic adaptation of the model to the adjusted maintenance policy with modified frequencies of repairs.

This paper is limited to typically the used for asset maintenance analysis rather than integrated into a network model. The effect of different asset failures on maintenance activities and demands is not studied. It also not considers the circuit breaker hidden failures.

B.Jian and Z.Wang[22] studies condition based asset management strategy in order to improve the forecasting accuracy and ensure reliable and stable operation of transformer asset. It uses health index estimation mode in order to evaluate the health condition of the asset. A condition-based evaluation tool quantifies power transformer degradation and clarifies the relationship between each health index and results are presented to verify the validity and feasibility of evaluating model and assessment algorithm.

The limitation of this study is it does not consider the effect of asset management strategy on asset failure rate and system reliability.

Meliopoulos, A.P. Sakis. et.all [23] studies the hidden failures of circuit breakers in power system for reliability enhancement. In this paper, a systematic methodology is studied to evaluate the effects of protection system hidden failures on bulk power system reliability in the general bulk power system reliability assessment procedure. A breaker-oriented bulk power system network model is developed to include detailed system substation configurations and protection system schemes. Any protection system constituents, such as transducers, relays, and circuit breakers, may suffer from hidden failures.

The disadvantage of this study is that it does not take into account the effect of asset management strategies on the asset and it does not show how the effect of change in hidden failures could changes the system reliability parameters. It also does not consider the use of other protection devices in system configuration to enhance reliability enhancement.

S.Skoonpong [24] studies distribution network reconfiguration for enhancing the reliability so that customer interruption cost is minimized subject to system operational constraints. A simulated annealing technique in conjunction with reliability worth analysis is used to search for the optimal or near-optimal network configuration. In this paper the reconfiguration optimization is to reduce the customer interruption cost. The disadvantage of this paper is it does not take into consideration the integration of asset management strategy and reconfiguration in distribution system. It also the study focus only on customer interruption cost is minimized rather than other reliability indices such as SAIFI and SAIDI.

Gupta and Pragya Kirti [25] propose distribution network reconfiguration for improving the reliability. Three reliability indices are focused on this study: the system average interruption frequency (SAIFI), the system average interruption duration (SAIDI), and the system average availability index (ASAI). It is shown that ASAI is linearly related to SAIDI. It is also shown that if the time required to restore service is the same as the time required to isolate a fault, minimizing SAIFI will lead to minimization of SAIDI. The mathematical formulations for calculating the change of SAIDI and SAIFI as a result of reconfiguration are presented.

The disadvantage of this paper is it does not take into consideration the integration of asset management strategy and reconfiguration in distribution system

Table.2. 1: Literature review analysis summary

Research papers	Method used	Advantage	Application
Osman Bulent.et al.[19]	Asset management strategies	Classifies asset management strategies based on time scale into short-term, mid-term and long-term. Incorporate SCADA IT and TRU to monitor Power system assets.	For power distribution sector
Bertling.et al. [20]	Maintenance strategies	relates reliability theory with the experience gained from statistics and practical knowledge of component failures and maintenance measures	maintenance strategies
Sugier.et al.[21]	scheduled inspections	It describes the discrete state-transition deterioration model to relate scheduled inspection and its repair activities. It yields numerous reliability characteristics including average equipment life, its deterioration rate	For maintenance policy decisions
JianWang et al. [22]	condition based asset management	It uses health index to evaluate the health condition of the asset	For forecasting transformer asset reliability.
Meliopoulos, et al.[23]	systematic methodology	Studies the hidden failures of circuit breakers in power system for reliability enhancement.	For system configurations
Skoonpong.et al. [24]	A simulated annealing technique	For enhancing the reliability and minimize customer interruption cost is subject to system operational constraints.	distribution network reconfiguration
Gupta et al.[25]	GA	For enhancing the reliability and minimize customer interruption cost is subject to system operational constraints.	distribution network reconfiguration

CHAPTER THREE

DATA COLLECTION AND ANALYSIS

3.1.Introduction

Nekemte City distribution network is selected as case study to analysis and simulate asset management strategy, network reconfiguration and reliability data's. Asset management strategy requires age, health condition asset data's to analysis the health score and health index of each asset. Data's used for Asset management strategy analysis are expressed in appendix (A).

Reliability assessment is the probabilistic assessment of power system interruptions during an operating period and it involves of total electric interruptions for loads within a power system. The interruptions are described by several indices that consider aspects such as; the number of customers; the connected load; the duration of the interruptions; the amount of power interrupted and the frequency of interruptions. Data's used for distribution system reliability analysis are expressed in appendix (B).

3.2. Nekemte City Electric Distribution Network

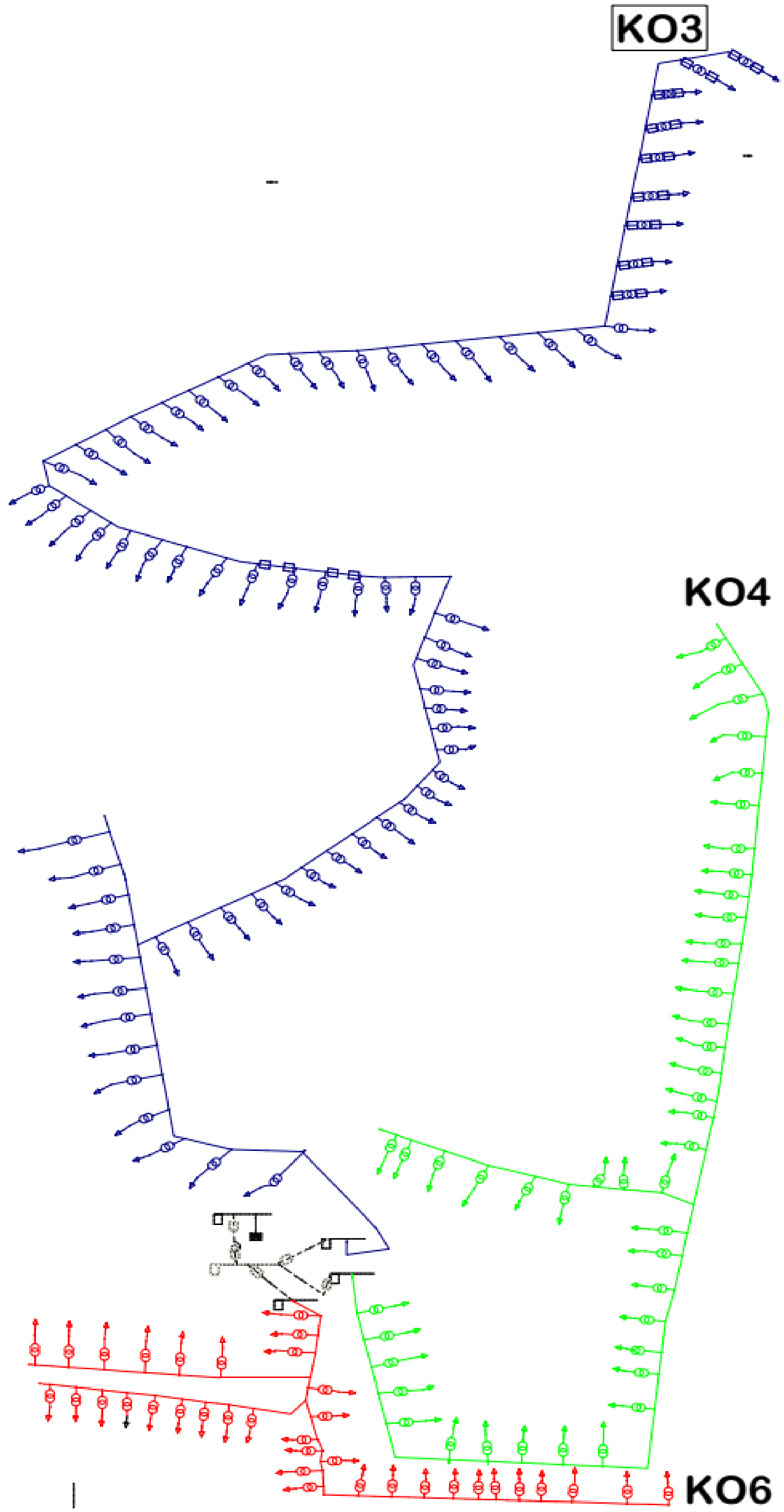
Nekemte substation has been supplied from interconnected system (ICS) main grid. The distribution system consist one hundred fifty three (153) different rates of distribution transformers, three circuit breakers and loads connected through 60.2 km of distribution overhead line of 15kV. It also consist three feeders, so called Bakke Jama feeder (KO4), Hospital feeder (KO3), and Wollaga university feeder (KO6), each feeders consists one SF6 circuit breakers and seventy four (74), forty five(45) and thirty four (34) distribution transformers respectively.

Table.3. 1 Selected assets population

Assets	Unit	Number	Capacity
Circuit breaker	Number	3	15Kv
Distribution Transformers	Number	153	15/0.4KV
Overhead distribution Line	Km	60	15 KV

Source: Nekemte Electric Service Office (2019)

Fig.3.1. shows the demonstration of Nekemte city distribution system, with three feeders Bakke Jama feeder and Hospital feeders.



Source: Nekemte Electric Service Office (2019)

Fig.3. 1.Nekemte city electric power distribution system

3.3.Assessments of Asset Management Strategy

An asset management strategy is the process of evaluating the health status of an asset in distribution network and to decide the best management strategy to enhance the asset health condition and distribution of the system. Asset management evaluation uses the assets age, observed condition and location factor as input and health score and health index as output to decide the best management strategy [19].

3.3.1. Assets Age Profile

This section describes the collection of age profiles of circuit breakers, transformers, overhead line assets of electrical power distribution network of Nekemte city. The city's substation is supplying by the electric transmission line which is stretched from Gedo substation since 1984 G.C.

I. Circuit Breaker Asset Age Profile

The distribution network consist three feeders and three circuit breakers, one circuit breaker at each feeders. Wollaga University feeder is the youngest feeder in age; it was updated during the establishment of Wollaga University in 2007.

Table 3.2.Shows the installation years of the circuit breaker asset and the circuit breaker CB1 was installed in 2007; CB2 and CB3 were installed in 1984. The two feeder's circuit breaker Bakke Jama feeder's circuit breaker (CB2) and Hospital feeder's circuit breaker (CB3) was installed earlier than Wollaga University's feeder circuit breaker (CB1).

Table.3. 2.Circuit breakers age profile data

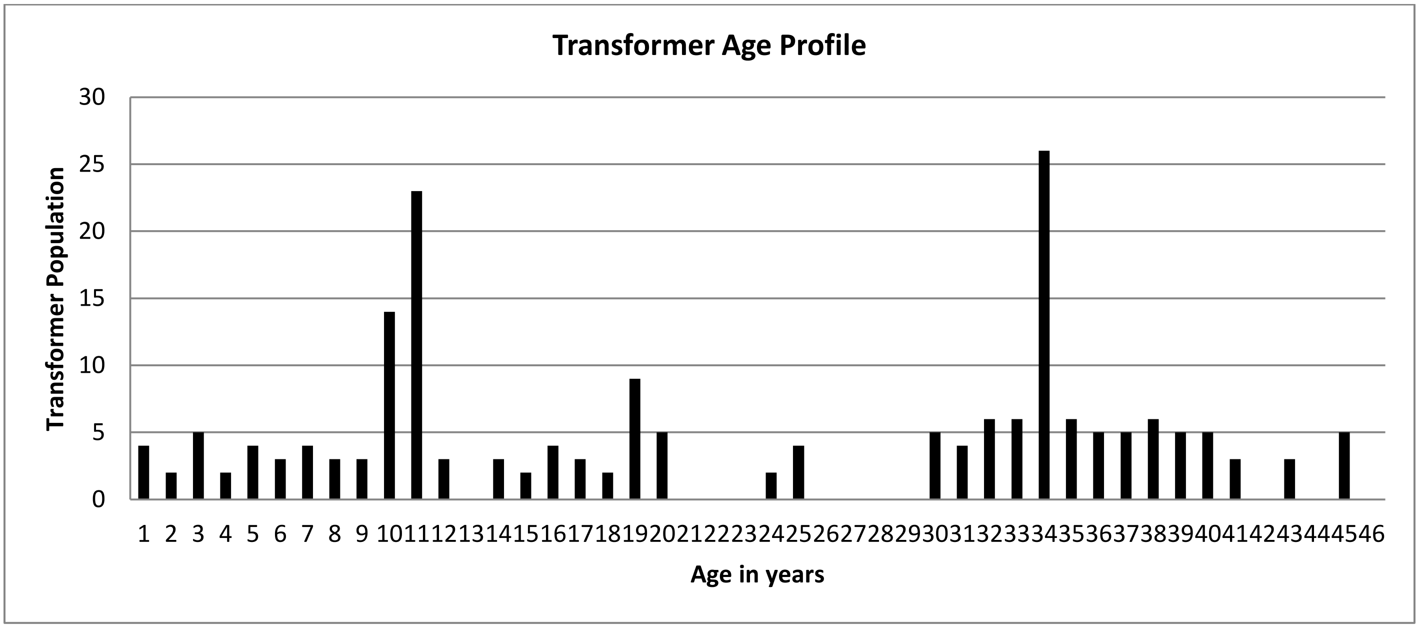
Circuit breaker	Installation in year	Age
CB1	2007	12
CB2	1984	35
CB3	1984	35

Source: Office of Nekemte Electric Utility, Ethiopia (2019)

II. Transformers Asset Age profile

Age profile of each transformer in distribution system is shown appendix (A). The distribution system consist transformers having different aged, installed in different years.

Fig.3.2 shows age profiles of each distribution transformers as determined from their installation year. It indicates the system has different aged distribution transformers installed in different years because of replacement while they burn and while the customers' expands city and upgrading.

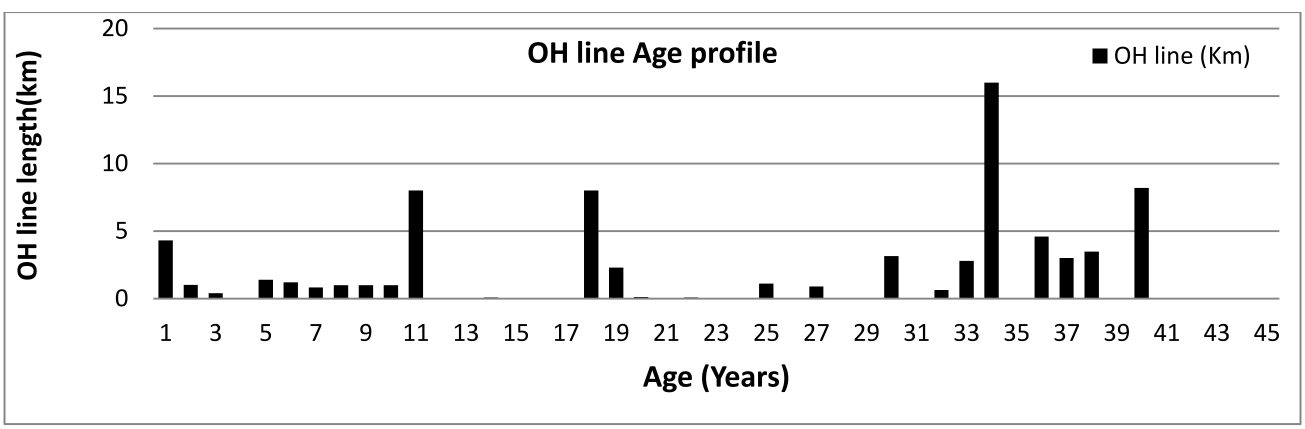


Source: - Ethiopian Electric Power Utility (Nekemte city), 2019

Fig.3. 2.Transformers asset age profile

III. Overhead Distribution line Asset Age Profile

The distribution line which carries a 15kv voltage from substation to distribution transformers in the system are divided into sections depending on their length between transformers for assessment purposes. The total length of distribution line is 60.63 km. is segmented into sections based on the location of tap points and transformers. The segments have been represented as line (1), line (2), line (3)… line (156). All successive lines are connected by nodes; Transformer (1), Transformer (2), Transformer (3) to Transformer (153) starting from substation to end load.



Source: - Ethiopian electric power utility (Nekemte city), 2019

Fig.3. 3.Overhead line age in years

Figure 3.3 shows majority of Nekemte city distribution system overhead lines are covered by old aged lines, above their expected life years.

3.3.2. Assets Health Condition Data

External observed condition is a parameter that related health status of an asset based on its deterioration. The observed condition inputs are parameters obtained by visual inspection of asset, to estimate the health score of the asset. Observed condition inputs of assets are determined as shown in table (3.3) and table (3.4) using [8, 26, 27] methodologies developed Distribution Network and Operation (DNO) Common Network Asset Indices

Table.3. 3 Circuit breaker External condition input factor criteria

External Condition criteria	Description	Condition input factor	Condition input cap	Condition input collar
As new	No observed deterioration	0.9	10	0.5
Normal wear	The asset component is fit for continued service. There is little deterioration	1	10	0.5
Some deterioration	Minor corrosion	1.3	10	0.5
Substantial deterioration	Major corrosion	1.6	10	8
Default	No data available	1	10	0.5

Table.3.3. shows circuit breaker and transformer asset condition data and corresponding condition input factor value. The circuit breaker condition is considered as new if it is new in age and if doesn’t have any corrosion, deterioration and linkages and its corresponding condition input factor is 0.9[8]. The circuit breaker condition is considered as Substantial deterioration if it had if it had major corrosion or evidence of significant oil leakage and its corresponding condition input factor is 1.6. Condition factor input of circuit breaker is limited 0.5 at minimum and 10 at maximum.

Table 3.4.shows transformer asset condition data and corresponding condition input factor value. The transformer asset input condition factors have a value of 0.9, 1, 1.1, 1.25 and 1.4 for transformer asset external condition of new, was not new but no evidence of corrosion, leakage (good), if it had minor localized surface corrosion, no evidence of oil leakage or slight but repairable oil leakage (slight deterioration), if it had some significant corrosion or evidence of slight oil, un repairable leakage (poor) and if it had major corrosion or evidence of significant oil leakage (very poor) respectively

Table.3. 4 Transformer External condition input factor criteria

External Condition criteria	Description	Condition input factor	Condition input cap	Condition input collar
As new	Condition as new	0.9	10	0.5
Good	e.g. no evidence of corrosion or oil leakage	1	10	0.5
Some deterioration	E.g. minor localized surface corrosion, no evidence of oil leakage or slight (but repairable) oil leakage.	1.1	10	0.5
Poor	Some significant corrosion, or evidence of slight oil (unrepeatable) leakage	1.25	10	8
Very poor	e.g. major corrosion or evidence of significant oil leakage	1.4		8
Default	No data available	1	10	0.5

The parameters used to assess the observed health condition of overhead line assets are its visual condition and its number of mid span joint between two successive transformers. Visual condition parameter focuses on the lines deterioration effects and mid span joint mainly focus on number of joints in between two successive poles of the line (span).

