DISTRIBUTION SYSTEM RELIABILITY ASSESSMENT AND ENHANCEMENT BY USING TIE SWITCHES AND SECTIONALIZER'S
(CASE STUDY: BULE HORA DISTRIBUTION SYSTEM)

By

ABABO BIKILA

A THESIS SUBMITTED TO THE HAWASSA UNIVERSITY INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

IN PARTIAL FULFILLMENT OF THE REQUIREMENTSFOR THE DEGREE OF MASTER OF SCIENCE IN POWER SYSTEM AND ENERGY ENGINEERING

HAWASSA UNIVERSITY

HAWASSA (ETHIOPIA)

MAY 2022

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SCHOOL OF RESEARCH AND POSTGRADUATE STUDIES

ADVISOR'S APPROVAL SHEET ONE

This is to certify that the thesis entitled "DISTRIBUTION SYSTEM RELIABILITY ASSESSMENT AND ENHANCEMENT BY USING TIE SWITCHES AND SECTIONALIZER'S

(CASE STUDY: BULE HORA DISTRIBUTION SYSTEM)" submitted in partial fulfillment of the requirements for the degree of Masters of Science in Electrical Engineering with specialization in "POWER SYSTEM AND ENERGY ENGINEERING". The Graduate Program of the Department of Electrical and Computer Engineering, and has been carried out by Ababo Bikila. ID No-PGPSER/0001/11, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Dr. Bassem. K	___________	_______
Major Advisor	Signature	Date
Mr. Mesfin. J	______________	___________
Co-Advisor	Signature	Date

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EXAMINER'S APPROVAL SHEET TWO

Under signed Board of examiners of the final open defense by Ababo Bikila have read and evaluated her thesis entitled "DISTRIBUTION SYSTEM RELIABILITY ASSESSMENT AND ENHANCEMENT BY USING TIE SWITCHES AND SECTIONALIZER'S

(CASE STUDY: BULE HORA DISTRIBUTION SYSTEM)" and examined the candidate. Therefore, to certify that the thesis has been accepted in partial fulfilment of the requirements for the degree.

Dr. Bassem. K	____________	____________
Major Advisor	signature	Date
____________	____________	____________
External Examiner	signature	Date
____________	____________	____________
Internal Examiner	signature	Date
____________	____________	____________
Chair holder	signature	Date
____________	____________	____________
Faculty Dean	Signature	Date
____________	____________	____________
SGS Approval	Signature	Date

Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the school of graduate studies (SGS) through the department Graduate Committee (DGC) of Electrical and Computer Engineering.

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DECLARATION

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

Ababo Bikila ________________

This thesis has submitted for examination with my approval as a university advisor

Dr. Bassem K. ________________________

Advisor Name Signature

Mr. Mesfin Jarso. __________________________

Co-Advisor Signature

ACKNOWLEDGEMENT

First of all, I would like to thank the Almighty of God for his endless support for the completion of this work. Then I would like to express my deepest thanks to Dr. Bassem K. And Mr. Mesfin J. for their interesting guidance, support, encouragement and giving the direction to does this research work.

I wish to give my sincere thanks to ECE power staff members who have been kind enough to attend the progress report seminars and giving their good advices. And special thanks for ECE power staff members and Bule Hora electric utility for their help when I collect the data

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ACRONOMYS

A	Ampere
AAC	All Aluminum Conductor
AENS	Average Energy Not Supplied
ALIDI	Average Load Interruption Duration Index
ALIFI	Average Load Interruption Frequency Index
ASAI	Average Service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Index
CAIFI	Customer Average Interruption Frequency Index
DA	Distribution Automation
Ds	Distribution System
DN	Distribution Network
DPEF	Distribution Permanent Earth Fault
DPSC	Distribution Permanent Short Circuit Fault
DTEF	Distribution Temporary Earth Fault
DTSC	Distribution Temporary Short Circuit Fault
DLOL	Distribution Line Overload
EMS	Energy Management System
EEP	Ethiopia Electric Power
EEU	Ethiopia Electric Utility
EEPCO	Ethiopia Electric Power Corporation
EENS	Expected energy not supplied index
ETAPS	Electrical Transient Analyzing Program Software
E/F	Earth fault Current
KM	Kilometer

KV	Kilo Volt
KVA	Kilo Volt Ampere
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
MVA	Mega Volt Ampere
PT	potential Transformers
PTOL	Power Transformer overload
OP	Operational Interruption
CT	Current Transformers
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
TCC	Time Current Curve

Abstract

The majority of outage events experienced by customers are due to electrical distribution failures. Increasing distribution network reliability is a necessity in order to reduce interruption events Unreliable electric power distribution affects daily activity and drags the modern lifestyle. Basically, Power Distribution Reliability has been a major challenge in Bule hora city. The interruptions are caused mainly by the short circuit (SC) and earth fault (EF). Bule hora substation's System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) are 341.46 interruptions per customer per year and 666.82 hours per customer per year, respectively.