Table.3. 5.Overhead line Visual observed condition input and mid-span joints factor criteria

Visual observed Condition criteria					
Condition criteria	Condition input factor	No: joints in mid- span	Condition input factor	Condition input cap	Condition input collar
As new	0.9	0	0.9	10	0.5
Normal wear	1.1	1	1.05	10	0.5
Some deterioration	1.3	2	1.1	10	0.5
Substantial deterioration	1.4	>2	1.2	10	8
Default	1	Default	1	10	0.5

Table.3.5.shows the overhead distribution line visual condition input factor and it’s observed mid span joint input factor criteria.

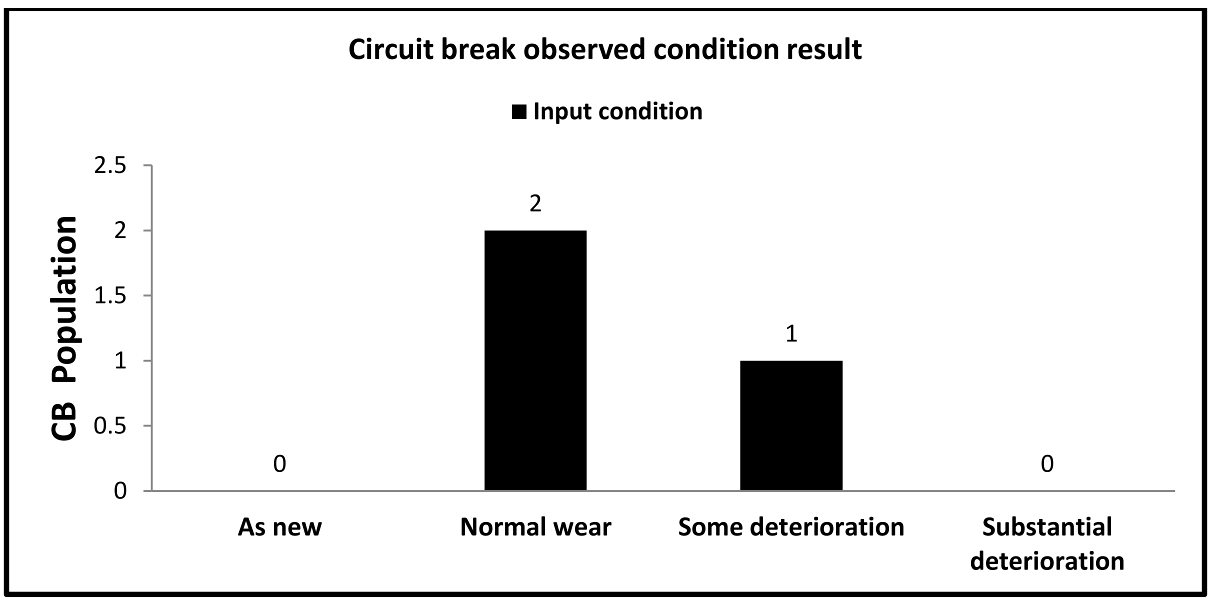
The visual condition input factor for the line will be 0.9 if it had no observed deterioration (if it is as new), 1.1 if the line component fits continuous service but there is little deterioration (if it is Normal wear), 1.3 if it had minor corrosion (some deterioration), 1.4 if it had broken strands, bird caging, loss of section (substantial deterioration).

Table 3.6 also shows observed mid span joint input factor criteria to assign to each line segment length, the mid span joint input factor is 0.9, 1.05, 1.1 and1.2, if it had no joints in the span, if it had one joint in the span, if it two joint in the span and if it had more than two joints in the span respectively.

Table.3. 6.Overhead line mid-span joints factor criteria

Visual observed Condition criteria				
External Condition criteria	No: joints in mid- span	Condition input factor	Condition input cap	Condition input collar
no joints	0	0.9	10	0.5
one joint	1	1.05	10	0.5
two joint	2	1.1	10	0.5
more than two	>2	1.2	10	8
Default	Default	1	10	0.5

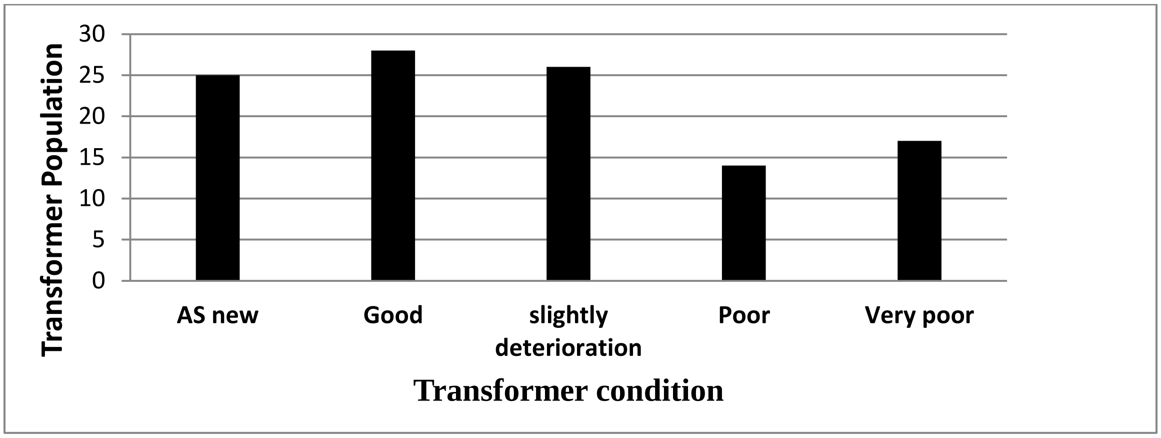
Figure 3.4 shows circuit breaker asset external observed condition input factor data for Nekemte city distribution network. The figure shows two circuit breakers have normal wear and one circuit breaker has some deterioration condition.



Source: own survey (2019)

Fig.3. 4.Circuit breaker observed condition factor result

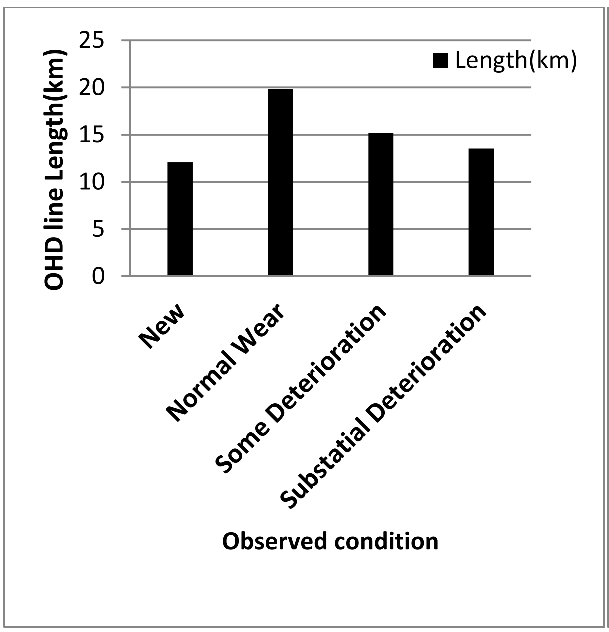
Figure 3.5 shows the observed condition of Nekemte distribution system transformer asset. Majority of transformers are poor and very poor condition and some of them are new and good condition. Poor and very poor conditioned transformers have oil linkage and corrosion that reduces their age and reliability.

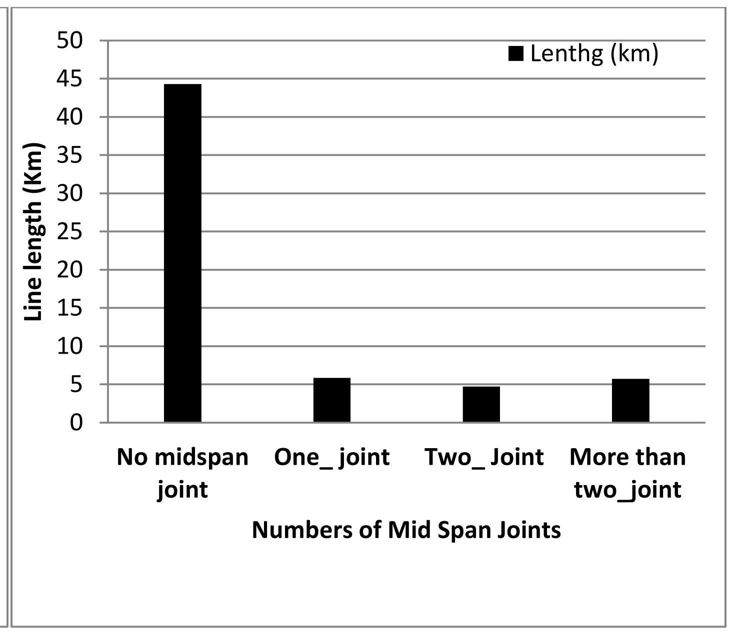


Source: - Ethiopian Electric Power Utility (Nekemte city), 2019

Fig.3. 5.Distribution transformer external observed conditions

The visual observed condition input factor and mid span joint input factor of the distribution network line is determined based on their condition criteria as shown in figure 3.6.





Source: - Ethiopian electric power utility (Nekemte city), 2019

Fig.3. 6.The visual observed condition and mid span joint of distribution line.

The figure also shows the major percentages of distribution line are substantially deteriorated and on few percentages are new. Majority of the line length are covered with no mid span and some portion of the line also consist more than one mid span joint in their span.

3.3.3. Asset Health Score Assessment

Asset health score is a measure of the condition of an asset and the proximity to the end of its useful life. The health score for an individual asset is derived from information relating to; the age of the asset, the normal expected life for an asset of its type, location factors, factors relating to the usage of the asset at its specific location that may impact upon its expected life (duty factors), factors relating to the observed condition of the asset (observed condition inputs).

MATLAB R2016a software is used to calculate the health score data of circuit breakers in the distribution network and the determined the health score asset is shown as in figure (3.7) and (3.8).

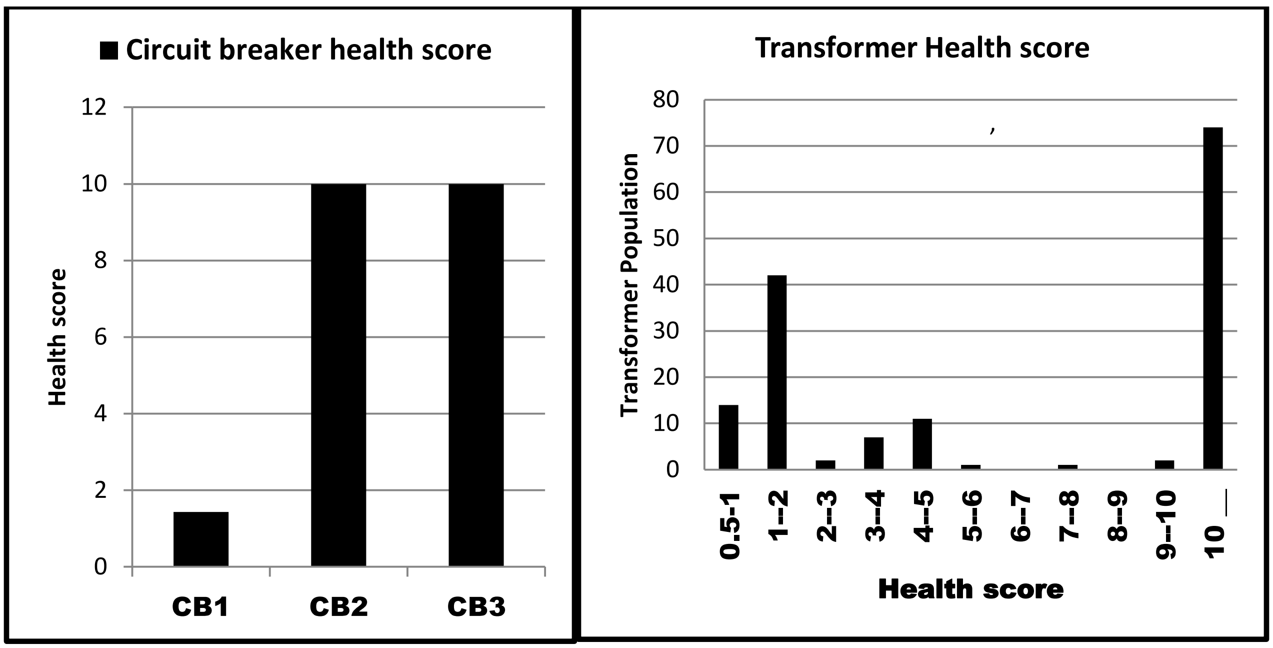


Fig.3. 7 Transformer and circuit breaker health score

Figure 3.7 shows the health score of circuit breakers (CB2 and CB3) is high, cap value health. Low health score value indicates that the asset is in good condition. It also shows that major population of distribution transformer had a score value of ten (10) and less transformer numbers had less than it. Low health score value indicates that the asset is in good condition and high value of health score indicates that the asset is at bad health condition.

Fig.3.8. shows health score values of distribution overhead line asset. Long length of distribution overhead line has a health score of ten (10) values. Less length of distribution overhead line have a health score of less than two (2). The figure also shows that forty point eleven (40.11) km length of the distribution line is covered with bad conditioned line.

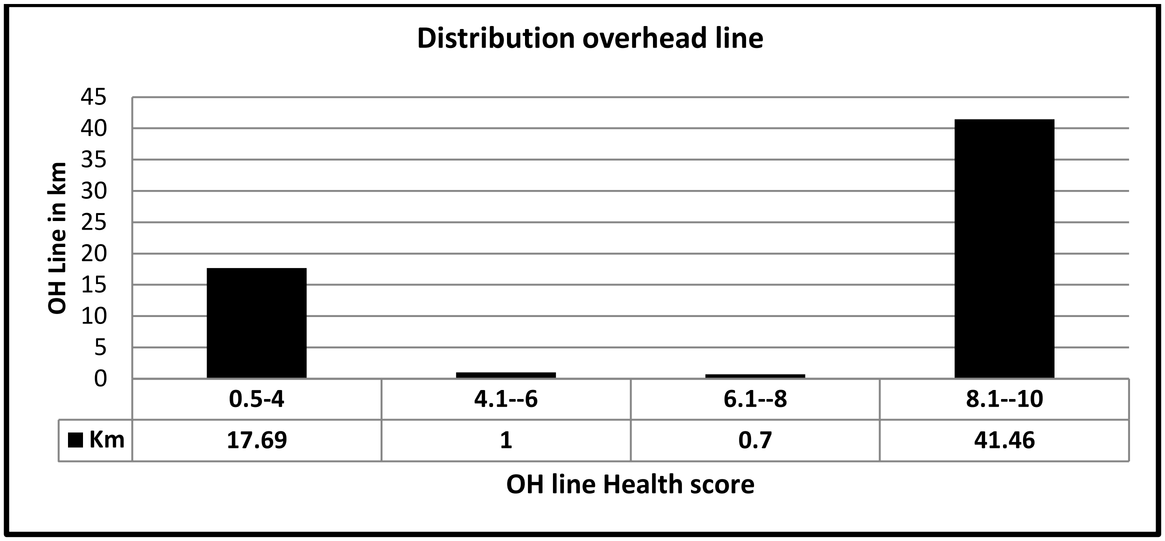


Fig.3. 8.The overhead distribution line asset health score result

3.3.4. Asset health Index Assessment

The health index of an asset is derived its health score depending on health condition using fuzzy logic. Fuzzy logic helps to decide the health index fuzzy set from health score depending on their degree of membership (DOM).To calculate the DOM of each asset trapezoidal fuzzy logic type is selected. Health index calculation using fuzzy logic includes the determination of fuzzy set, degree of membership, fuzzy rules and de-fuzzification.

I. Fuzzy set

Fuzzy set is a set that in which the input variables in a fuzzy control system are in general mapped by sets of membership functions similar to it. In this methodology have five fuzzy sets to calculate the health index of each asset based health score value as shown in table 3.6.

Table.3. 7.Asset health score fuzzy sets

Health Index	Health score range	Fuzzy set
HI_1	0.5 - 4.5	Set 1
HI_2	4 - 5.5	Set 2
HI_3	5 - 6.5	Set 3
HI_4	6 - 8	Set 4
HI_5	7.5 -10	Set 5

II. Degree of member function determination(DOF)

A degree of member function is assumed in this case is of 50% degree of member function.

III. Fuzzy rules

Fuzzy rules are determined from fuzzy set and Degree of member function based on their health score value. In general there five fuzzy rules in this method,

Rule_1: If Health scores less than 4.5 and DOM ≥ 0.5, then Health index is HI_1

Rule_2: If Health scores value is between 4 and 5.5 and DOM ≥0.5, then Health index is HI_2

Rule_3: If Health score value is between 5 and 6.5 and DOM ≥0.5, then Health index is HI_3

Rule_4: If Health score value is between 6 and 8 and DOM ≥0.5, then Health index is HI_4.

Rule_5: If Health scores value is between 7.5 and 10 and DOM ≥ 0.5, then Health index is HI_5.

The assets health index was derived from their health score value and summarized in five health index bands as shown in figure.

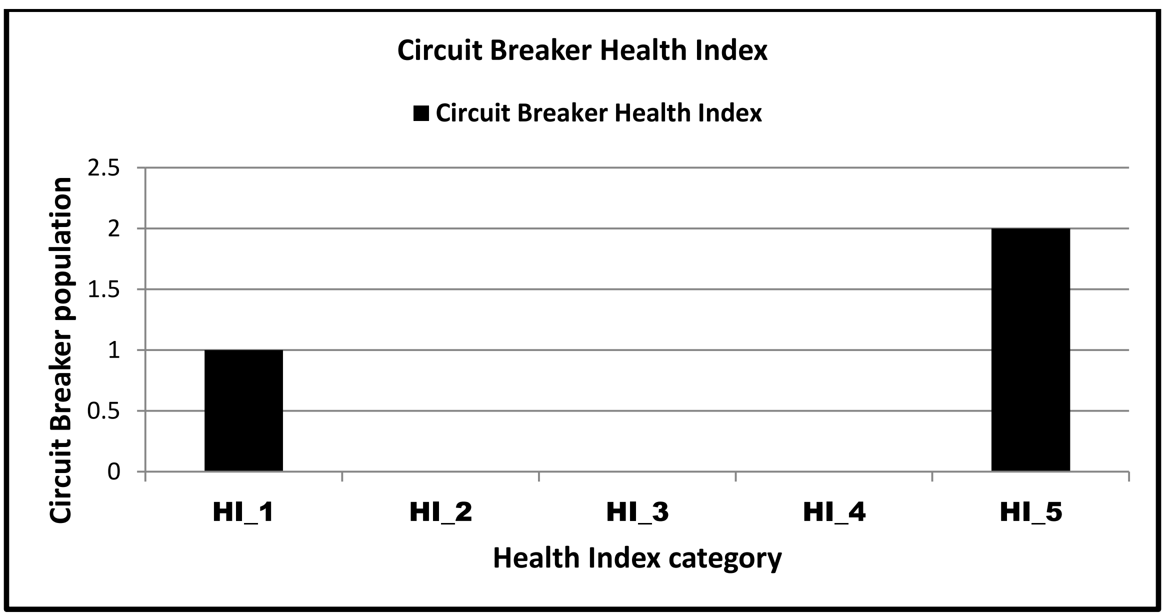


Fig.3. 9.Circuit breaker health Index

Fig.3.9 indicates that less population of circuit breaker assets are scored HI-which is considered as new and more of it populations were categorized under HI_5 which the worst health level.