Bule hora substation is not reliable by the standard of Ethiopian Electric Agency (EEA) which has set SAIFI as equal to 20 interruptions per customer per year and SAIDI which is around 25 hours per customer per year. Thus, the objective of the study is to assess the reliability of the existing distribution system and suggest solutions for reliability improvement in heuristic techniques. To limit the scope of the study, 15 kV Bule hora city feeder of the substation has been chosen for reliability enhancement measures. The historical outage interruption data of years 2009-2011 E.C has been used as a base year. The study has evaluated four different mitigation cases to improve the system reliability. From the mitigation cases with the lowest SAIDI, SAIFI and Expected Energy Not Supplied (EENS) at a reasonable cost has been selected. The simulation results have been done with the help of Electrical Transient Analysis Program (ETAP 16.0) software. The result of this thesis work reveals that the reliability of the system has been improved significantly by assessing reliability enhancement solutions that are justified economically and technically. Hence, the overall reliability of Bule hora city feeder indices SAIFI by 83.23%, SAIDI by 89.48% and EENS by 97.51%, have been improved as compared with the existing system for the simulated best option. The economic analysis shows that the selected solution results in a cost saving of 2,105,530.3 ETB per year from the unsold energy of one feeder only with 1.48 payback period investment. Satisfaction of the society has been considered as a priceless benefit as well.

Keywords: Distribution System, Power Reliability, Reliability Indices, ETAP Software.

CHAPTER ONE

Introduction

1.1. Background

A power system is a system from generation to the load and these consists of three hierarchies' levels. These are generation, transmission and a distribution system. Distribution systems are typically of radial configuration. This means that there are no other power supply options from another feeder. Unidirectional energy runs from the source point to the load points through distribution cables, lines and bus bars are connected in series [1].

Nowadays Ethiopian Electric Utility (EEU) Power system has 400 kV, 230 kV, 132 kV primary transmission systems and 66 kV, 45 kV as sub-transmission system and 33 kV and 15 kV as a distribution system. Substation power transformers of various ratings like 25/12 /6.3/3 MVA are installed for stepping down the voltage to 15 kV to feed the power to distribution transformers. The outgoing feeders are connected in radial fashion.

Reliability is considered as one of the major power system operation, particularly in distribution system areas. Occasionally poor reliability may cause power interruption, blackouts, decreased efficiency of appliance, blackening of light bulbs and damage of electronic and electrical appliances [2]. Having a reliable supply of electricity is essential for the operation of any firm. In most developing countries, however, electricity supply is highly unreliable [3].

Today, utilities try to alleviate or eliminate system disturbances and maximize system reliability, improve efficiency, and reduce costs. Distributed generation, sectionalizer, distribution Network Reconfiguration, etc. are implemented to minimize system outages and the amount of customers affected by permanent outages. Installing recloser or single- phase tripping also decreases the quantity of customers impacted. By using multiple levels of protection with increased fault clearing speed power reliability can be improved [4, 5].

Protection systems play a key role in the development of the system reliability. These are the ordinary protective devices in distribution networks. A recloser can avoid long-time outages by clearing temporary faults in the system. It detects phase and phase‐to‐ground overcurrent conditions, to interrupt the circuit if the overcurrent persists after a predetermined time. Thus, it decreases the length of outages and improves system reliability [6-8].

Meanwhile, as the main aim of a power system is to meet the electricity needs of the customers and this can only be achieved when the components making up the system are performing their intended function properly for as long as the system is in operation. It is important that the demand for electricity and its supply be properly viewed and included in setting up the system. Therefore, due to its high impact on the cost of electricity and its corresponding effect on customer satisfaction, distribution reliability is very important. However, as in any other viable engineering system, there are challenges that face power distribution system which tends to make the system unreliable. One of these is the issue of serving its main purpose which is to supply quality electricity with little or no interruptions. This problem is inevitable in power systems across the world but the way they are managed is what makes it different from country to country. For instance, in the United States, there is nearly an uninterrupted delivery of quality electricity to its numerous customers which makes it rank among the most dependable in the world. It is the management of the power systems that reliability evaluation becomes significant. Reliability evaluation does not in any way make a system more reliable but it helps in system planning and identification of weak components

Feeder reconfiguration is the process of changing the topology of distribution network by altering the open/closed status of switches. The switching devices include:(i) sectionalizing or normally closed switches; (ii) tie or normally open switches [9]. It is used to reduce real power losses, increase system stability and improve the voltage profile. Feeders may serve a variety of different consumers who can be rearranged into residential, industrial and commercial [10, 11].