Fig.3.10 shows transformers and overhead distribution line health indexes. It indicates the less population of transformer assets are scored HI-I which is considered as new and more of it populations were categorized under HI_5 which the worst health level.

It also indicates that less population of overhead lines assets are scored HI-I which is considered as new and more of it populations are categorized under HI_5 which indicate worst health level.

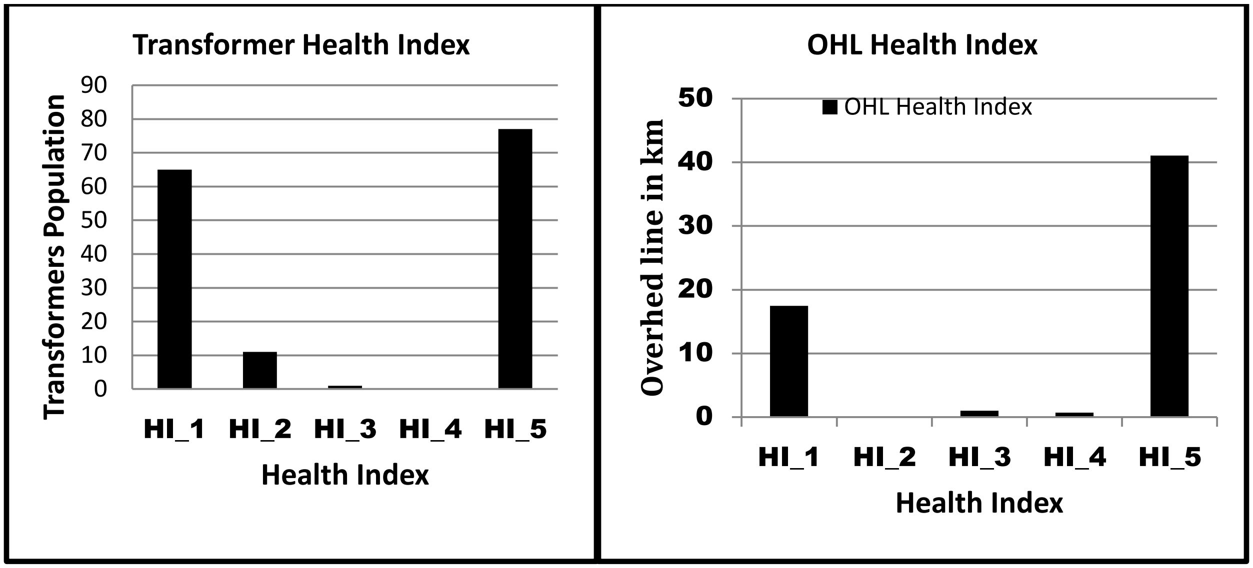


Fig.3. 10.Transformer and OH distribution line health Indexes

These health index bands are subsequently translated to POF values. The Health index band HI1 represents assets where the POF is the same as that for a new asset.

3.3.5. Assets Failure Rate Assessment

Electrical distribution is comprised of asset such as transformers, overhead lines, circuit breakers to supply customer without interruption. The system components can experiences failures (outages) to the customers due to aging, corrosion and deterioration assets. In general an asset failure rate due to its age and health condition degradation performance is expressed in equation (2.4) and repair duration of all assets is estimated accordingly historically recorded of Nekemte electric power utility office and data analysis based on health condition of the asset.

Table.3. 8.Circuit breaker failure and repair duration data

Asset	Failure rate(λ)	Repair duration (hrs. per failure)
CB1	0.1169	72.8947
CB2	1.1685	71.5666
CB3	1.1685	71.4543

Table (3.7) shows the number of failures experienced by circuit breaker, failure rate per year and it's time taken to repair or back to service, repair rate.

Fig.3. 11 shows the failure rate data of transformers and overhead distribution line.

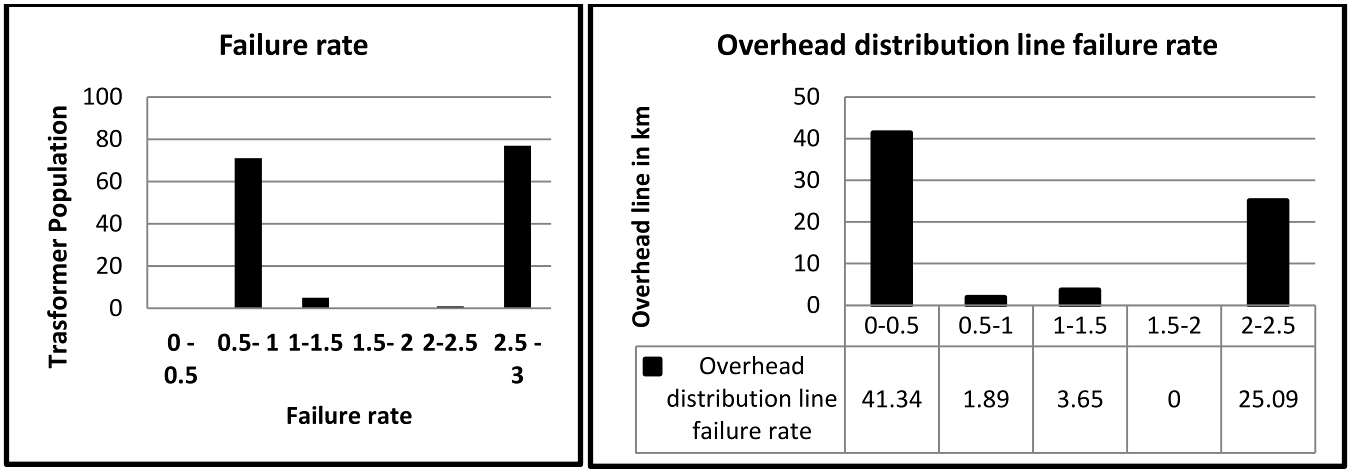


Fig.3. 12.Transformer failure rate data

Fig.3.12 shows that major transformer population consist failure rate of 2.5 to 3 failures in a year. The figure also shows that most of distribution overhead line experiences failure more than twice in a year.

3.3.6. Discussions of Distribution System Asset Management Strategy

The aged and deteriorated asset in electrical distribution network requires maintenance and replacement strategy in order to reduce reliability degradation on the system. The specific issue in power equipment asset management is how to determine equipment maintenance and replacement prioritize activities. One of a promising approach to this challenge is using health index, where it is a number based on analyzing age, historical failure and impact of failure data, to determine what equipment is most likely to fail and when such a failure may have a significant impact. These health index of each assets are categorized as HI-1, new or as new, HI-2, good or serviceable, HI3, which had some deterioration, HI-4, material deterioration, HI-5, end serviceable life in order to prioritize asset management strategy [8.26].

The objective of asset management is to take action of maintenance and replacement strategies for asset health index categories of HI4 and HI5. Assets having health index of (HI5) requires replacement intervention and HI4 requires maintenances.

Table 3.8.shows the asset management strategy applied in the distribution system according to health index and five (5) transformers require replacement strategy, seventy seven (77) transformers require maintenance strategy.

Table.3. 9 Asset maintenance and replacement strategy

Health Index	Circuit Breaker	Transformer	OH line (km)	Asset Management strategy decision
HI-1	1	60	17.46	Do nothing
HI-2	0	11	0	Do nothing
HI-3	0	1	1	requires assessment and monitoring
HI-4	0	5	0.7	Maintenance strategy
HI-5	2	77	41.06	Replacement strategy

3.3.7. Effect of asset management strategy on health level

To consider the effect of asset management applied to the assets on health status and reliability of the system it is necessary to re assess the health score, health index and failure rate of assets after maintenance and replacement strategy. Maintenance and replacement strategy decrease the age rate factor and their observation condition input factor.

The circuit breaker and transformer assets health index before and after asset management strategy application to the system is shown in fig.3.13.

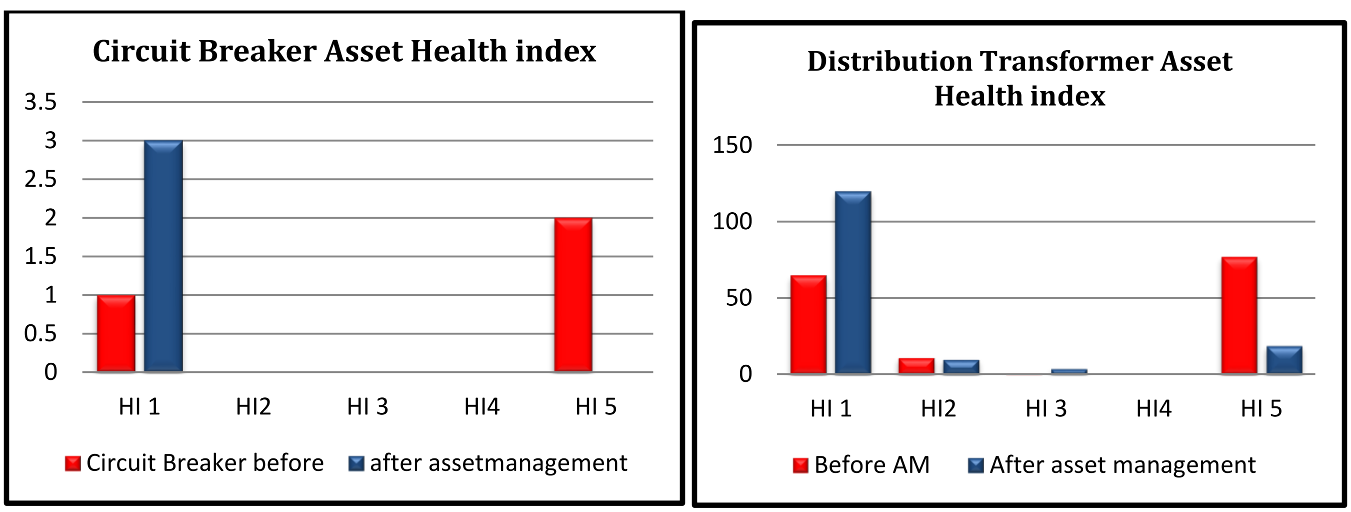
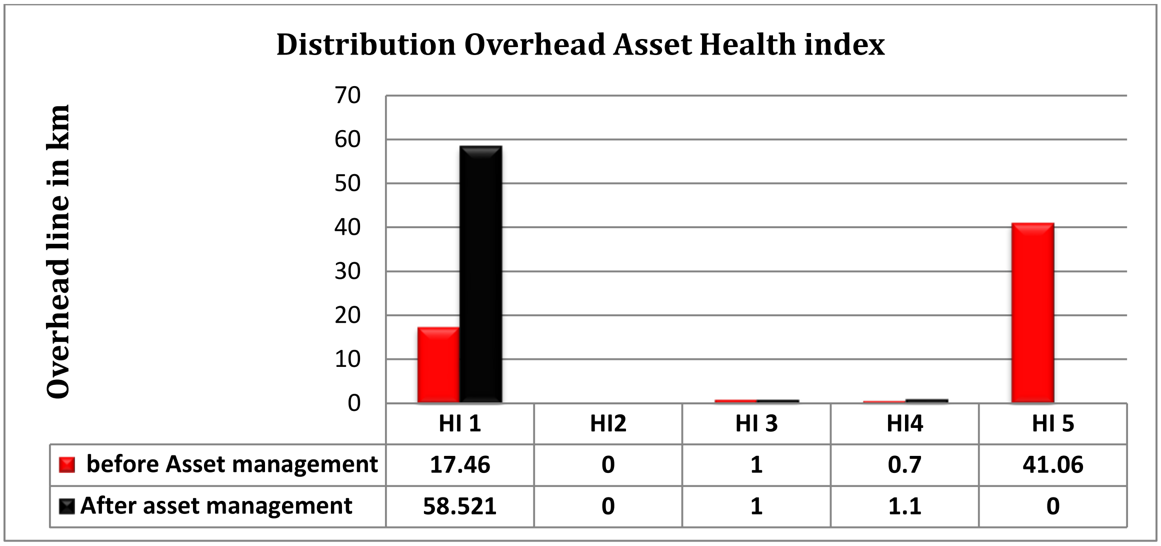


Fig.3. 13.Circuit breaker asset health index

The figure shows the health index of circuit breaker is changes to HI-1from HI-5 health index after the asset maintenance and replacement have been applied the circuit breaker asset. This indicates, the circuit breakers of HI-5 are replaced by new assets to possess health index of HI-1 which considered as good health level. It also indicates the health index of transformer is changed to HI-1 and HI-2 from HI-5 health index after the asset maintenance and replacement have been applied the transformer asset.

Distribution Overhead Asset Health index before and after maintenance and replacement asset management is applied to it is shown in figure (3.14).



	HI 1	HI2	HI 3	HI4	HI 5
before Asset management	17.46	0	1	0.7	41.06
After asset management	58.521	0	1	1.1	0

Fig.3. 14 Distribution Overhead Asset Health index

The figure indicates the health index of overhead is changed to HI-1 and HI-2 from HI-5 health index after the asset maintenance and replacement had applied the overhead line asset. This indicates maintaining and replacing assets change their health condition and performance as new asset.

3.4. Distribution System Network Reconfiguration Analysis

Distribution network will be reconfigured by installing electrical device such as recloser, switches and automations in the system in order to improve the reliability of system. Sectionalizing and tie switch enable to restore power to customers. The normally closed and normally open switches can be operated to supply customer before even faults are repaired.

The problem of improving reliability by the use of reclosing and switching capability is subjected to cost of installation and operation of new devices. The cost optimization is done under reliability target constraints to achieve reliability targets.

The more devices used to reclosing and switching are placed in a feeder, the higher reliability of the feeder will be. As a result, cost of installing new devices increases. Therefore to minimize the total cost of sectionalizing switches, recloser and automation, and to maximize the distribution system reliability.

In order to solve the reconfiguration optimization problem, genetic algorithm method and Particle swarm optimization are used.

3.4.1. Distribution Network Reconfiguration using Genetic Algorithm

The placement of automating device is done using Genetic Algorithm assuming the line segments of the system as chromosomes of the algorithm. For each location, the feeder’s reliability indices are evaluated to insure improvement in reliability. Reliability improvement in is assumed to be achieved by installment of suitable device from either of automating equipment, recloser or switches.

The developed Genetic algorithm optimization procedures include the following steps.

Step 1: Generate the initial population for each individual. Initial population is a matrix of number of line segment by 11 sizes.

b1	b2	b3	b4	b5	b6	b7	b8	b9	b10	b11

Fig.3. 15 Initial population chromosome

The first eight digits, b1 to b8, represent the line segment in the feeder. B9 stands for the installment of new device. Value of b9 is one implies new device is placed in the line segment (chromosome) and value of zero means no device is placed. B10 represent if the installed device is switch or recloser. B10=1 means recloser is placed and b10=0 indicates the newly installed device is a switch. If the switch installed has an automating device or not is represented using the eleventh digit of the chromosome. B11=1 indicates to automating device installment.

B9=1, b10=0, b11 =1 represent the new device placed as sectionalizing switch that has automating equipment connected with it. For b9=1, if b10=1, it represents new recloser is installed. B11, automating equipment, is required to enable remote-control capability of sectionalizing switches. It’s not required if the installed device is recloser. Therefore, in this case, the value of b11 doesn’t represent anything.

B9 =0 shows the status of b10 and b11 has no effect in the process. It means no device is installed.

Step 2: Apply genetic operators depending on the problem (crossover, mutation, etc.) to generate a single descendant. One-point crossover is carried out in this section. The combination assumes that variation of location points in the last three genes can reach into the optimal solution. The cross over at this point enables alternative approach to installment of device at different location (chromosomes).

Eight genes from parent one is placed in the first offspring and same from parent two in the second offspring. Gene exchange occurs after the eight digits.

The last three of the first parent is put into the second offspring and vice versa. Such combination is applied to consecutive chromosomes in the population. At first the initial population gives 153 new individuals and using selection function fittest ones are promoted to the next era.

MATLAB R2016a user defined function in m-file programming is developed for this recombination. In this optimization, a mutation probability of 0.08 is applied in the offspring.

Step3:- Evaluate fitness function

The objective of this optimization is to minimize the cost of installing new devices in Nekemte distribution network. Cost optimization is done under reliability constraints as expressed in equation (2.16). The program analyzes the fitness value of individuals only those who have b9=1 in their chromosomes. Because of different individuals represent different line segments in a generation, it is the cumulative reliability of the system that corresponds to the cost minimization process.

Reliability indices are evaluated for each generation to minimize the cost within the constraint. To evaluate reliability of the system the line, recloser, sectionalizing switch and automating equipment failure and the portion of the feeder it affects is considered. The failure rates of newly installed devices are also assumed in each line segment.

X1= [1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36]
X2= [37 38 39 40 41 42 43 44 45 46 47 48 49 50 0 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 0 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109
37 38 39 40 41 42 43 44 45 46 47 48 49 50 0 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 0 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111]
X3= [110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153
110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153]

Line sections and load points affected by upstream and downstream failure are exclusively and mutually grouped. First row of X1 is the load points in the feeder and the second row is line segments where any failure occurring in line sections affects the load points.

Step 4: Local search optimization: improve the resulting descendant with information about the nature of the problem.

Step 5: If the stop criterion was satisfied, stop. Otherwise, return to step 2

If the resulting SAIFI and SAIDI violate target limits, a new location for placement of devices is tested for better solution. By varying the type of devices installed under the required reliability, the cost of installment is also minimized. In such a process, optimal solution of new device placement location is achieved. In general the position and numbers of switches, recloser and automating devices were summarized in table 3.9.

Table.3. 10 Reconfiguring devices placement using Genetic algorithm result

Wollaga University feeder		
	Numbers	Line segment Position
Switch	4	4 12 20 28
Recloser	5	2 5 10 16 24
Automation	4	9 14 22 30
Bakke Jama feeder		
Switch	7	36 44 52 60 68 84 100
Recloser	6	48 56 77 80 88 109
Automation	7	46 54 65 70 78 94 105
Hospital feeder		
Switch	5	115 123 131 139 147
Recloser	4	120 127 133 152
Automation	5	110 142 145 150 153

The cost optimization is done under reliability target constraints to achieve reliability targets. The more devices used to reclosing and switching are placed in a feeder, the higher the reliability of the feeder will be. As a result, cost of installing new devices increases. Figure 3.16 shows the Genetic algorithm (GA) simulation cost function per iteration.

The simulation takes 150 iterations to search the minimum total cost devices of sectionalizing switches, reclosers and automation by changing their position and numbers.