1.2. Statement of problem

The distribution system is the core part of the power system network, which delivers power to the end user. It connects the customer to the power generation. Reliable power delivery plays a key role in profitability and customer satisfaction. Ethiopian Electric utility has tried to improve the delivery mechanism and quality of supply. But the power distribution system in Bule hora city has remained insufficient to meet customer demand both in required reliability and reduce safety risks of the customers. The power failure impacted to varying degrees, a wide range of critical infrastructure like the industry, the business enterprises and for the residential users. Low system reliability has led to increased outages resulting in more losses to business sectors. Reliability and consistency of electricity supplies are critical to mainly industrial and service activities. The unreliable power supply does not only slow down or damages production or results in shutting down of the plant but also leads to equipment damage, additional maintenance and the industry's reputation for the quality of the product. The power outage has resulted in customer stoppage of production and unavailability of lighting in the major areas of Bule hora city. Achieving reliability of power supply in Bule hora city has a major challenge for the last many years and it will continue to be a challenge in the future if an amicable solution is not found to the problem. How a reliable distribution system can be reconfigured for optimal power reliability enhancement of the study area is the main question for this study tries to address. Therefore, the recloser and the tie switch coordination together with substation circuit breaker to achieve the distribution system reliability improvement is studied to enhance this public problem.

1.3. Objectives of the Study

The objective of this thesis work can be categorized into two these are general objective and specific objective.

1.3.1. General objective

The main objective of this thesis work is to assess and enhance the reliability of Bule hora power distribution system by using tie switches and sectionalizer's

1.3.2. Specific objective

The specific objectives of this study are as follows:

- ✓ Assess Bule hora city power distribution system in terms of its reliability problems.
- ✓ Identify the major causes of power interruptions in the existing system based on historical outage data.
- ✓ Evaluate system reliability indices based on selected base year's interruption data of the city feeder using an available reliability analysis tool (ETAP16.0).
- ✓ Propose and evaluate proper power outage mitigation techniques and draw relevant conclusions.

1.4. Significance of the Study

The benefit of this study is mainly the residential customers by solving the problem of power interruption in the city of Bule Hora city. The other benefit of the study is significant economic impact it might bring to the commercial sectors. In addition to this in the utility side, the study has a major role to reduce the interruption cost during power outage.

1.5. Scope of the Study

The thesis focuses on studying the current power system reliability problems of the Bule hora substation of the medium voltage feeder connecting to the customers of the city. It is limited to calculate the customer based reliability indices and also the calculation of energy oriented indices. In addition to this, the thesis also studies the improvement of power reliability network topology reconfiguration with protection systems.

1.6. Methodology

Due to the nature of the study, it starts by reviewing literature related to the enhancement of the reliability problems of power distribution systems. Recent and unpublished important historical outage data's related to power reliability have been collected from Ethiopian Electric Utility (EEU) at Bule hora substation.

Previously historical outage data's have been gathered for detail assessment and investigation to come up with a clear solution of the problem at hand.

Generally, the following methodology has been followed in conducting the thesis work:

- **Literature review**: A number of journals, article and papers on power distribution system reliability assessment and study feeder reconfiguration and other related works have been reviewed.
- **Assessment of the existing network**: an assessment of the physical system in the case study area, understanding and adopting the system as a whole.
- **Data Collection**: Data collection plays a very crucial role in the statistical analysis. In this thesis work, the primary data type has been used which is collected for the first time by the researcher from the case study area. In this thesis work, the data can be collected through various methods like surveys, observations, personal interviews, telephonic interviews and case study.
  - ✓ Primary data collection like feeder length, number and ratings of transformers and Load of the system has been collected from the existing system of Bule hora feeder line -3 though site visit and the Bule hora utility.

- ✓ Secondary data like three years (2009-2011E.C.) interruption data has been collected from Bule hora substation.
- ✓ The data obtained from different categories of concerned bodies has been organized to make it available for analysis.
- ✓ The collected data has been used to clearly analyze the problems of the Bule hora city feeder

1.7. Thesis Layout

The thesis is organized into five chapters which are briefly summarized below.

Chapter one, presents the introduction, background, objectives, problem statements, scope, the significance of the study and methodology followed in the thesis work. In addition, it provides the outline of the thesis. The second chapter discusses the theoretical frameworks of reliability, protection system and a review of the literature on power reliability and distribution systems. In chapter three of the thesis, the electrical data of Bule hora substation and interruption data's collected has been analyzed. These include the number of customers, the number of distribution transformers, interruption duration and frequency and so on. The collected data is analyzed numerically and reliability indices are calculated. Simulation studies, system modeling and analysis of different mitigation alternatives have been presented in chapter four, and the results are presented with reasonable explanations in this chapter. Finally, the conclusions, recommendations, and future work for researches are discussed in chapter five.

CHAPTER 2

Theoretical Backgrounds and Literatures Review

2.1. Introduction

Distribution reliability primarily relates to equipment outages and customer interruptions. In normal working conditions, all material (except standby) and all customers are energized. Schedule and unscheduled activities disrupt normal working conditions and can make to outages and interruptions. The unscheduled situation is caused either due to human error or due to Electrical material failures. The scheduled events are meant for periodic maintenance of the equipment and shall be notified in advance to the customers. Different indicators are used to evaluate reliability in the transmission and distribution system. The Regulation can aim to compensate customers for very long interruptions, keep restoration times under control and create incentives to decrease the total number and duration of interruptions (disincentives to raise them).

Distribution system reliability is the ability to deliver electricity to all point of power utilization with acceptable limits of power flow constraints [14]. i.e., Reliability is the degree of the performance of the elements of the bulk electric system that results in electricity being deliver to customer within acceptable standards and in the amount desired. Distribution system reliability plays an important role in bringing Customer satisfaction and attains power delivery goals, minimizing number of interruption and interruption duration increases public productivity and earns utility profit [14]. Evaluation of reliability must be taken in Distribution system to keep connected load energized and customer's full power access. Reliability may be defined in many ways for electrical distribution system. These include continuity of services meeting customer demand and the availability of the power system.

Electric system reliability concepts can be addressed by considering two basic and function aspects of electrical system

1. Adequacy
2. Security

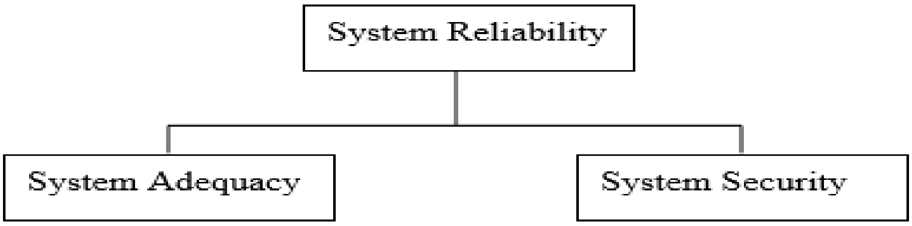

Figure 2.1: System Reliability Subdivision

Adequacy is the ability of the electrical system to supply the aggregated electrical demand and energy requirements of the customers at all times, taking into account scheduled outages of system element.

There is three condition must be met to ensure system adequacy that is

i. Its availability generation capacity must be greater than the demand load plus system losses

ii. It must be able to transport this power to its customers without over loading any equipment. iii. It must serve its load with acceptable voltage level

System adequacy assessment is probabilistic in nature in which each generator has a probability of being available probability of being available with a reduced capacity and probability of being unavailable.

Security is the ability of the electric system to with stand sudden disturbance such as electric short circuit or unanticipated loss of system element i.e. it is the ability to continue supplying power to its customer or load in the event of the one or more contingencies of if some unforeseen event disturbs the system. System security assessment determines whether a power system is able to supply peak demand after one or more piece of equipment are disconnected.

In brief, reliability has to do with total Electric interruptions and complete loss of voltage, no just deformations of the Electric sine wave. Power reliability does not cover to sag, swells, impulse or harmonic. Reliability indices typically consider such aspects as [4].

- The number of customers
- The duration of the interruption measures in seconds, minutes, hours or days.
- The amount of Power (KVA) interrupted and
- The frequency of interruptions.

There are many terms and definitions used in Reliability Engineering. Some of the frequently used terms and definitions are presented below [4].

Reliability R(t): It is the probability that an item will carry out its assigned mission satisfactorily for the stated time period when used under the specified conditions. In short, reliability refers to the probability that a component experiences no failure during a time period.

Failure: It is the inability of an item to function as the initially defined guideline.

Downtime: It is the time period during which the item is not in a condition to carry out its stated mission.

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

Availability: This is the probability that an item is available for application or use when needed. **Useful life:** It is the length of the time an item operates on an acceptable level of failure rate. **Failure Frequency (f):** It refers to the number of failures that may happen to a time period. In this study, the unit of the failure rate frequency is failure per year.

$$f = \frac{number\ of\ failures}{Studied\ Period\ x\ Circut\ length\ of\ Transmission\ lines\ or\ Cables} \quad 2.1$$

Mean Time to Failure (MTTF): The average time it takes to the occurrence of the component or system failure measured from t=0. The relationship between the failure frequency and the mean time to failure is given by;

$$\mathrm{f} = \frac{1}{MTTF+MMTR} \quad 2.2$$

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

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

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

Availability (A): It is the probability that the component is normal at an arbitrary time t, given that it was good at a time zero [4].

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

Unavailability (U): It is the probability that the component is down at any arbitrary time t and unable to operate [4].

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

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

U= 1-A 2.6.

2.2. Electricity Service Faults

Transient Faults: A transient fault is a fault that disappears either by itself or by de energization of the faulted circuit and it does not require any immediate repair work. The majority of the faults occurring on the overhead feeders are Transient faults. Common causes of Transient faults are momentary tree contacts with conductor and flashovers initiated either by lighting or by conductors temporarily swinging together. In this thesis it is assumed that in the event of a transient fault, reclosing of the associated circuit breaker or reclosing is always successful, though it might not be successful on the first or second attempt.

Permanent Forced Outage Duration: It is defined as the average time it takes to restore the affected components to service without deliberate delays when the component outage occurrence has been automatically initiated due to a permanent fault with the components [4,5].