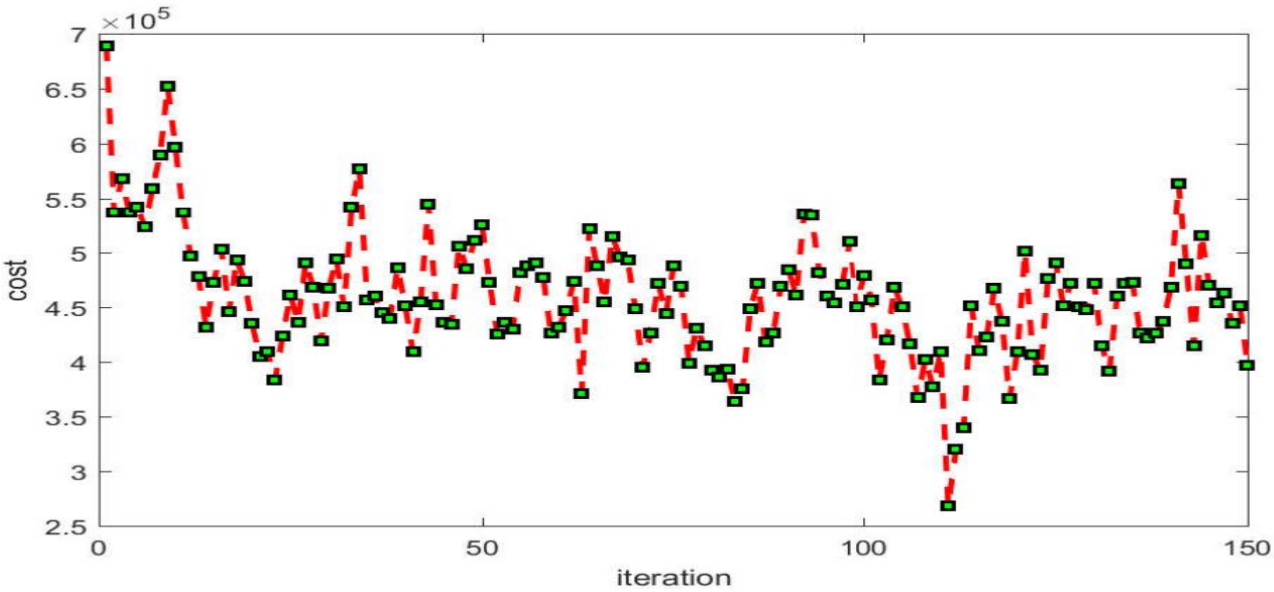


Fig.3. 16 cost function result

3.4.2. Distribution Network Reconfiguration Analysis Using Particle Swarm

PSO optimization is used for solving the recloser, switches and automation allocation optimization problem. The developed PSO algorithm optimization procedures include the following steps.

Step 1: Generate the initial population. Generation initial population of in PSO is the same as that of genetic algorithm optimization.

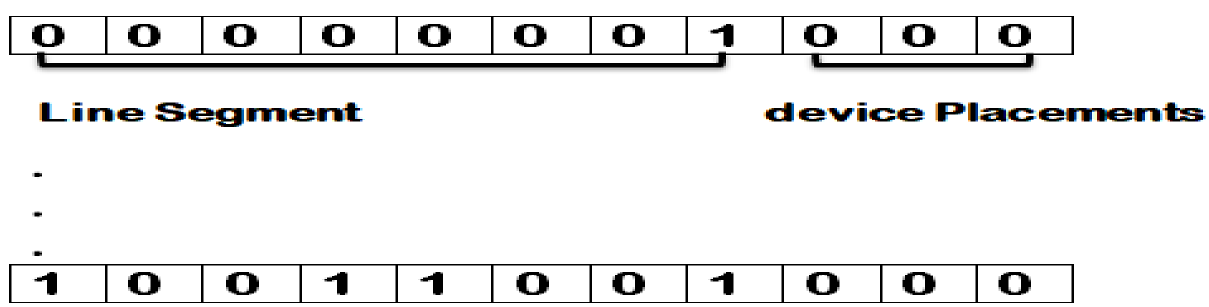


Fig.3. 17 PSO initial population

Step 2: Calculate the Objective Function: **-** The objective of this optimization is to minimize the cost of installing new devices in Nekemte distribution network. Cost optimization is done under reliability constraints as expressed in equation (2.15). The program analyzes the fitness value of individuals only those who have b9=1 in their chromosomes.

Step 3: (Calculate P_{best}): The objective function related to each particle in the population of the current iteration is compared with it in the previous iteration and the position of the particle enjoying a lower objective function as P_{best} for the current iteration is recorded.

Step 4: (Calculate G_{best}): In this step, the best objective function associated with the P_{bests} among all particles in the current iteration is compared with that in the previous iteration and the lower value is chosen as the current overall G_{best}.

Step 5: (Update Velocity): After calculation of the P_{best} and G_{best}, the velocity of particles for the next iteration should be modified.

Step 6: (Update Position): The position of each particle at the next iteration (k+1) is modified.

Step 7: (Check Convergence Criterion):- If the stop criterion was satisfied, stop. Otherwise, return to step 2.

The number and location results of PSO of new protective devices have been summarized in table 3.10.

Table.3. 11 Sectionalizing switches, Recloser and Automation location result using PSO

Wollaga University feeder	numbers	Line segment position
Sectionalizing switches	1	8
Recloser	4	5,6,17,24
Automation	3	9,11,19
Bakke Jama feeder		
Sectionalizing switches	2	49,51
Recloser	8	37,42,58,65,72,83,93,104
Automation	3	47,77,99
Hospital feeder		
Sectionalizing switches	2	125,129
Recloser	6	115,122,133,142,146,152
Automation	1	140

Table3.10 indicates the new position of switches reclosers and automation in each feeder. For instance Wollaga university feeder has sectionalizing switch at line segment position eight (8) and recloser at line segment position five (5), six (6), seventeen (17), twenty four (24) line segments.

The problem of improving reliability by the use of reclosing and switching capability is subjected to cost of installation of new devices.

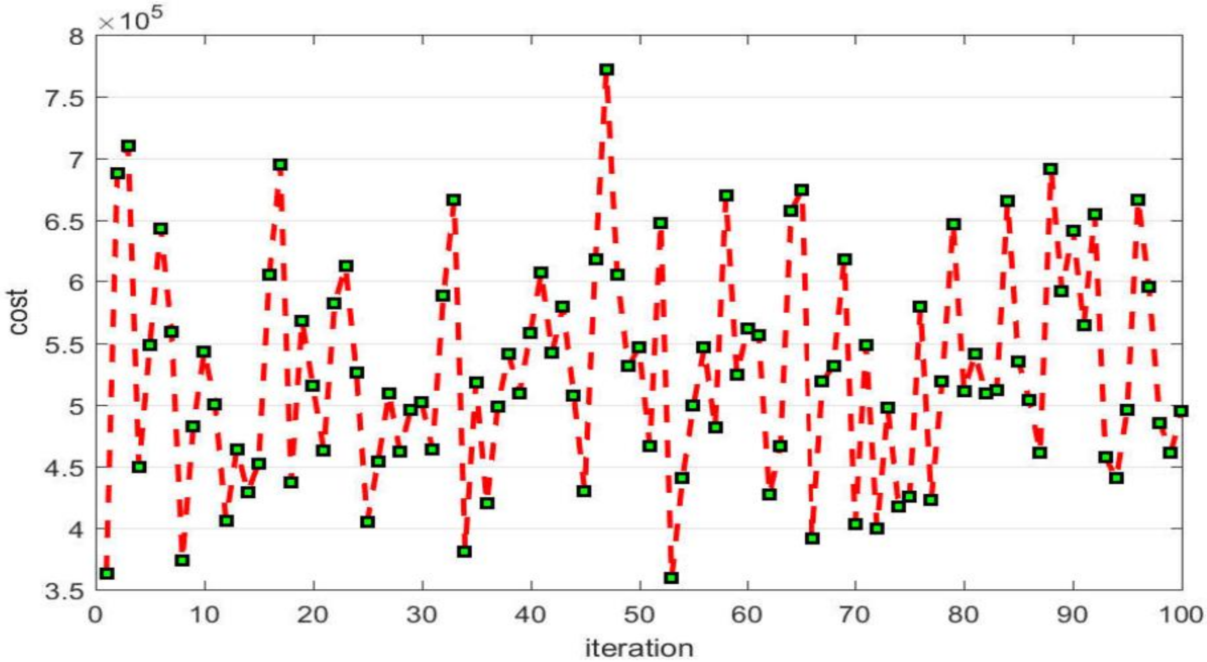


Fig.3. 18 Cost function result using PSO

3.4.3. Compressions GA and PSO Optimization Techniques

Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) are the most famous optimization techniques among various modern heuristic optimization techniques.

Table.3. 12 related to parameters of GA and PSO

GA		PSO	
Parameters		Parameters	
Initial population	153X11 binary matrix	Initial particles	153X11 binary matrix
Chromosome	1X11 binary matrix	Chromosome	1X11 binary matrix
Genes	1 or 0	Genes	1 or 0
Obj. function	Min(C=1000*Nr+15000Na+500Ns)	Obj. function	Min(C=crNr+caNa+csNs)
Constraint function	SAIFI<25 SAIDI<20	Constraint function	SAIFI<25 SAIDI<20
Tran, failure rate	153X1 matrix	Tr. failure rate	153X1 matrix
Overhead line failure rate	153X1 matrix	Overhead line failure rate	153X1 matrix

3.5. Reclosers, Automatic Sectionalizes, Switches Design criteria

Automatic Circuit Reclosers: Reclosers are available with a wide range of current and voltage ratings and are suitable for use on virtually all distribution circuits.

The original concept of reclosers was to provide a self-contained, low-cost tripping and reclosing circuit interrupter, which could be used economically for pole-mounted protection of distribution feeders. These reclosers employ a series coil that causes tripping of the recloser at approximately two times the continuous current rating of the coil. They can be either single-phase or three-phase devices. The recloser standards used is ANSI/IEEE C37.60 - 1981 and C37.61 – 1973. Automatic Circuit Recloser is a self-controlled device for automatically interrupting and reclosing an alternating-current circuit, with a predetermined sequence of opening and reclosing followed by resetting, hold closed, or lockout.

Rated interrupting current: - A recloser is rated on the basis of the maximum symmetric fault current it is designed to interrupt

Duty cycle: **-** Duty cycle is a standardized test sequence to which a recloser is subjected to establish its minimum life and rated interrupting current. A recloser duty cycle (Standard Operating Duty) establishes the capability of a recloser to interrupt a relatively large number of faults, tested at three separate current values. For instance, the Type VSA12 recloser duty cycle is a total of 232 operations consisting of 88-112-32 interruptions at the specified currents.

Derating of rated interrupting current for reclosing duty

A recloser is capable of its full interrupting rating for a complete four-operation sequence, based on the sequence used to determine the Standard Operating Duty. Reclosers, therefore, do not require derating

Required asymmetrical interrupting capability

When applied within the maximum symmetric fault current rating and the maximum X/R ratio, a recloser is capable of interrupting any degree of asymmetrical current that can occur

Required closing-latching-carrying-interrupting capabilities

Recloser standards define a “rated symmetrical making current”. The rated symmetrical making current shall be the same value as the rated symmetrical interrupting current, with maximum symmetry corresponding to the X/R ratio”. This rating establishes the capability to close in on any symmetric or asymmetric current within the interrupting rating of the recloser

Required short-time current carrying capability*:* **-** Recloser standards do not include any short-time requirements. A short-time current capability is established during testing of the Standard Operating Duty (duty cycle), where the recloser must withstand the maximum time delay curve with the maximum available minimum trip value as part of the recloser operating sequence.

While not required by standards some reclosers are tested to establish a short-time current rating.

Continuous current: - Recloser current rating originated with the series-coil type of recloser, utilizing coil ratings of 25, 35, 50, 70, 100, 140, 200, 280, 400 and 560 Amps.

Each succeeding rating is approximately 1.4 (or √2) times larger than the previous value. Higher ratings of 800 and 1120 Amps are extensions of this number series. Essentially, the 560 and 1120 Amp ratings are equivalent to 600 and 1200 Amp

Load current switching capability: - No ratings are specified in standards. However, some reclosers have been tested and are rated for Capacitance Current Switching in accordance with C37.06.

Reclosing interval time: - The reclosing interval is “The open-circuit time between an automatic opening and the succeeding automatic reclosures.” (C37.100). this is the actual “dead” time (no current flow) of the circuit since the recloser control determines the interval between opening and reclosures.

Table.3. 13.Automatic recloser rating

Rating	**Value**
Nominal operating voltage	14.4 KV
Rated maximum voltage	15.5 KV
Rated power frequency	50 HZ
Rated continuous current	800 A
Rated symmetrical interrupting current	12.5/16 KA
Rated lighting impulse withstand(BIL)	125 KV
Dry withstand 50HZ 1min:	50 KV
Wet withstand 50HZ 10 sec:	45 KV

Automatic Line Sectionalizes: An automatic line sectionalizes is an oil, air, or vacuum switch that automatically opens to isolate a faulted section of line.

It employs either a hydraulic or electronic counting mechanism, which is actuated by a system overcurrent and an up line circuit breaker or recloser tripping action. Unlike other overcurrent protection devices, a sectionalized does not operate on a time-current curve.

Automatic line sectionalizes are available as either three-phase or single phase devices. They are not rated to interrupt fault current and, therefore, must be used in conjunction with up line reclosers or circuit breakers capable of sensing and interrupting minimum fault currents beyond the sectionalizing. The recloser or circuit breaker must sense a fault and perform the circuit tripping and fault-clearing operation. The sectionalizing counts the preset number of recloser or breaker trips and senses minimum fault current through the sectionalizing. After both conditions are met, the sectionalizing automatically locks open during the open circuit time of the breaker or recloser. A sectionalizing may be used for switching loads within its load-interrupting rating.

Table.3. 14 Automatic Line Sectionalizes rating

Rating	**Value**
Rated voltage	15 KV
Insulation level	110KV BIL
Rated frequency	50
Nominal current	200A
Manual load break	200A
Number of counts before operation	Resettable 1-4
Inrush detection time	<1 cycle
Short time current.1 sec (effective)	4 KA
Asymmetrical initial (peak)	10KA
Dead line detection	<200mA
Dead line verification time	80ms
Maximum memory time dead line	>3.5minute

Line Switches. Line switches typically do not have overcurrent characteristics, but are extremely valuable in the operation of a distribution system, especially in the restoration of service. Sectionalizing studies should consider the prevention of outages as well as measures to partially restore service, especially along main feeders. Line switches can be individually operated or gang-operated, load-breaking or non-load-breaking, and manually operated or remotely operated through SCADA systems. Load-break gang-operated switches are typically located at open points between feeders and substations to facilitate switching load between areas for maintenance or restoration. Non-load-break switches are economically beneficial in locations where main feeders go cross country or through heavily treed rights of-way or just past a load center; they can be used to isolate the part of a circuit requiring repair, allowing the feeder to be reenergized to that point.

Table.3. 15 line switches rating

Rating	**Value**
Rated voltage	15 KV
Rated power frequency dry withstand voltage (60s)	50 KV
Rated power frequency wet withstand voltage (60s)	45 KV
Frequency	50 HZ
Nominal current	200 A
Manual load break	200 A
Actuating current	6-215 A
Number of counts before operation	1-4
Short time current .1s (rms value)	4 KA rms
Asymmetrical initial (peak)	10 KA
Dead line detection	<200mA
Memory resetting time	30 sec

CHAPTER FOUR

SIMULATION RESULTS AND DISCUSSION

The power distribution system reliability in existing case and with asset management strategy and distribution system reconfiguration with GA and PSO algorithm is simulated in this chapter. Base case reliability assessment considers the failure rate of each asset derived from health score assets in existing system. The failure rate after considering the maintenance and replacement strategy is used to analyze implication of asset management strategy on distribution system reliability.

4.1. Simulation of Existing Distribution System Reliability

Reliability assessment is the probabilistic assessment of power system interruptions during an operating period and it involves of total electric interruptions for loads within a power system. Distribution System Reliability Assessment Inputs includes, failure rate, repair duration of each asset, number of customers on each load, mount of power interrupted and frequency of interruptions.

4.1.1. Existing Distribution System Reliability Outputs

Distribution system reliability is measured using their reliability indices as a tool of distribution performance evaluation.

Table.4. 1Nekemte distribution system summary Reliability Index

	| DIgSILENT Power Factory | Project: |
	| 15.1.7 | Date: 3/9/2020
Reliability Assessment	
Study Case: Nekemte city distribution system	| Annex / 1
System Summary	
System Average Interruption Frequency Index	: SAIFI = 87.169978 1/Ca
Customer Average Interruption Frequency Index	: CAIFI = 87.169978 1/Ca
System Average Interruption Duration Index	: SAIDI = 5889.865 h/Ca
Customer Average Interruption Duration Index	: CAIDI = 67.568 h
Average Service Availability Index	: ASAI = 0.3276409388
Average Service Unavailability Index	: ASUI = 0.6723590612
Energy Not Supplied	: ENS 118.039228 MWh/a
Average Energy Not Supplied	: AENS = 5.646MWh/Ca
Expected Interruption Cost	: EIC = 11.942 M$/a
Interrupted Energy Assessment Rate	: IEAR = 0.101 $/kWh
Average System Interruption Frequency Index	: ASIFI = 87.181476 1/a
Average System Interruption Duration Index	: ASIDI = 5890.692757 h/a

The existing system of Nekemte city distribution is summarized in table 4.1. The table indicates that the system has average interruption frequency index (SAIFI) of 87.169978 per/customer year and average interruption duration index (SAIDI) of 5889.86 hours per customer year.

Table 4.2 shows the comparison of the most commonly used reliability indices SAIFI and SAIDI of Nekemte city distribution network with the standards of Ethiopian Electric Agency (EEA), with IEE and other countries [22]. Smaller values of indices indicate better reliability. Whereas larger values the indices indicates poor reliability.

Table.4. 2: Summary of comparison of reliability indices

Country	SAIFI	SAIDI
United States	1.5	4
Australia	0.9	1.2
France	1.0	1.03
Germany	0.5	0.383
Italy	2.2	0.967
Spain	2.2	1.73
United Kingdom	0.8	1.5
Ethiopia	20	25
IEEE	2.23	1.03
Nekemte City	87.17	5889.865

In general, based on collected data and the analysis of its results, the following major points can be drawn, the reliability of the power supply in Nekemte city:-

- It does not meet the requirement of Ethiopian Electric Agency (EEA) regulatory.
- It is not good enough as compared to international reliability indices of best experienced countries such as Germany.
- It is not good enough as compared to IEEE standards reliability indices
- There is high unavailability of electric power in network
- There is also much loss of unsupplied energy.

4.2. Distribution Reliability Simulation with Asset Management Strategy

Asset management is the technique that can enhance the distribution network reliability performance through maintaining and replacing the aged and deteriorated assets.

Maintaining and replacing assets improves their aging rate and health condition input factor, this in turn improves the failure rate of assets. Therefore, this considers the effect proper asset management strategy by re assessing health score and failure rate of assets modified by maintenance and replacement strategy.

Figure 4.1 shows the transformer and OH line asset failure rate before and after asset management strategy consideration. Before the application asset management strategy majority of transformers have records the failures of 2.5 - 3 per year and after asset management strategy consideration majority of transformers have records of failure rate 0-1 per year.