Tra**nsient Forced Outage Duration:** It is defined as the average time it takes to restore the affected components to service without deliberate delays when the component outage occurrence has been automatically initiated due to transient faults with the components [4,5].

2.3. Types of Power Interruption

There are different types of interruption and they are as discussed below.

2.3.1. Momentary Interruption

This is a situation where a customer is without electricity supply from the utility for less than a few minutes. When the power supply is interrupted and restored in less than five minutes, then the customer is said to have experienced momentary interruption according to IEEE 1366-2003 standard. The operation of a circuit breaker or reclosers, which opens the circuit momentarily to clear faults and closes back, brings about this interruption. Momentary interruptions sometimes affect power quality and sometimes lead to voltage sags [15].

2.3.2. Temporary Interruption

This is usually categorized as interruptions that last a few hours. It is usually less in duration than a sustained interruption and higher than a momentary interruption. This interruption usually requires an operator to put the system back on by manual operation. Hence, the duration is usually as determined by the unavailability of an operator to perform the switching operation immediately. This interruption is expected to last for less than two hours. Both momentary and temporary interruptions can be as a result of faults due to lightning, two conductors in contact when there is wind etc. [15].

2.3.3. Sustained Interruption

This is a loss of supply to the customer which is usually more than many hours and can sometimes last for days. A temporary fault can lead to sustained interruption if it does not take care of as soon as possible. However, the sustained interruption could be as a result of transformer failure, insulator failure, damaged wires etc.

2.3.4. Planned Interruption

This happens when deliberate action is taken on a component by removing it from service in order to carry out maintenance work or construction. This interruption usually accompanies scheduled outage. It is usually planned and the customers are aware of the loss of supply that ensues.

2.4. Distribution System Reliability Indices

Reliability evaluation of a distribution system is associated with the continuity of supply of energy from the supply points to the individual customer load point. Reliability indices is used to measure the performance of distribution system utilities typically keep tray of customer reliability by using reliability indices. The most commonly used reliability indices give each customer equal weight. This means that a large industrial customer and a small residential customer will each have an equal impact on computed indices [23]. These reliability indices include measures of outage duration, frequency of outages, system availability and response time according to IEEE-P1366 2003. Interruption of greater than five minute is generally considered a reliability indices and interruption less than five minute are considered as a power quality concerns therefore system reliability is not the same as power quality. System reliability pertains to sustained interruption but power quality relates to momentary interruption. The study of this is not considered no matter interruption only sustained interruption.

There are various reliability indices that can be employed in measuring reliability of a given system and / or comparing the reliability of different electric utility companies. Reliability indices are statistical aggregations of reliability data for a set of loads, components or customers. The reliability of the power supply is assessed using the known reliability indices. Most reliability indices are average values of a particular reliability characteristic for an entire system, operating region, or feeder. The indices for distribution system analysis include customer oriented indices and energy-oriented indices as defined in IEEE Standard 1366. The commonly used reliability indices for distribution systems that most countries use to assess previous performances and predict the next performance of a power system are as follows:

A. Customer Oriented Indices

1. System average interruption frequency indices /SAIFI/ is the average number of times that a system customer experiences an outage during the year. It is the average frequency of sustained interruption per customer over a predefined area. This index specifies on how many times the customer experiences a nonstop interruption with a period of time in their respective area. In order to obtain an accurate result, the improvement of SAIFI's index is the fixed number of customers also reducing the number of the continuous interruptions on the system

It shows that the customers at the utility that the probability of experience a power outage:

$$\text{SAIFI} = \frac{\sum TOTAL\ NUMBER\ OF\ CUSTOMER\ INTERUPTION}{TOTAL\ NUMBER\ OF\ CUSTOMER\ SERVED} = \frac{\sum \lambda_i N_i}{\sum N_i} = \frac{\sum \text{Ni}}{\text{NT}} \qquad 2.7$$

Where, Ni is the number of interrupted customers for each interruption event i during the reporting period, NT is the total number of customers served in the area.

2. System average interruption duration indices /SAIDI/ is used for performance measurement of sustained interruption which measures the total duration of an interruption for the average customer during the given time period. This index is responsible for the average service interruption in the system. SAIDI's purpose is to indicate the total duration of an outage when continuous interruption occurs that result in power loss [27]. It is commonly referred to as customer minutes of interruption or customer hour and provides information as to the average time the customer is interrupted.

$$\text{SAIDI} = \frac{SUM\ OF\ CUSTOMER\ INTERUPTION\ DURATION}{TOTAL\ NUMBER\ OF\ CUSTOMER\ SERVED} = \frac{\sum U_i N_i}{\sum NT} \qquad 2.8$$

Where, Ni is the number of interrupted customers for each interruption event i during the reporting period, NT is the total number of customers served in the area and is outage duration for event i.

3. Customer Average interruption frequency indices /CAIFI/ is gives the average frequency of sustained interruption for these customer experiencing sustained interruption. It measures the average number of interruption per customer interrupted per year. It is simply the number of interruptions that occurred divided by the number of customers affected by the interruption.

$$\text{CAIFI} = \frac{TOTAL\ NUMBER\ OF\ INTERUPTION}{TOTAL\ NUMBER\ OF\ CUSTOMER\ INTERUPTED} = \frac{\sum No}{\sum N_i} No \qquad 2.9$$

4. Customer Average Interruption Duration indices /CAIDI/ is once an outage occurs the average time to restore service is found from the customer average interruption duration indices. It is the average time needed to restore service to the average customer per sustained interruption. It is the average interruption duration for those customers interrupted during a year. It is determined by dividing the sum of all customer interruption durations by the number of customers experiencing one or more interruptions over a one-year period.

$$\text{CAIDI} = \frac{SUM\ OF\ CUSTOMER\ INTERUPTION\ DURATION}{TOTAL\ NUMBER\ OF\ CUSTOMER\ INTERUPTION} = \frac{\sum U_i N_i}{\sum N_i} = \frac{SAIDI}{SAIFI} \qquad 2.10$$

5. Average Service Availability Index (ASAI): This index represents the fraction of time (often in percentage) that a customer has power provided during one year or the defined reporting period.

$$\mathrm{ASAI} = \frac{CUSTOMER\ HOURS\ SERVICE\ AVAILABILITY}{CUSTOMER\ HOURS\ SERVICE\ DEMAND} = \frac{Ni * 8760 - \sum r_i N_i}{N_i * 8760} \qquad 2.11$$

6. Average Service Unavailability Index (ASUI)

This index is the complementary value of the average service availability index (ASAI) [6].

$$\mathrm{ASUI} = 1 - \mathrm{ASAI} \qquad 2.12$$

B. Load or Energy Oriented Indices

1. Expected Energy Not Supplied Index (EENS): This index represents the total energy not supplied by the system [25].

$$\mathrm{ENS} = \sum_{k=0}^{n} \mathrm{r}\mathit{i}.\,\mathrm{L}\mathit{i}2.1 \qquad 2.13$$

The unit is ($Watt - Hours$)

Where, La(i) is given by:

$$\mathrm{La(i)=Lp(i)*Lf(i)} = \frac{Ed(i)}{t} \qquad 2.14$$

Where, Lp(i) is a peak load demand,

Lf(i) is the load factor and

Ed(i) is the total energy demanded in the period of interest t.

2. Average Energy Not Supplied Index (AENS): This index represents the average energy not supplied by the system.

$$\mathrm{AENS} = \frac{Total\ Energy\ not\ suplied}{Total\ number\ of\ Customers\ served} = \frac{\sum La(_i)U_i}{\sum N_i}. \qquad 2.15$$

3. Average Customer Curtailment Index (ACCI): This index represents the total energy not supplied per affected customer by the system

$$\text{ACCI} = \frac{Total\ Energy\ not\ suplied}{Total\ number\ of\ Customers\ served} = \frac{\sum La(_{i})U_{i}}{\sum No}. \qquad 2.16$$

Where, La(i) and Ui respectively, are the average connected load and the average annual outage time at load point i and No is the number of customers affected.

In this thesis works, System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI) and Expected Energy Not Supplied (EENS) are used to measure reliability performance of utilities.

2.5. Distribution System Protection

Power system protection is a branch of electrical power that deals with the protection of electrical power systems from faults through the disconnection of faulted parts from the rest of the electrical network. Proper coordination between these protecting devices must be assured in order to reduce the number of customer interruptions during a fault which will improve reliability of the distribution system [16].

Power system protection is the process of making the distribution of electrical energy as safe as possible from the effects of failures and events that place the power system at risk.

The main objective of power system protections is: -

- to minimize the duration of a fault and the outage,
- To minimize the number of consumers affected by the fault.

The secondary objectives of distribution system protection are:

- To eliminate safety hazards as fast as possible.
- To limit service outages to the smallest possible segment of the system.
- To protect the consumers' apparatus.
- To protect the system from unnecessary service interruptions and disturbances.
- To disconnect faulted lines, transformers, or other apparatus.

The Overhead distribution systems are subject two types of electrical faults, namely, transient (or temporary) faults and permanent faults. Depending on the nature of the system involved, approximately 75-90% of the total number of faults are temporary in nature. [8] Usually transient faults occur when phase conductors electrically contact other phase conductors or ground momentarily due to trees, birds or other animals, high winds, lightning, flashovers, and so on. Transient faults are cleared by a service interruption of sufficient length of time to extinguish the power arc. Here, the fault duration is minimized by using instantaneous or high-speed tripping and automatic reclosing of a relay-controlled power circuit breaker or the automatic tripping and reclosing of a circuit recloser. The breaker speed, relay settings, and recloser characteristics are selected in a manner to interrupt the fault current before a series fuse which would cause the transient fault to become permanent.