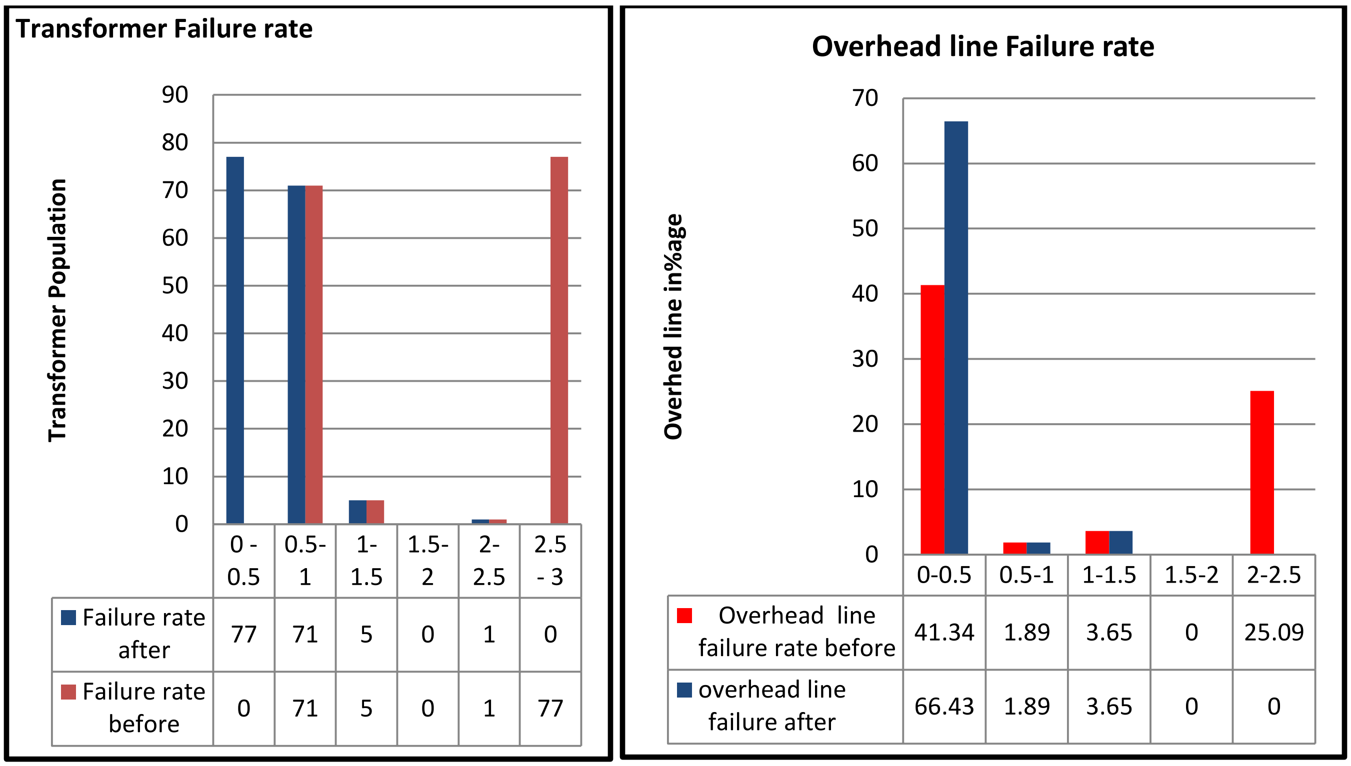


Fig.4. 1 Failure rate of transformer and overhead line asset after management strategy

To evaluate distribution system performance modified failure rate due to maintenance strategy and replacement strategy is included.

Table4.3 shows the Nekemte city distribution System reliability index simulation result by implying maintenance and replacement strategy. The system average interruption frequency index (SAIFI) 53.2 per customer annual and system average interruption duration index (SAIDI) is 1526.34 hours per customer annual. This result shows maintaining and replacing bad conditioned assets using assets improves the distribution system reliability.

Table.4. 3 System reliability Index simulation result after asset management

| | |	| DIgSILENT | Project:
| | |	| Power Factory |------------------------
| | |	| 15.1.7 | Date: 9/15/2019
Reliability Assessment	
System Summary	
System Average Interruption Frequency Index	: SAIFI = 53.238815 1/Ca
Customer Average Interruption Frequency Index	: CAIFI = 53.238815 1/Ca
System Average Interruption Duration Index	: SAIDI = 1526.343 h/Ca
Customer Average Interruption Duration Index	: CAIDI = 28.670 h
Average Service Availability Index	: ASAI = 0.8257599278
Average Service Unavailability Index	: ASUI = 0.1742400722
Energy Not Supplied	: ENS = 31.315590 MWh//a
Average Energy Not Supplied	: AENS = 1.498MWh/Ca
Expected Interruption Cost	: EIC = 3.190 M$/a
Interrupted Energy Assessment Rate	: IEAR = 0.102 $/kWh
Average System Interruption Frequency Index	: ASIFI = 52.921474 1/a
Average System Interruption Duration Index	: ASIDI = 1514.838097 h/a

4.3. Distribution System Reliability Simulation with Network Reconfiguration

Network reconfiguration is achieved using Sectioning switches, reclosers and automation switches. The optimum position of these switches are determined using Genetic Algorithm(GA) and Particle Swarm Optimization(PSO) as shown in table (3.9) and table (3.10) respectively.

Figure 4.2 indicates the network reconfiguration Nekemte city distribution system using optimum positions of sectionalizing switches, recloser and automation switches.

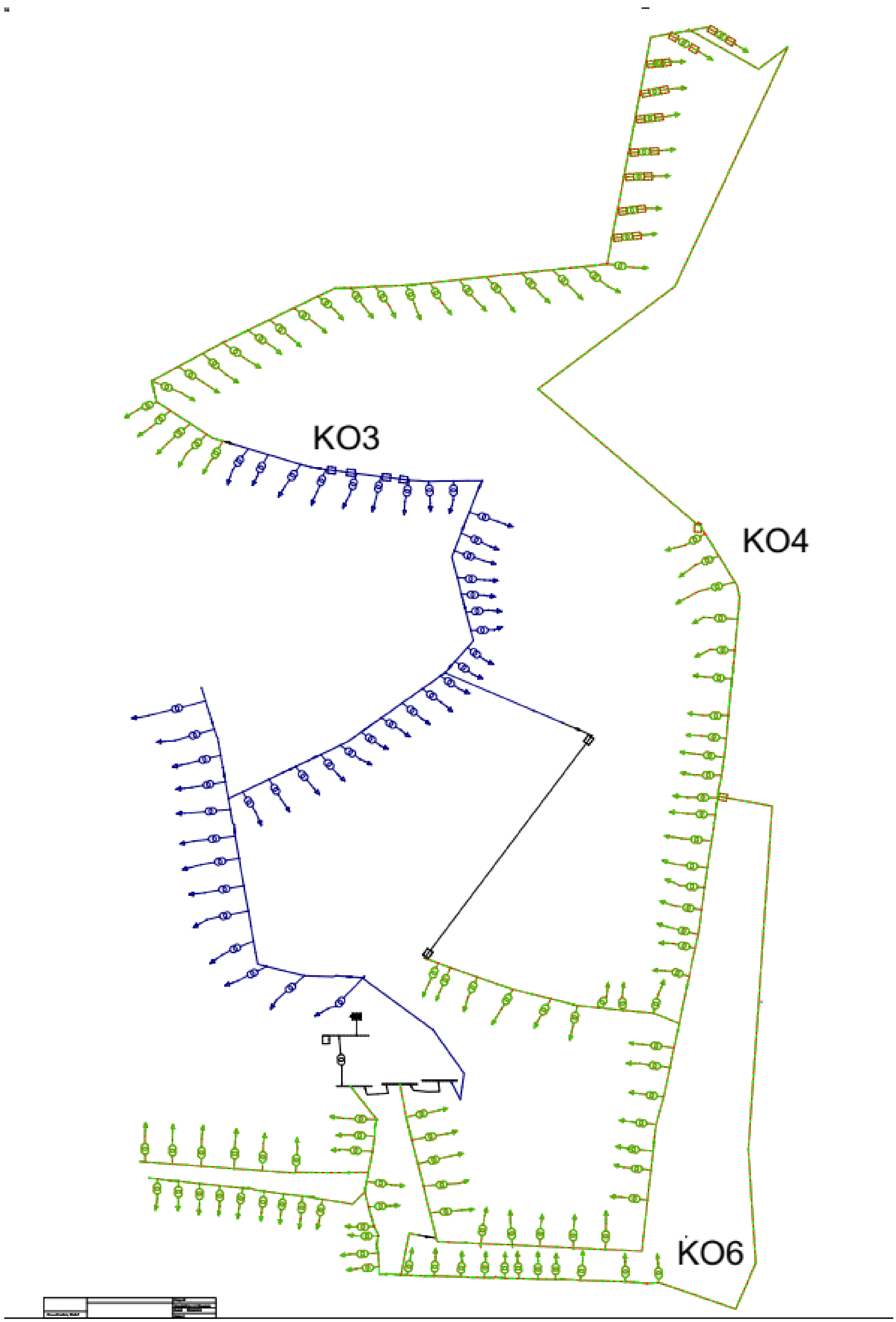


Fig.4. 2 Distribution network reconfiguration

Table 4.4, shows the distribution system reliability simulation result with network reconfiguration using Genetic Algorithm. The assessment result indicates that the system average interruption frequency index (SAIFI), system average interruption frequency index (SAIDI), energy not supplied were improved to 13.902528 per customer annual, 101.565 h/ Customer annual 2.101392 MWh/annual respectively.

Table.4. 4 Reliability indices results after reconfiguration.

| |	| DIgSILENT | Project: |
| |	| Power Factory |------------------------------
| |	| 15.1.7 | Date: 3/10/2020 |
Reliability Assessment	
System Summary	
System Average Interruption Frequency Index	: SAIFI = 13.902528 1/Ca
Customer Average Interruption Frequency Index	: CAIFI = 13.902528 1/Ca
System Average Interruption Duration Index	: SAIDI = 101.565 h/Ca
Customer Average Interruption Duration Index	: CAIDI = 7.306 h
Average Service Availability Index	: ASAI = 0.9884058238
Average Service Unavailability Index	: ASUI = 0.0115941762
Energy Not Supplied	: ENS = 2.101392 MWh/a
Average Energy Not Supplied	: AENS = 0.1MWh/Ca
Average Customer Curtailment Index	: ACCI = 0.102 MWh/Ca
Expected Interruption Cost	: EIC = 0.210 M$/a
Interrupted Energy Assessment Rate	: IEAR = 0.100 $/kWh
Average System Interruption Frequency Index	: ASIFI = 13.772384 1/a
| Average System Interruption Duration Index	: ASIDI = 101.501226 h/a

Using genetic algorithm distribution reconfiguration the system average interruption frequency index (SAIFI) is below the Ethiopian Electric Agency (EEA) regulatory.

This simulation considers placement of recloser, sectionalizing switch and automating switches using PSO. The configure structure of distribution network was done in DIgSILENT Power Factory software to evaluate the system reliability performance.

Table.4. 5 Reliability indices result after reconfiguration with PSO

| | | DIgSILENT | Project: |
| | | Power Factory |-------------------------------
| | | 15.1.7 | Date: 3/10/2020 |
| Reliability Assessment |
| Study Case: | Annex: / 1 |
System Summary
System Average Interruption Frequency Index : SAIFI = 13.461822 1/Ca
Customer Average Interruption Frequency Index : CAIFI = 13.461822 1/Ca
System Average Interruption Duration Index : SAIDI = 195.742 h/Ca
Customer Average Interruption Duration Index : CAIDI = 14.541 h
Average Service Availability Index : ASAI = 0.9776550161
Average Service Unavailability Index : ASUI = 0.0223449839
Energy Not Supplied : ENS = 3.981279 MWh/a
Average Energy Not Supplied : AENS = 0.188MWh/Ca
Expected Interruption Cost : EIC = 0.401 M$/a
Interrupted Energy Assessment Rate : IEAR = 0.101 $/kWh
Average System Interruption Frequency Index : ASIFI = 13.459468 1/a
Average System Interruption Duration Index : ASIDI = 195.738378 h/a

Table4.5 shows the reliability index result of reconfigured Nekemte City distribution network with PSO. The result indicates that the system average interruption frequency index (SAIFI), system average interruption frequency index (SAIDI), energy not supplied were improved to 13.4618221 per customer annual, 195.742 h per customer annual and 3.981279 MWh per annual respectively.

4.4. Comparison of Existing Reliability with improvement techniques

Fig 4.3 shows the system average interruption frequency index SAIFI comparison by considering reliability improvement techniques such as asset management strategy, reconfiguring the distribution network using automation, recloser and switches. The system average interruption frequency index SAIFI is reduced from 87.2 to 13.902 per customer year by implying asset management strategy and network reconfiguration.

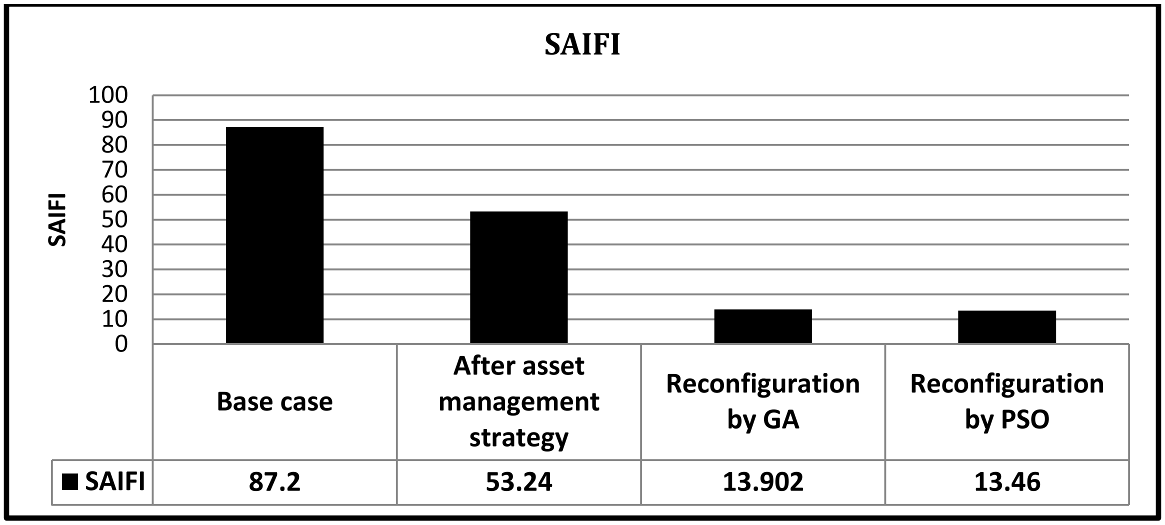


Fig.4. 3.System average interruption frequency index SAIFI comparison

Fig.4.4. shows the customer average interruption duration index is reduced from 67.568 to 14.54 by, it improved by 78.47 percentages using asset management strategy for network reconfiguration.

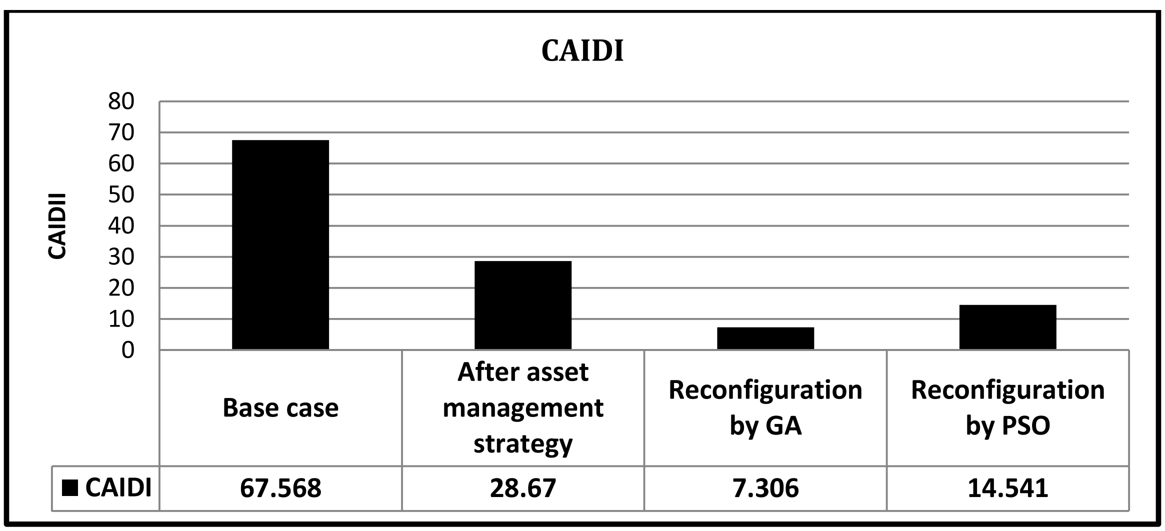


Fig.4. 4.Customer average interruption duration index (CAIDI) comparison

Figure 4.5.shows the system average interruption duration index SAIDI comparison and it indicates the system average interruption duration index SAIDI is reduced by 98.27 percentages from 5889.86 to 101.565 h/ca. by using asset management strategy and reconfiguration techniques.

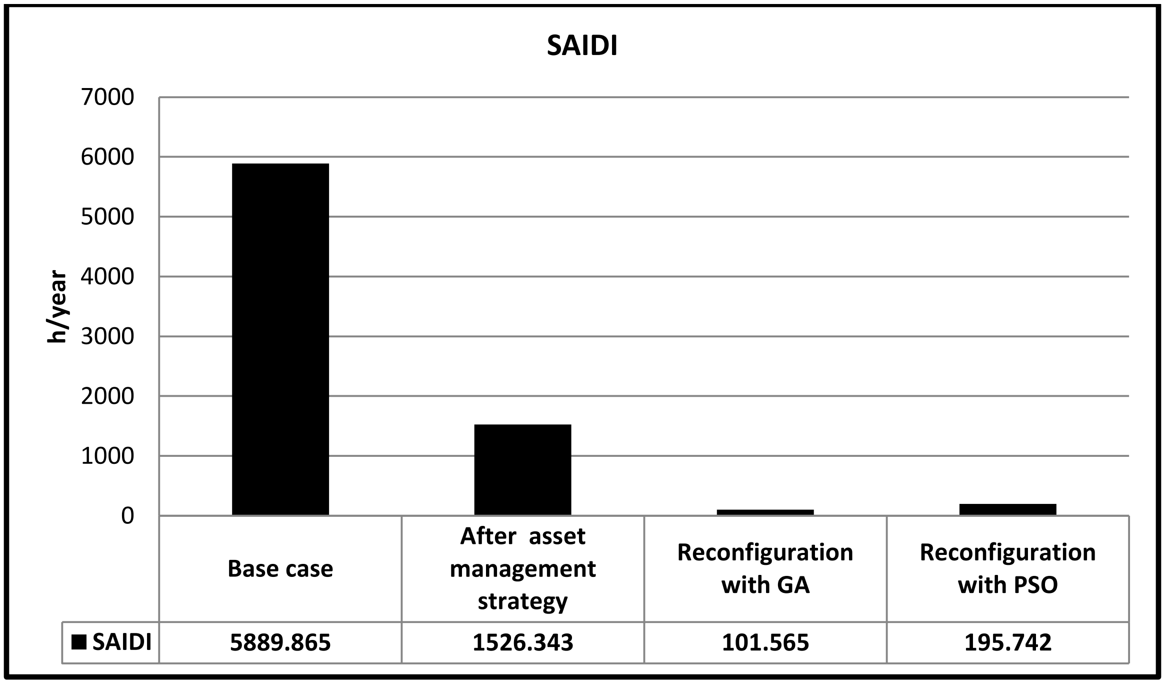


Fig.4. 5, System Average Interruption Duration index SAIDI

Figure4.6.shows the energy not supplied ENS comparison and it indicates reduces the total ENS from 119407 to2101, 392 MWh per year, improved by 98.24 percentages.

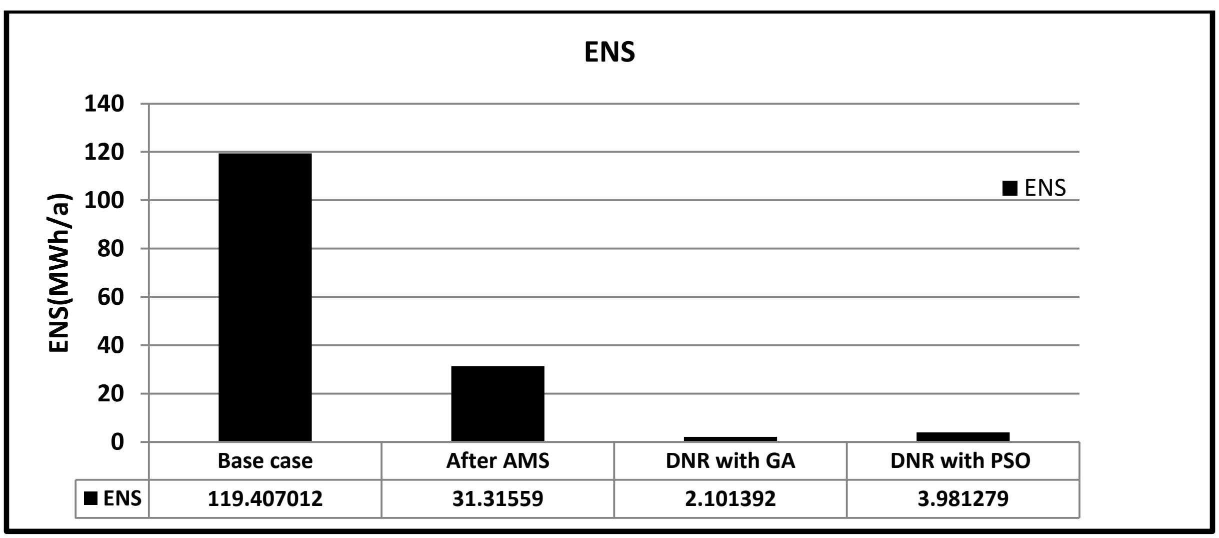


Fig.4. 6 ENS Result Comparisons

Figure 4.7.shows the system Expected Interruption Cost (EIC) comparison and it is reduced from 12.093 to 0.21 and save 11.883 M$ in a year.

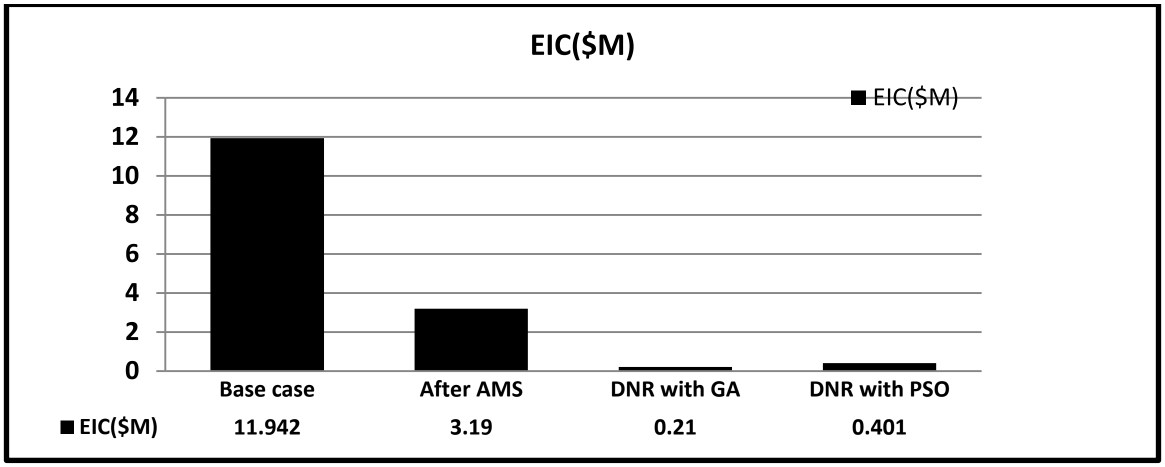


Fig.4. 7 Expected interruption cost (EIC) comparison

Figure 4.8.shows average system availability is increasing from existing system while implying asset management strategy and reconfiguration and in contradiction ASUI is decreasing.

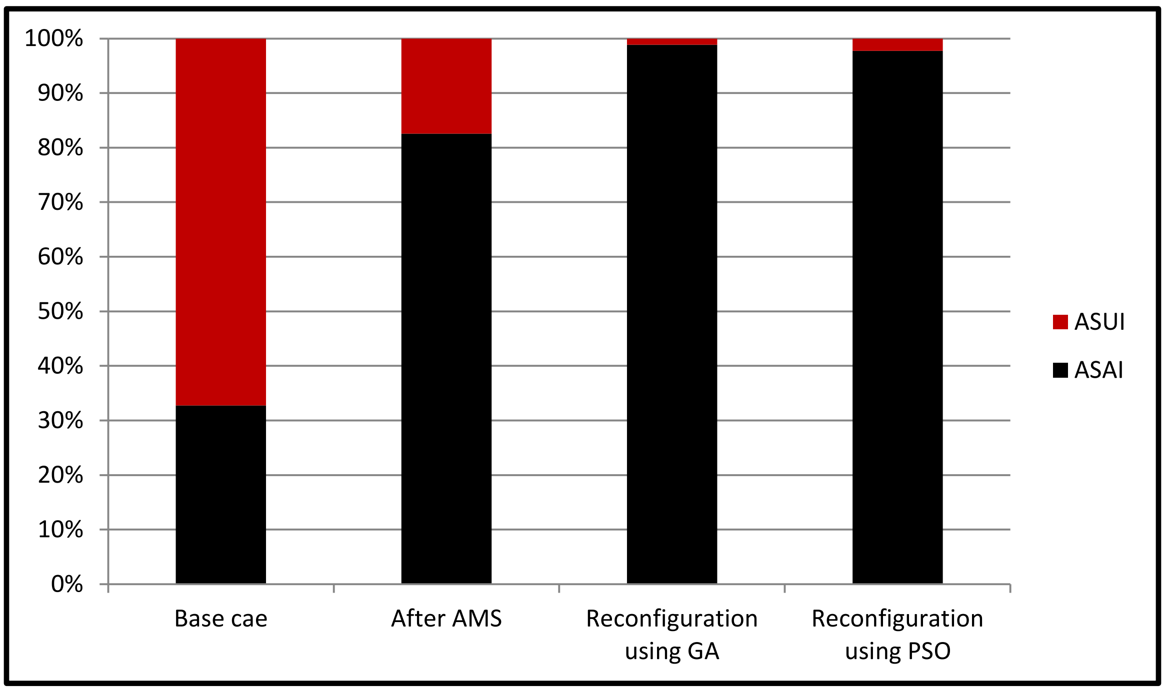


Fig.4. 8 ASUI and ASAI comparison

4.5. Reliability Cost-Benefit Analysis

Reliability cost-benefit analysis is used to determine the feasibility of a project that improves the reliability of supply to customers and the project cost (investment and operational). The two aspects of reliability and economics can be appraised more consistently by comparing reliability cost with reliability benefit.

4.5.1. Benefit Analysis of Reliability Improvement

Improving distribution system reliability using asset management strategy (maintenance strategy and replacement strategy transformers, overhead and circuit breaker asset) for network reconfiguration is summarized in table (4.6).

Table.4. 6 Benefits of reliability improvement techniques

Reliability improving techniques	Benefits
Asset management strategy	Increase health status of the asset Increase operating life of asset Reduce failure rate , outage , Reduce ENS, Reduce interruption cost of the distribution system
Reconfiguration and placing Automation switches Recloser Sectionalizing switches	Reduce repair duration state of an asset Reduce outage duration Reduce ENS Reduce Interruption cost

4.5.2. Cost Analysis

Cost analysis includes operational and investment costs of maintenance and replacement of asset such as transformers circuit breaker and overhead distribution line, operational and investment costs for new placements of network reconfiguration devices such as automating switches, recloser and sectionalizing switches of distribution network.

Table 4.6.shows the maintenance and replacement costs of assets such as transformer, circuit breaker and distribution overhead line. The total maintenance costs of transformers are 28,390 US dollars and its replacement cost is 708,096.4 US dollars. The circuit breakers replacement costs are 30,000 US dollars and the maintenance cost of overhead distribution line is 1,176 US dollars and its replacement cost are 110,862US dollars. Total maintenance and replacement cost of transformer, circuit breaker and distribution overhead line is 878,524.4US dollars.

Table.4.7.describes the costs of protective devices such as automation switches, reclosers and sectionalizing switches and tie lines required for the distribution system reconfiguration.

Total investment cost for network reconfiguration is 398,150 US dollars

Table.4. 7 Asset Maintenance and Replacement cost

Transformer asset maintenance and replacement cost							
	Maintenance cost			**Replacement cost**			**Total Cost**
KVA	Unit in Number	Unit Cost(USD)	Total Cost(USD)	Total number	Unit Cost(USD	Total Cost (USD)	Total Cost (USD)
25KVA	1	2,356	2,356	18	3,956	71,208	73,564
200KVA	2	6,200	12,400	22	10,572.2	232,588.4	244,988.4
275KVA	1	6,634	6,634	23	10,700	246,100	252,734
300KVA	1	7,000	7,000	14	11,300	158,200	165,200
Sub-total	**5**		**28,390**	**77**	**35,700**	**708,096.4**	**736,486.4**
Circuit breaker asset maintenance and replacement cost							
	-			2	15,000	30,000	30,000
Sub-total							**30,000**
OH distribution line asset maintenance and replacement cost							
Maintenance cost				**Replacement cost**			
OH line (15 KV)	Length (km)	Unit Cost ($) /km per phase	**Total Cost per three phase**	Total length (km)	Unit Cost ($) /km per phase	**Total Cost($) Per three**	**Total Cost($)**
(AAC-50)	0.7km	560	**1,176**	41.06km	900	**110,862**	**112,038**
Sub-total			**1,176**			**110,862**	**112,038**
Total							**878,524.4**

Table.4. 8 Investment cost for network reconfiguration

Device	Number	Costs ($) per unit	Total cost
Automating switch	7	1000	7,000
Recloser	24	15000	360,000
Switch	5	5000	25,000
OH line (15kv)	4.5 (km)	900	12,150
Total			**398,150**

Total cost is the sum of investment cost for asset management strategy, investment cost for network reconfiguration. Labor cost for maintenance and replacement, operational and installation cost network reconfiguration equipment's. Total sum of labor and operational cost is 766,004.64 US dollars

Total investment and operation cost=20,426,790.4 (USD)

Annual Saving cost from EIC=11.942-0.21=11.732 million (USD**)** million

Cost to benefit ratio which is defined as the ratio of investment cost to annual saving cost helps to know the period back of the year.

$$\text{Payback period} = \frac{\text{Total investment cost}}{\text{Annual Saving cost}}$$

Payback period $=\frac{20{,}426{,}790.4\ (\text{USD})}{11{,}732{,}000(\text{USD})} \quad = 1.741$.

This indicates the project has a payback period of one year and seven months. Therefore, using asset management strategy for distribution network reconfiguration is economically feasible.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This thesis implies asset management strategy for distribution reconfiguration to enhance the reliability affected by assets ageing, deterioration and corrosion. It also relates maintenance and replacement strategy to distribution system reliability

This study uses health score and health index technique to develop the best maintenance and the best replacement strategy to the distribution network assets.

The asset management strategies based condition assessment helps the distribution utilities and services to identify the health status of each asset and to take maintenance and replacement strategies on time before they cause power failure.

Asset management strategy decides that five (5) transformers and point seven (0.7) km of distribution overhead line requires preventive maintenances and two (2) circuit breakers, seventy seven(77) transformers and forty pointy one (40.1) km distribution overhead line requires replacement. .

Genetic Algorithm and Particle Swarm Optimization techniques are used to solve the number and placement optimization recloser, switches and automation devices. PSO technique is the best one in order to solve the optimum numbers and location of Reclosers, sectionalizing and automation devices at low cost. The demonstration distribution networks for reconfiguration and reliability assessment is performed on DIgSILENT power factor software.

In general by implying asset management strategy and distribution network reconfiguration:-

- The system average interruption frequency index (SAIFI) is improved by 84.56 percentages.
- The system average interruption frequency index (SAIDI) is improved by 98.27 percentages.
- The system energy not supplied (ENS) is improved by 98.24 percentages.
- The system expected Interruption cost (EIC) is reduced from 11.942 to 0.21 million US dollars by 11.732 million US dollars per year.

The project have payback period of 1.741 year or it less than a year. Therefore implementation of such work is economically feasible.

The system average interruption frequency index (SAIFI) satisfies the Ethiopian Electric Agency (EEA) regulatory standards.

5.2. Recommendation

Based on this thesis work the following recommendations are drawn:-

The asset management strategies based condition assessment helps the distribution utilities and services to identify the health status of each asset and to take maintenance and replacement strategies on time before they cause power failure. Therefore the distribution electric utilities and service have better focus on improving the customer's satisfaction by using asset management strategy and distribution network reconfiguration through recloser and automations.

The distribution electric utilities and service have better use asset management strategy to develop their asset balance maintenance and replacement rate.

In general this thesis recommends to Nekemte city electric utility and service to imply Asset management strategy for network reconfiguration to distribution system because it:-

- Helps the distribution utilities to identify the health status of each asset helps the distribution utilities to take maintenance and replacement strategies on time before they cause power failure.
- Helps the distribution utilities to plan maintenance and replacement strategy for further years.
- It helps reduce cost of corrective maintenance
- It helps to improve the customer's satisfaction

5.3. Future Work

The asset condition assessment technique developed for poles, disconnections, fuses and resistors could be further developed for other system components. Once, such models are developed for all the components in the system, its impact on the performance of system reliability shall be studied.

The study is also limited to reliability and cost optimization while reconfiguring, it also better look into the Power losses during reconfiguration solving.

Assets in distribution systems are the products of different countries such Italy, Ethiopia (METEC), Indian and Chinese, therefore they have different management and reliability performance. Such performance factors are not considered in reliability and asset management evaluations, further research could also focus on the impacts of assets condition based on their product country.

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APPENDIX

APPENDIX A: ASSET MANAGEMENT STRATEGY DATA

Circuit Breaker asset management Data

CB	Installation Year	Age	Observed condition factor	Normal expected life	Expected life	H_new	H_Expected	Age rate	Health score	Failure rate	Health Index	Condition
1	2007	11	1	25	25	0.5	5.5	0.095916	4	0.122552	HI-I	Good
2	1984	34	1	25	25	0.5	5.5	0.095916	10	1.22554	HI-5	Bad
3	1984	34	1.4	25	25	0.5	5.5	0.095916	10	1.22554	HI-5	Bad
TR	**Transformer Asset data**											
1	1980	38	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
2	1980	38	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
3	2012	6	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
4	2017	1	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
5	1975	43	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
6	2011	7	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
7	1984	34	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
8	1984	34	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
9	1983	35	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
10	1993	25	0.9	20	20	0.5	5.5	0.119895	9.014	1.681899	HI-5	Bad
11	2016	2	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
12	2015	3	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
13	2014	4	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
14	1993	25	1	20	20	0.5	5.5	0.119895	10.01	2.232942	HI-5	Bad
15	2013	5	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
16	2008	10	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
17	2008	10	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good

18	1984	34	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
19	1984	34	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
20	1983	35	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
21	1983	35	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
22	1984	34	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
23	1983	35	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
24	1984	34	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
25	1977	41	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
26	1975	43	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
27	1984	34	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
30	1994	24	0.9	20	20	0.5	5.5	0.119895	7.996	1.223893	HI-4	Bad
31	1998	20	0.9	20	20	0.5	5.5	0.119895	4.95	0.36519	HI-2	Moderate
32	2000	18	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-5	Bad
33	1993	25	0.9	20	20	0.5	5.5	0.119895	9.013	1.681899	HI-5	Bad
34	2001	17	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
35	1984	34	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
36	1984	34	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
37	1984	34	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
39	2008	10	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
40	1984	34	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
41	1984	34	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
42	1980	38	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
43	1980	38	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
44	1985	33	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
45	1985	33	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
46	1981	37	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad

47	1985	33	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
48	2017	1	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
50	1981	37	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
51	1981	37	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
52	1981	37	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
53	1980	38	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
54	1980	38	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
55	1985	33	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
56	1984	34	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
57	1979	39	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
58	1979	39	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
59	1979	39	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
60	1984	34	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
61	1984	34	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
62	2012	6	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
63	2017	1	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
64	1984	34	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
65	1978	40	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
66	1988	30	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
67	1984	34	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
68	2011	7	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
69	1988	30	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
70	2013	5	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
71	1985	33	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
72	1984	34	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
73	2013	5	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good

74	1988	30	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
75	1977	41	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
76	1978	40	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
77	1978	40	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
78	1988	30	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
79	1982	36	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
80	1982	36	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
81	1983	35	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
82	1978	40	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
83	1984	34	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
84	2011	7	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
85	1984	34	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
82	1998	20	0.9	20	20	0.5	5.5	0.119895	4.95	0.36519	HI-1	Good
83	1984	34	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
84	1984	34	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
85	1979	39	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
86	1984	34	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
87	2008	10	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
88	1998	20	0.9	20	20	0.5	5.5	0.119895	4.95	0.36519	HI-2	Moderate
89	2008	10	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
90	2008	10	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
91	2006	12	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
92	1984	34	1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
93	1973	45	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
94	1982	36	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
95	1982	36	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad

96	1984	34	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
97	1998	20	1	20	20	0.5	5.5	0.119895	5.5	0.47162	HI-2	Moderate
98	1999	19	1	20	20	0.5	5.5	0.119895	4.878	0.352709	HI-2	Moderate
99	1999	19	1	20	20	0.5	5.5	0.119895	4.878	0.352709	HI-2	Moderate
100	1984	34	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
101	1984	34	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
102	1973	45	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
103	1973	45	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
104	1973	45	1.4	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
105	2006	12	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
106	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
107	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
108	1984	34	1.25	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
109	2004	14	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-5	Bad
110	1999	19	0.9	20	20	0.5	5.5	0.119895	4.390	0.275196	HI-1	Good
111	1984	34	1.1	20	20	0.5	5.5	0.119895	10	2.223073	HI-5	Bad
112	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
113	2010	8	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
114	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
115	2008	10	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
116	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
117	2010	8	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
118	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
119	2001	17	1	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
120	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
121	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good