Permanent faults are those which require repairs by the repair crew in terms of:

- ✓ Replacing burned-down conductors, blown fuses, or any other damaged apparatus
- ✓ Removing tree limbs from the line
- ✓ Manually reclosing a circuit breaker or Recloser to restore service

Here, the number of customers affected by a fault is minimized by properly selecting and locating the protective apparatus on the feeder main, at the tap point of each branch, and at critical locations on branch circuits. Permanent faults are cleared by fuse cutouts installed at sub main and lateral tap points. This practice limits the number of customers affected by a permanent fault and helps locate the fault point by reducing the area involved. In general, the only part of the distribution circuit not protected by fuses is the main feeder and feeder tie line. The substation is protected from faults on feeder and tie lines by circuit breakers and Reclosers located inside the substation [8].

2.5.1. Distribution System Protection Devices

A wide variety of equipment is used to protect distribution networks. The particular type of protection used depends on the system element being protected and the system voltage level, and, even though there are no specific standards for the overall protection of distribution networks, some general indication of how these systems work can be made.

The devices most used for distribution system protection are:

- ✓ Overcurrent Relays
- ✓ Reclosers
- ✓ Sectionalizers

✓ Fuses

Reclosers: - A recloser is a device with the ability to detect phase and phase-to-ground overcurrent conditions, to interrupt the circuit if the overcurrent persists after a predetermined time, and then to automatically reclose to re-energize the line. If the fault that originated the operation still exists, then the recloser will stay open after a preset number of operations, thus isolating the faulted section from the rest of the system. In an overhead distribution system between 75 to 95 percent of the faults are of a temporary nature and last, at the most, for a few cycles or seconds. Thus, the recloser, with its opening/closing characteristic, prevents a distribution circuit being left out of service for temporary faults. Typically, Reclosers are designed to have up to three open-close operations and, after these, a final open operation to lock out the sequence. One further closing operation by manual means is usually allowed. The counting mechanisms register operations of the phase or ground-fault units which can also be initiated by externally controlled devices when appropriate communication means are available. The operating time/current characteristic curves of reclosers normally incorporate three curves, one fast and two delayed, designated as A, B, and C, respectively. Figure 2.2 shows a typical set of time/current curves for reclosers. However, new reclosers may have keyboard-selectable time/current curves which enable an engineer to produce any curve to suit the coordination requirements for both phase and ground-faults. This allows reprogramming of the characteristics to make an arrangement to a customer's specific needs without the need to change components.

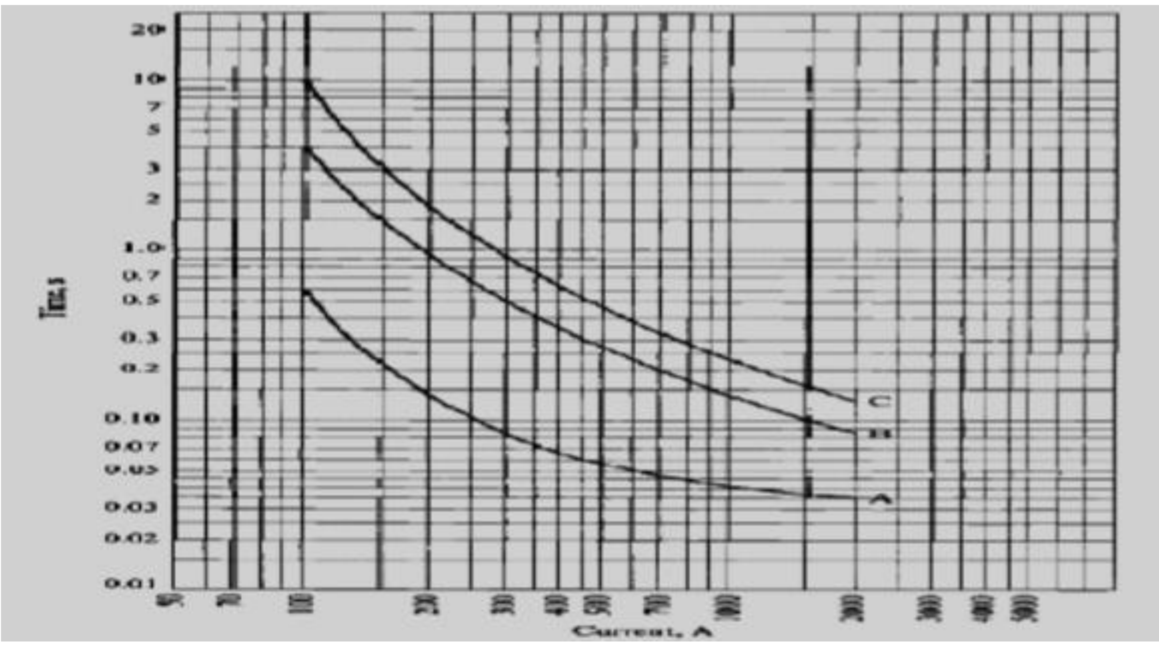

Figure 2.2: Typical set of time/current curves for Recloser [8]

protection devices is important in order to ensure that, when a fault occurs, the smallest section of the circuit is disconnected to minimize disruption of supplies to customers. Generally, the time characteristic and the sequence of operation of the recloser are selected to coordinate with mechanisms upstream towards the source. After selecting the size and sequence of operation of the recloser, the devices downstream are adjusted in order to achieve correct coordination. A typical sequence of a recloser operation for a permanent fault is shown in Figure 2.3. The first shot is carried out in the instantaneous mode to clear temporary faults before they cause damage to the lines. The three later ones operate in a timed manner with predetermined time settings. If the fault is permanent, the time-delay operation allows other protection devices nearer to the fault to open, limiting the amount of the network is disconnected.