122	2002	16	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
123	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
124	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
125	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
126	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
127	2002	16	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
128	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
129	1999	19	1	20	20	0.5	5.5	0.119895	4.878	0.352709	HI-2	Moderate
130	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
131	2002	16	1	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
132	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
133	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
134	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
135	2003	15	1	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
136	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
137	2004	14	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
138	1999	19	1	20	20	0.5	5.5	0.119895	4.878	0.352709	HI-2	Good
139	2008	10	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
140	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
141	2015	3	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
142	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
143	2008	10	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
144	1999	19	1	20	20	0.5	5.5	0.119895	4.878	0.352709	HI-2	Moderate
145	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
146	1999	19	1	20	20	0.5	5.5	0.119895	4.878	0.352709	HI-2	Moderate
147	1999	19	1	20	20	0.5	5.5	0.119895	4.878	0.352709	HI-2	Moderate

148	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
149	2015	3	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
150	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
151	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
152	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good
153	2007	11	0.9	20	20	0.5	5.5	0.119895	4	0.222304	HI-1	Good

Distribution Overhead Line asset data

Line number	From	To	Length(Km)	Age	factor	factor	Expected Life	H-New	H_Expected	Aging rate	Failure rate	Health score	Health Index	Condition
1	0	1	0.1	34	1.3	1.1	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
2	1	2	0.4	34	1.4	1.1	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
3	2	3	0.6	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
4	3	4	0.5	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
5	4	5	0.4	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
6	5	6	0.3	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
7	6	7	0.4	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
8	7	8	0.4	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
9	8	9	0.2	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
10	9	10	0.4	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
11	10	11	0.4	11	1.1	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
12	11	12	0.6	11	1.1	1.1	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
13	12	13	0.8	36	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
14	13	14	0.6	36	1.4	1.05	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
15	14	15	0.8	36	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad

16	15	16	0.5	36	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
17	16	17	0.4	11	1.3	1.05	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
18	17	18	0.8	11	1.1	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
19	18	19	0.4	11	1.1	1.2	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
20	19	20	0.3	11	1.1	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
21	20	21	0.4	11	1.1	1.2	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
22	21	22	0.3	11	1.1	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
23	22	23	0.5	11	1.1	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
24	23	24	0.4	11	1.1	1.05	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
25	24	25	0.6	11	1.1	1.05	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
26	25	26	0.6	11	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
27	26	27	0.4	11	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
28	27	28	0.8	5	0.9	1.2	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
29	28	29	0.3	5	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
30	29	30	0.2	5	0.9	1.05	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
31	30	31	0.3	11	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
32	31	32	0.3	11	1.3	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
33	32	33	0.3	11	1.3	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
34	33	34	0.5	11	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
35	34	35	0.5	11	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
36	35	0	0.2	34	1.3	1.2	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
37	0	37	0.5	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
38	37	38	0.5	34	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
39	38	39	0.5	34	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
40	39	40	0.5	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad

41	40	41	0.4	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
42	41	42	0.4	34	1.3	1.05	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
43	42	43	0.4	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
44	43	44	0.3	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
45	44	45	0.4	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
46	45	46	0.2	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
47	46	47	0.3	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
48	47	48	0.3	34	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
49	48	49	0.3	37	1.4	1.2	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
50	49	50	0.3	37	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
51	50	51	0.15	37	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
52	51	52	0.1	37	1.4	1.1	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
53	52	53	0.1	37	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
54	53	54	0.24	37	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
55	54	55	0.2	37	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
56	55	56	0.2	37	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
57	56	57	0.2	37	1.4	1.05	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
58	57	58	0.2	37	1.4	1.2	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
59	58	59	0.2	37	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
60	59	60	0.6	40	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
61	60	61	0.5	40	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
62	61	62	0.8	40	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
63	62	63	0.9	40	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
64	63	64	0.03	34	1.4	1.05	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
65	64	65	0.1	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad

66	65	66	0.4	34	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
67	66	67	0.7	34	1.1	1.2	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
68	67	68	0.6	34	1.1	1.05	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
69	68	69	0.4	34	0.9	1.1	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
70	69	70	0.4	34	0.9	0.9	25	0.5	5.5	0.095916	1.18572	10	HI-5	Bad
71	70	71	1.2	34	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
72	71	72	0.7	34	1.1	1.05	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
73	72	73	0.5	34	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
74	73	74	0.4	40	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
75	74	75	0.1	40	1.3	1.05	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
76	75	76	0.6	40	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
77	76	77	0.5	40	1.4	1.1	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
78	77	78	0.3	40	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
79	78	79	0.6	40	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
80	79	80	0.5	40	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
81	80	81	0.4	40	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
82	81	82	0.4	40	1.4	1.2	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
83	82	83	0.5	40	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
84	83	84	0.4	40	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
85	84	85	0.6	40	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
86	85	86	0.5	38	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
87	86	87	0.5	38	1.3	1.2	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
88	87	88	0.09	38	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
89	88	89	0.5	38	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
90	89	90	0.6	38	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad

91	90	91	0.4	38	1.3	1.1	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
92	91	92	0.4	38	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
93	92	93	0.4	38	1.3	1.05	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
94	93	94	0.4	37	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
95	94	95	0.4	37	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
96	95	96	0.2	37	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
97	96	97	0.4	37	1.4	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
98	97	98	0.2	37	1.3	1.05	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
99	98	99	0.1	3	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
100	99	100	0.2	3	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
101	100	101	0.5	36	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
102	101	102	0.2	36	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
103	102	103	0.7	36	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
104	103	104	0.2	36	1.3	1.2	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
105	104	105	0.2	36	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
106	105	106	0.7	34	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
107	106	107	0.5	34	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
108	107	108	0.5	34	1.1	1.2	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
109	108	109	0.4	34	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
110	0	110	0.5	34	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
111	110	111	0.5	33	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
112	111	112	0.6	33	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
113	112	113	0.6	33	1.1	1.1	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
114	113	114	0.6	33	1.1	1.1	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
115	114	115	0.4	33	1.3	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad

116	115	116	0.6	30	1.1	0.9	25	0.5	5.5	0.095916	1.16984	9.18	HI-5	Bad
117	116	117	0.2	30	0.9	0.9	25	0.5	5.5	0.095916	1.153329	7.40	HI-4	Bad
118	117	118	0.5	30	0.9	1.2	25	0.5	5.5	0.095916	1.178184	10	HI-5	Bad
119	118	119	0.5	30	0.9	0.9	25	0.5	5.5	0.095916	1.153329	7.4	HI-4	Bad
120	119	120	0.5	30	1.1	0.9	25	0.5	5.5	0.095916	1.16984	9.18	HI-5	Bad
121	120	121	0.5	30	1.1	1.05	25	0.5	5.5	0.095916	1.178184	10.	HI-5	Bad
122	121	122	0.25	30	1.1	0.9	25	0.5	5.5	0.095916	1.16984	9.18	HI-5	Bad
123	122	123	0.5	25	1.1	0.9	25	0.5	5.5	0.095916	1.137563	5.68	HI-3	Moderate
124	123	124	0.5	25	1.1	0.9	25	0.5	5.5	0.095916	1.137563	5.68	HI-3	Moderate
125	124	125	0.4	8	0.9	1.2	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
126	125	126	0.5	8	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
127	126	127	0.5	19	1.1	1.05	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
128	127	128	0.3	19	1.1	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
129	128	129	0.2	19	1.1	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
130	129	130	0.3	19	1.1	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
131	130	131	0.3	19	0.9	1.1	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
132	131	132	0.3	19	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
133	132	133	0.3	19	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
134	133	134	0.2	34	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
135	134	135	0.2	34	1.1	0.9	25	0.5	5.5	0.095916	1.177531	10	HI-5	Bad
136	135	136	0.5	10	0.9	1.1	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
137	136	137	0.3	10	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
138	137	138	0.2	10	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
139	138	139	0.02	10	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
140	139	140	0.25	9	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good

141	140	141	0.02	9	0.9	1.05	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
142	141	142	0.2	9	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
143	142	143	0.25	9	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
144	143	144	0.2	9	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
145	144	145	0.2	6	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
146	145	146	0.24	6	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
147	146	147	0.4	6	1.1	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
148	147	148	0.24	6	0.9	1.1	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
149	148	149	0.02	6	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
150	149	150	0.24	7	0.9	1.2	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
151	150	151	0.24	7	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
152	151	152	0.24	7	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
153	152	153	0.6	2	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
154	153	154	0.1	2	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
155	154	155	0.3	2	0.9	0.9	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good
156	155	156	0.001	2	0.9	1.2	25	0.5	5.5	0.095916	1.122346	4	HI-1	Good

APPENDIX B: RELIABILITY DATA

Transformer	Rate (MVA)	Transformer	Rate (MVA)	Load Point	Number of Population	Load Point	Number of Population
Transformer(1)	0.2	Transformer(78)	0.2	Lp_001	20	Lp_078	178
Transformer(2)	0.2	Transformer(79)	0.25	Lp_002	50	Lp_079	114
Transformer(3)	0.075	Transformer(80)	0.25	Lp_003	114	Lp_080	130
Transformer(4)	0.2	Transformer(81)	0.075	Lp_004	1	Lp_081	110
Transformer(6)	0.275	Transformer(82)	0.25	Lp_005	231	Lp_082	123
Transformer(7)	0.075	Transformer(83)	0.075	Lp_006	215	Lp_083	189
Transformer(8)	0.275	Transformer(84)	0.2	Lp_007	155	Lp_084	276
Transformer(9)	0.275	Transformer(85)	0.2	Lp_008	10	Lp_085	119
Transformer(10)	0.25	Transformer(86)	0.075	Lp_009	132	Lp_086	211
Transformer(11)	0.25	Transformer(87)	0.2	Lp_010	151	Lp_087	114

Transformer(12)	0.2	Transformer(88)	0.2	Lp_011	112	Lp_088	56
Transformer(13)	0.2	Transformer(89)	0.25	Lp_012	1	Lp_089	333
Transformer(14)	0.2	Transformer(90)	0.025	Lp_013	141	Lp_090	243
Transformer(15)	0.2	Transformer(91)	0.075	Lp_014	200	Lp_091	122
Transformer(16)	0.075	Transformer(92)	0.315	Lp_014	121	Lp_092	123
Transformer(17)	0.3	Transformer(93)	0.075	Lp_016	211	Lp_093	100
Transformer(18)	0.075	Transformer(94)	0.1	Lp_017	110	Lp_094	10
Transformer(19)	0.2	Transformer(95)	0.075	Lp_018	134	Lp_095	121
Transformer(20)	0.25	Transformer(96)	0.275	Lp_019	187	Lp_096	117
Transformer(21)	0.25	Transformer(97)	0.2	Lp_020	114	Lp_097	132
Transformer(22)	0.2	Transformer(98)	0.2	Lp_021	166	Lp_098	144
Transformer(23)	0.2	Transformer(99)	0.075	Lp_022	109	Lp_099	156
Transformer(24)	0.25	Transformer(100)	0.075	Lp_023	104	Lp_100	131
Transformer(25)	0.25	Transformer(101)	0.25	Lp_024	118	Lp_101	221
Transformer(26)	0.2	Transformer(102)	0.075	Lp_025	115	Lp_102	2
Transformer(27)	0.2	Transformer(103)	0.2	Lp_026	112	Lp_103	122
Transformer(28)	0.1	Transformer(104)	0.2	Lp_027	123	Lp_104	2
Transformer(29)	0.2	Transformer(105)	0.075	Lp_028	98	Lp_105	122
Transformer(30)	0.2	Transformer(106)	0.075	Lp_029	178	Lp_106	123
Transformer(31)	0.1	Transformer(107)	0.2	Lp_030	114	Lp_107	118
Transformer(32)	0.1	Transformer(108)	0.25	Lp_031	110	Lp_108	221
Transformer(33)	0.1	Transformer(109)	0.025	Lp_032	123	Lp_109	144
Transformer(34)	0.1	Transformer(110)	0.25	Lp_033	189	Lp_110	122
Transformer(35)	0.075	Transformer(111)	0.075	Lp_034	276	Lp_111	123
Transformer(36)	0.2	Transformer(112)	0.075	Lp_035	119	Lp_112	145
Transformer(37)	0.25	Transformer(113)	0.1	Lp_036	211	Lp_113	162
Transformer(38)	0.075	Transformer(114)	0.075	Lp_037	211	Lp_114	123
Transformer(39)	0.2	Transformer(115)	0.275	Lp_038	114	Lp_115	120
Transformer(40)	0.2	Transformer(116)	0.075	Lp_039	56	Lp_116	230
Transformer(41)	0.2	Transformer(117)	0.075	Lp_040	333	Lp_117	203
Transformer(42)	0.2	Transformer(118)	0.2	Lp_041	243	Lp_118	120
Transformer(43)	0.275	Transformer(119)	0.075	Lp_042	123	Lp_119	1
Transformer(44)	0.075	Transformer(120)	0.25	Lp_043	100	Lp_120	20
Transformer(45)	0.075	Transformer(121)	0.25	Lp_044	10	Lp_121	11
Transformer(46)	0.275	Transformer(122)	0.2	Lp_045	121	Lp_122	231
Transformer(47)	0.2	Transformer(123)	0.2	Lp_046	117	Lp_123	232
Transformer(48)	0.075	Transformer(124)	0.25	Lp_047	120	Lp_124	221
Transformer(49)	0.1	Transformer(125)	0.2	Lp_048	132	Lp_125	100
Transformer(50)	0.075	Transformer(126)	0.2	Lp_049	144	Lp_126	220
Transformer(51)	0.2	Transformer(127)	0.25	Lp_050	156	Lp_127	133
Transformer(52)	0.075	Transformer(128)	0.025	Lp_051	131	Lp_128	143
Transformer(53)	0.2	Transformer(129)	0.025	Lp_052	221	Lp_129	231
Transformer(54)	0.2	Transformer(130)	0.315	Lp_053	122	Lp_130	211

Transformer(55)	0.2	Transformer(131)	0.075	Lp_054	123	Lp_131	153
Transformer(56)	0.075	Transformer(132)	0.075	Lp_055	118	Lp_132	144
Transformer(57)	0.315	Transformer(133)	0.075	Lp_056	221	Lp_133	187
Transformer(58)	0.3	Transformer(134)	0.275	Lp_057	144	Lp_134	179
Transformer(59)	0.075	Transformer(135)	0.2	Lp_058	10	Lp_135	122
Transformer(60)	0.075	Transformer(136)	0.02	Lp_059	122	Lp_136	134
Transformer(61)	0.3	Transformer(137)	0.2	Lp_060	123	Lp_137	2
Transformer(62)	0.2	Transformer(138)	0.2	Lp_061	145	Lp_138	214
Transformer(63)	0.075	Transformer(139)	0.25	Lp_062	162	Lp_139	122
Transformer(64)	0.1	Transformer(140)	0.25	Lp_063	123	Lp_140	111
Transformer(65)	0.1	Transformer(141)	0.2	Lp_064	121	Lp_141	104
Transformer(66)	0.1	Transformer(142)	0.2	Lp_065	211	Lp_142	244
Transformer(67)	0.1	Transformer(143)	0.25	Lp_066	110	Lp_143	234
Transformer(68)	0.075	Transformer(144)	0.2	Lp_067	134	Lp_144	176
Transformer(69)	0.2	Transformer(145)	0.02	Lp_068	187	Lp_145	214
Transformer(70)	0.1	Transformer(146)	0.25	Lp_069	2	Lp_146	1
Transformer(71)	0.2	Transformer(147)	0.025	Lp_070	114	Lp_147	3
Transformer(72)	0.2	Transformer(148)	0.25	Lp_071	166	Lp_148	210
Transformer(73)	0.275	Transformer(149)	0.315	Lp_072	109	Lp_149	134
Transformer(74)	0.275	Transformer(150)	0.3	Lp_073	104	Lp_150	178
Transformer(75)	0.075	Transformer(151)	0.1	Lp_074	118	Lp_151	188
Transformer(76)	0.2	Transformer(152)	0.075	Lp_075	112	Lp_152	212
Transformer(77)	0.075	Transformer(153)	0.3	Lp_076	123	Lp_153	2

APPENDIX C: GENETIC ALGORITHM MATLAB CODE

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0	0	0	1	1	0	0	0	0	0	0
0	0	0	1	1	0	0	1	0	0	0
0	0	0	1	1	0	1	0	0	0	0
0	0	0	1	1	0	1	1	0	0	0
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0	0	1	0	1	0	0	1	0	0	0
0	0	1	0	1	0	1	0	0	0	0
0	0	1	0	1	0	1	1	0	0	0
0	0	1	0	1	1	0	0	0	0	0
0	0	1	0	1	1	0	1	0	0	0
0	0	1	0	1	1	1	0	0	0	0
0	0	1	0	1	1	1	1	0	0	0
0	0	1	1	0	0	0	0	0	0	0
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0	0	1	1	0	0	1	0	0	0	0
0	0	1	1	0	0	1	1	0	0	0
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0	0	1	1	0	1	0	1	0	0	0
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0	0	1	1	1	0	1	0	0	0	0
0	0	1	1	1	0	1	1	0	0	0
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0	0	1	1	1	1	0	1	0	0	0
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0	0	1	1	1	1	1	1	0	0	0
0	1	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	1	0	0	0
0	1	0	0	0	0	1	0	0	0	0
0	1	0	0	0	0	1	1	0	0	0
0	1	0	0	0	1	0	0	0	0	0
0	1	0	0	0	1	0	1	0	0	0
0	1	0	0	0	1	1	0	0	0	0
0	1	0	0	0	1	1	1	0	0	0
0	1	0	0	1	0	0	0	0	0	0
0	1	0	0	1	0	0	1	0	0	0
0	1	0	0	1	0	1	0	0	0	0
0	1	0	0	1	0	1	1	0	0	0
0	1	0	0	1	1	0	0	0	0	0
0	1	0	0	1	1	0	1	0	0	0
0	1	0	0	1	1	1	0	0	0	0
0	1	0	0	1	1	1	1	0	0	0

0	1	0	1	0	0	0	0	0	0	0
0	1	0	1	0	0	0	1	0	0	0
0	1	0	1	0	0	1	0	0	0	0
0	1	0	1	0	0	1	1	0	0	0
0	1	0	1	0	1	0	0	0	0	0
0	1	0	1	0	1	0	1	0	0	0
0	1	0	1	0	1	1	0	0	0	0
0	1	0	1	0	1	1	1	0	0	0
0	1	0	1	1	0	0	0	0	0	0
0	1	0	1	1	0	0	1	0	0	0
0	1	0	1	1	0	1	0	0	0	0
0	1	0	1	1	0	1	1	0	0	0
0	1	0	1	1	1	0	0	0	0	0
0	1	0	1	1	1	0	1	0	0	0
0	1	0	1	1	1	1	0	0	0	0
0	1	0	1	1	1	1	1	0	0	0
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0	1	1	0	0	0	0	1	0	0	0
0	1	1	0	0	0	1	0	0	0	0
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0	1	1	0	0	1	0	0	0	0	0
0	1	1	0	0	1	0	1	0	0	0
0	1	1	0	0	1	1	0	0	0	0
0	1	1	0	0	1	1	1	0	0	0
0	1	1	0	1	0	0	0	0	0	0
0	1	1	0	1	0	0	1	0	0	0
0	1	1	0	1	0	1	0	0	0	0
0	1	1	0	1	0	1	1	0	0	0
0	1	1	0	1	1	0	0	0	0	0
0	1	1	0	1	1	0	1	0	0	0
0	1	1	0	1	1	1	0	0	0	0
0	1	1	0	1	1	1	1	0	0	0
0	1	1	1	0	0	0	0	0	0	0
0	1	1	1	0	0	0	1	0	0	0
0	1	1	1	0	0	1	0	0	0	0
0	1	1	1	0	0	1	1	0	0	0
0	1	1	1	0	1	0	0	0	0	0
0	1	1	1	0	1	0	1	0	0	0
0	1	1	1	0	1	1	0	0	0	0
0	1	1	1	0	1	1	1	0	0	0
0	1	1	1	1	0	0	0	0	0	0
0	1	1	1	1	0	0	1	0	0	0
0	1	1	1	1	0	1	0	0	0	0
0	1	1	1	1	0	1	1	0	0	0
0	1	1	1	1	1	0	0	0	0	0
0	1	1	1	1	1	0	1	0	0	0
0	1	1	1	1	1	1	0	0	0	0
0	1	1	1	1	1	1	1	0	0	0
1	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	1	0	0	0
1	0	0	0	0	0	1	0	0	0	0
1	0	0	0	0	0	1	1	0	0	0
1	0	0	0	0	1	0	0	0	0	0
1	0	0	0	0	1	0	1	0	0	0
1	0	0	0	0	1	1	0	0	0	0
1	0	0	0	0	1	1	1	0	0	0
1	0	0	0	1	0	0	0	0	0	0
1	0	0	0	1	0	0	1	0	0	0
1	0	0	0	1	0	1	0	0	0	0

```
     1      0      0      0      1      0      1      1      0      0      0
     1      0      0      0      1      1      0      0      0      0      0
     1      0      0      0      1      1      0      1      0      0      0
     1      0      0      0      1      1      1      0      0      0      0
     1      0      0      0      1      1      1      1      0      0      0
     1      0      0      1      0      0      0      0      0      0      0
     1      0      0      1      0      0      0      1      0      0      0
     1      0      0      1      0      0      1      0      0      0      0
     1      0      0      1      0      0      1      1      0      0      0
     1      0      0      1      0      1      0      0      0      0      0
     1      0      0      1      0      1      0      1      0      0      0
     1      0      0      1      0      1      1      0      0      0      0
     1      0      0      1      0      1      1      1      0      0      0
     1      0      0      1      1      0      0      0      0      0      0
     1      0      0      1      1      0      0      1      0      0      0];
             % failure rate   customer
failure_data=[0.323307     20
              0.502875     50
              0.3625875    114
              0.3625875    1
              0.289638     231
              0.255969     215
              0.390645     155
              0.44676      10
              0.44676      132
              0.3098394    123
              0.255969     151
              0.55899      112
              0.33453      1
              0.33453      141
              0.55899      200
              0.78345      121
              0.502875     211
              0.2806596    110
              0.233523     134
              0.300861     187
              0.502875     114
              0.390645     166
              0.244746     109
              0.2273       104
              0.244746     118
              0.67122      115
              0.55899      112
              0.78345      123
              0.44676      98
              0.3625875    178
              0.2503575    114
              0.255969     110
              0.2380122    123
              0.2380122    189
              0.2380122    276
              0.255969     119
              0.255969     211
              0.255969     211
              0.255969     114
              0.78345      56
              0.267192     333
              0.502875     243
              0.78345      123
```

0.502875	100
0.44676	10
0.244746	121
0.233523	117
0.78345	120
0.502875	132
0.3625875	144
0.289638	156
0.255969	131
0.255969	221
0.502875	122
0.502875	123
0.2761704	118
0.379422	221
0.502875	221
0.3625875	10
0.3625875	122
0.3625875	123
0.278415	145
0.255969	162
0.255969	123
0.244746	121
0.244746	211
0.244746	110
0.244746	134
0.3625875	187
0.2492352	2
0.3921252	114
0.2492352	166
0.2492352	109
0.2492352	104
0.2492352	118
0.2492352	112
0.55899	123
0.55899	98
0.278415	178
0.278415	114
0.278415	130
0.278415	110
0.278415	123
0.278415	189
0.78345	276
0.502875	119
0.502875	211
0.78345	114
0.289638	56
0.278415	333
0.278415	243
0.78345	122
0.502875	123
0.502875	100
0.36258	10
0.502875	121
0.502875	117
0.239835	132
0.502875	144
0.502875	156
0.502875	131
0.502875	221

```
            0.502875     2
            0.502875     122
            0.502875     2
            0.502875     122
            0.502875     123
            0.502875     118
            0.502875     221
            0.502875     144
            0.502875     122
            0.502875     123
            0.502875     145
            0.502875     162
            0.502875     123
            0.502875     120
            0.502875     230
            0.502875     203
            0.502875     120
            0.502875     1
            0.502875     20
            0.502875     11
            0.502875     231
            0.502875     232
            0.502875     221
            0.502875     100
            0.502875     220
            0.502875     133
            0.502875     143
            0.502875     231
            0.502875     211
            0.502875     153
            0.502875     144
            0.502875     187
            0.502875     179
            0.502875     122
            0.502875     134
            0.502875     2
            0.502875     214
            0.502875     122
            0.502875     111
            0.502875     104
            0.502875     244
            0.502875     234
            0.502875     176
            0.636765     214
            0.502875     1
            0.502875     3
            0.502875     210
            0.502875     134
            0.752195     178
            0.633285     188
            0.633285     212];

 mycustomer=failure_data(:,2);
total_customer=sum(failure_data(:,2));
failureratematrix=failure_data(:,1);

x1=[1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
30 31 32 33 34 35 36
```

```
    0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
30 31 32 33 34 35];
x2= [37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62
63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109
 0 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63
64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91
92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108];
x3= [110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128
129 130 131 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148
149 150 151 152 153
 0   110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128
129 130 131 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148
149 150 151 152];

lineno=zeros(153,1);
for myrun=1:150
% function [newpop]=mylinecrossover(d)
[x,y]=size(d);
i=1;
a=1;
mynewpop=zeros(x,y);% matrix of zeros with size of matrix d
while i<x
for j=9:11
geneparent1(a,j-3)=d(i,j-3); %taking last three genes
end
t=i;
i=i+1;
for k=9:11
geneparent2(a,k-3)=d(i,k-3);
end
% code for child1#################
for e=1:8
mynewpop(t,e)=d(t,e);% first eight genes from parent one
end
for n=9:11
mynewpop(t,n)=geneparent2(a,n-3);% last three genes from parent two
end
%##############################
t=i;
% code for child2########################
for e=1:8
mynewpop(t,e)=d(t,e);
end
for n=9:11
mynewpop(t,n)=geneparent1(a,n-3);
end
%###############################################
i=i+1;
a=a+1;
end
% MUTUATION
crossed_over_pop=mynewpop;
stringlength=11;
dimension=1;
pm=0.08;
new_popsize=size(crossed_over_pop,1);
for i=1:new_popsize
```

```
if rand <pm
mpoint=round(rand(1,dimension)*(stringlength-1))+1;
for j=1:dimension
    crossed_over_pop(i,j)=~ crossed_over_pop(i,j);
mynewpop(i,(j-1)*stringlength+mpoint(j))=1-mynewpop(i,(j-
1)*stringlength+mpoint(j));
end
end
end
mutated_pop=crossed_over_pop;
mutated_pop;
% Line number code function
% this function displays the line number of the chromosome
% it takes 8 binary digits and converts to integer value of the line
% segment representing the chromosome
[x,h]=size(mutated_pop);
for i=1:x
z=0;
for j=0:7
z=z+mutated_pop(i,8-j)*2^j; % Binery to decimal
end
mylinecode(1,i)=z;
end

%COST CALCULATION
% this program returns the fitness values of individuals in a population
% device installments are for sectionalizing switch, recloser, and
% automating device
cost=0;
for i=1:x
  if mylinecode(1,i)<=154
if mutated_pop(i,9)==1    % Sectionalizing switch cost
if mutated_pop(i,10)==0
 if mutated_pop(i,11)==0
    cost=cost+1000;
    switch_pos(1,i)= mylinecode(i);
 end
end
if mutated_pop(i,10)==1   % Recloser cost
cost=cost+15000;
recloser_pos(1,i)=mylinecode(i);
end
 if mutated_pop(i,10)==0
if mutated_pop(i,11)==1   % Automation cost
cost=cost+5000;
Automation_pos(1,i)= mylinecode(i);
end
end
end
 end
end
switch_pos;
recloser_pos;
Automation_pos;
linefit=cost;

% RELIABILITY INDEX CALCULATION
mymutated=mutated_pop;
```

```
linenumber=mylinecode;
for h=1:35
    s=0;
    ss=0;
    for t=1:35  % wollaga Unuversity feeder
        s=0;
        ss=0;
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
    if mutated_pop(t,9)==1
    if mutated_pop(t,10)==0
    if mutated_pop(t,11)==0
    for t=h:35
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
    end
    end
    end
    if mutated_pop(t,10)==1   % Recloser cost
     for t=h:35
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
     end
    end
     if mutated_pop(t,10)==0
    if mutated_pop(t,11)==1   % Automation cost
      for t=h:35
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
     end
    end
     end
    end
    end
 mylinefailurematrix(1,h)=s;
myfailureduration(1,h)=ss;
end
 for h=36:109
    s=0;
    ss=0;
    for t=36:109 % HOSPITAL LINE
        s=0;
        ss=0;
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
    if mutated_pop(t,9)==1
    if mutated_pop(t,10)==0
    if mutated_pop(t,11)==0
    for t=h:109
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
    end
    end
    end
    if mutated_pop(t,10)==1   % Recloser cost
     for t=h:109
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
     end
```

```
    end
     if mutated_pop(t,10)==0
    if mutated_pop(t,11)==1   % Automation cost
      for t=h:109
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
     end
    end
     end
    end
    end
  mylinefailurematrix(1,h)=s;
 myfailureduration(1,h)=ss;
 end
 for h=110:153
    s=0;
    ss=0;
    for t=110:153 % BAKKE JAMA FEEDER
        s=0;
        ss=0;
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
    if mutated_pop(t,9)==1
    if mutated_pop(t,10)==0
    if mutated_pop(t,11)==0
    for t=h:153
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
    end
    end
    end
    if mutated_pop(t,10)==1   % Recloser cost
     for t=h:153
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
     end
    end
     if mutated_pop(t,10)==0
    if mutated_pop(t,11)==1   % Automation cost
      for t=h:153
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
     end
    end
     end
    end

  mylinefailurematrix(1,h)=s;
  myfailureduration(1,h)=ss;
 end
 end
 mylinefailurematrix;
mysum=0;
mysum2=0;
for b=1: size(mycustomer)
mysum=mysum+(mycustomer(b,1)*mylinefailurematrix(1,b));
mysum2=mysum2+(mycustomer(b,1)* myfailureduration(1,b));
end
```

```
SAIFI(1,myrun)=mysum/total_customer;
SAIDI(1,myrun)=mysum2/total_customer;
selfit(1,myrun)=linefit;
if SAIFI(1,myrun)<=0.20 && SAIDI(1,myrun)<=0.25
    selfit(1,myrun)=linefit;
if linefit>40000
break
end
end
d=mymutated;
switch_pos;
recloser_pos;
Automation_pos;
end

minim_cost=min(selfit);

d;
%fitness
last_gcode=[mymutated mylinecode'];
% selfit % fitness of selected individuals that meet the criteria
selectedlines=[mymutated linenumber'];
figure(1)
 plot(selfit,'--rs','LineWidth',2,...
'MarkerEdgeColor','k',...
'MarkerFaceColor','g',...
'MarkerSize',5)
xlabel('iteration')
ylabel('cost')
```

APPENDIX D: PSO MATLAB CODE

```
clear all
 clc
  d     % copy initial population Under GA
  % failure rate
failure_data  % copy failure rate under GA
 mycustomer=failure_data(:,2);
total_customer=sum(failure_data(:,2));
failureratematrix=failure_data(:,1);

x1=[1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
30 31 32 33 34 35 36
    1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
30 31 32 33 34 35 36];
x2= [37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62
63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109
     37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62
63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109];
x3= [110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128
129 130 131 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148
149 150 151 152 153
```

```
     110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128
129 130 131 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148
149 150 151 152 153];

lineno=zeros(153,1);
% pso parameters values

 x0=d;
% m=3;  % number of variables
[n,z]=size(x0);  % population size
wmax=0.9;  % inertia weight
wmin=0.4;  % inertia weight
%c1=2;  % acceleration factor
%c2=2;  % acceleration factor
r1=rand(n,z);% Creating a randomized matrice,
r2=rand(n,z);% Creating a randomized matrice
iter=0;
s=zeros(n,z);
% pso main program----------------------------------------------------start
maxiter=4; % set maximum number of iteration
maxrun=100;  % set maximum number of runs need to be
for myrun=1:maxrun
myrun;
for m=1:153
lineno(m,1)=m;
end
% pso initialization----------------------------------------------start
x=x0;  % initial population
v=0.1*x0;  % initial velocity
%gbest=min(linefit);

% pso initialization------------------------------------------------end
% pso algorithm---------------------------------------------------start
iter=0;
while iter<maxiter
    iter=iter+1;
    pbest=x0;     % initial pbest
    gbest=rand(n,z);  % initial gbest
    w=wmax-(wmax-wmin)*iter/maxiter;% Specilize the weight coefficient
     c1=2*rand(1);
     c2=2*rand(1);
    % Updating velocity
   Vmax=0.6 ;
    vnew=v;
    for i=1:n
        for j=1:z
        vnew(i,j)=w*vnew(i,j)+c1*r1(i,j)*(pbest(i,j)-x(i,j))+c2*r2(i,j)*(gbest(j)-
x(i,j));
       if(vnew(i,j)>Vmax)
                vnew(i,j)=Vmax;
        end
            if(vnew(i,j)<-Vmax)
                vnew(i,j)=-Vmax;
            end
        end
    end
    % pso position update
    xnew=x;
```

```
for i=1:n
for j=1:z
 s(i,j)=1/(1+exp(-vnew(i,j)));
end
end
for i=1:n
for j=1:z
xnew(i,j)=x(i,j)+vnew(i,j);
end
end
r3=rand(n,z);
for i=1:n
for j=1:z
  if r3(i,j)<s(i,j)                    %
     xnew(i,j)=1;
      else
      xnew(i,j)=0;
 end
end
end
end
% BINARY TO DECIMAL

for i=1:n
k=0;
for j=0:7
k=k+xnew(i,8-j)*2^j;
end
mylinecode(1,i)=k;
end
% COST  FUNCTION
mysum1=0;
switch_pos=0;
for i=1:n
 if mylinecode(1,i)<=153
if xnew(i,9)==1     %  % switch cost
if xnew(i,10)==0
 if xnew(i,11)==0
   i;
     mysum1=mysum1+1000;
    switch_pos =i;

 end
end

if xnew(i,10)==1         % recloser
mysum1=mysum1+1500;
recloser_pos(1,i)=mylinecode(i);
end
if xnew(i,10)==0
if xnew(i,11)==1
mysum1=mysum1+5000;
Automation_pos(1,i)= mylinecode(i);
end
end
end
 end
```

```
end
switch_pos;
recloser_pos;
Automation_pos;
linefit=mysum1;
% F.  Line number code function
[x,t]=size(xnew);
for i=1:x
s=0;
for j=0:7
s=s+xnew(i,8-j)*2^j;
end
mylinecode(1,i)=s;
end
linenumber=mylinecode;
% RELIABILITY INDEX CALCULATION
mutated_pop=xnew;
linenumber=mylinecode;
for h=1:35
    s=0;
    ss=0;
    for t=1:35  % wollaga Unuversity feeder
        s=0;
        ss=0;
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
    if mutated_pop(t,9)==1
    if mutated_pop(t,10)==0
    if mutated_pop(t,11)==0
    for t=h:35
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
    end
    end
    end
    if mutated_pop(t,10)==1   % Recloser
     for t=h:35
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
     end
    end
     if mutated_pop(t,10)==0
    if mutated_pop(t,11)==1   % Automation
      for t=h:35
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
     end
    end
     end
    end
    end
 mylinefailurematrix(1,h)=s;
myfailureduration(1,h)=ss;
end
 for h=36:109
    s=0;
    ss=0;
    for t=36:109 % HOSPITAL LINE
        s=0;
```

```
        ss=0;
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
    if mutated_pop(t,9)==1
    if mutated_pop(t,10)==0
    if mutated_pop(t,11)==0
    for t=h:109
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
    end
    end
    end
    if mutated_pop(t,10)==1    % Recloser
     for t=h:109
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
     end
    end
     if mutated_pop(t,10)==0
    if mutated_pop(t,11)==1    % Automation
      for t=h:109
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
     end
    end
     end
    end
    end
  mylinefailurematrix(1,h)=s;
 myfailureduration(1,h)=ss;
 end
 for h=110:153
    s=0;
    ss=0;
    for t=110:153 % BAKKE JAMA FEEDER
        s=0;
        ss=0;
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
    if mutated_pop(t,9)==1
    if mutated_pop(t,10)==0
    if mutated_pop(t,11)==0
    for t=h:153
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
    end
    end
    end
    if mutated_pop(t,10)==1    % Recloser
     for t=h:153
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
     end
    end
     if mutated_pop(t,10)==0
    if mutated_pop(t,11)==1    % Automation
      for t=h:153
    s=s+failureratematrix(t,1);
    ss=ss+failureratematrix(t,1)*2;
```

```
      end
     end
      end
     end
   mylinefailurematrix(1,h)=s;
   myfailureduration(1,h)=ss;
  end
  end
  mylinefailurematrix;
 mysum=0;
 mysum2=0;
 for b=1: size(mycustomer)
 mysum=mysum+(mycustomer(b,1)*mylinefailurematrix(1,b));
 mysum2=mysum2+(mycustomer(b,1)* myfailureduration(1,b));
 end
 SAIFI(1,myrun)=mysum/total_customer;
 SAIDI(1,myrun)=mysum2/total_customer;
 selfit(1,myrun)=linefit;    % Cost
 if SAIFI(1,myrun)<=0.5 && SAIDI(1,myrun)<=0.25
     selfit(1,myrun)=linefit;
 if linefit>40000
 break
 end
 end
 d=xnew;
 %switch_pos;
 %recloser_pos;
 %Automation_pos;
 end
 minim_cost=min(selfit)

 SAIDI;

 %fitness
 last_gcode=[xnew mylinecode'];
 % selfit % fitness of selected individuals that meet the criteria
 selectedlines=[xnew linenumber'];
  plot(selfit,'--rs','LineWidth',2,...
 'MarkerEdgeColor','k',...
 'MarkerFaceColor','g',...
 'MarkerSize',5)
 xlabel('iteration')
 ylabel('cost')
```