Ground faults are less severe than phase faults and, therefore, it is important that the recloser has an appropriate sensitivity to detect them. One method is to use CTs connected residual so that the resultant residual current under normal conditions is approximately zero. The recloser should operate when the residual current exceeds the setting value, as would occur during ground faults.

Reclosers can be classified as follows:

- ✓ Single phase and three phase;
- ✓ Mechanisms with the hydraulic or electronic operation;
- ✓ Oil, vacuum or SF6.

Single phase Reclosers are used when the load is a predominantly single phase. In such a case, when a single phase fault occurs the Recloser should permanently disconnect the faulted phase, so that supplies are maintained on the other phases. Three phase Reclosers are used when it is necessary to disconnect all three phases in order to prevent unbalanced loading on the system. Reclosers with hydraulic operating mechanisms have a disconnecting coil in series with the line. When the current exceeds the setting value, the coil attracts a piston that opens the recloser main contacts and interrupts the circuit. The time characteristic and operating sequence of the Recloser are dependent on the flow of oil in different chambers. The electronic type of control mechanism is normally located outside the Recloser and receive current signals from a CT-type bushing. When the current exceeds the predetermined setting, a delayed shot is initiated that finally results in a tripping signal being transmitted to the recloser control mechanism. The control circuit determines the subsequent opening and closing of the mechanism, depending on its setting. Reclosers with electronic operating mechanisms use a coil or motor mechanism to close the contacts. Oil reclosers use the oil to extinguish the arc and also to act as the basic insulation. The same oil can be used in the control mechanism. Vacuum and SF6 reclosers have the advantage of requiring less maintenance.

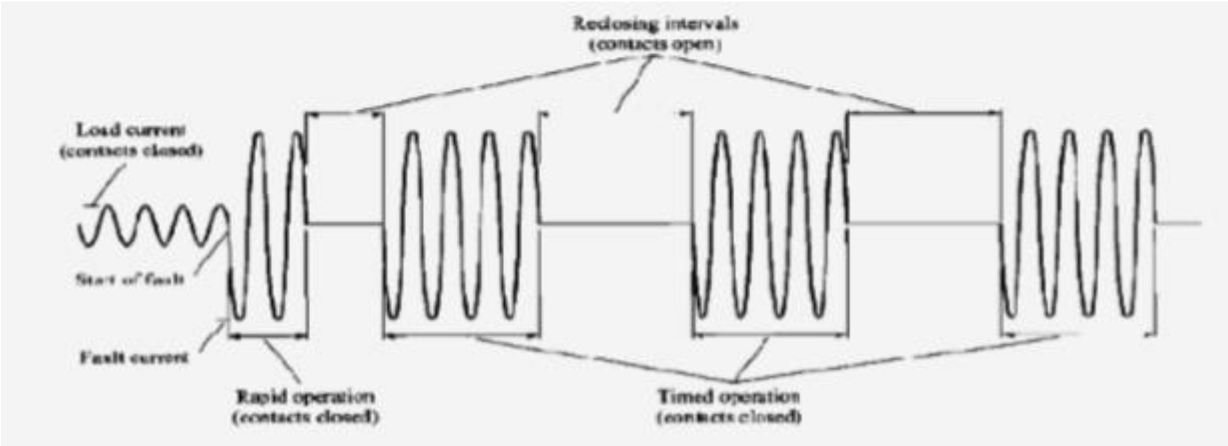

Figure 2.3: Typical sequence for Recloser operation

Reclosers are used at the following points on a Power Distribution System:

- In substations, to provide primary protection for a circuit;
- In main feeder circuits, in order to permit the sectioning of long lines and thus prevent the loss of a complete circuit due to a fault towards the end of the circuit;
- In branches or spurs, to prevent the tripping of the main circuit due to faults on the spurs.

When installing reclosers it is necessary to take into account the following factors:

- System voltage.
- Short circuit level.
- Maximum load current.
- Minimum short-circuit current within the zone to be protected by the recloser.
- . The Sensitivity of operation for ground faults

The voltage rating and the short circuit capacity of the recloser should be equal to, or greater than, the values that exist at the point of installation. The same criteria should be applied to the current capability of the recloser in respect of the maximum load current to be carried by the circuit. It is also necessary to ensure that the fault current at the end of the line being protected is high enough to cause operation of the recloser.

Sectionalizes: - A sectionalizer is a device that automatically isolates faulted sections of a distribution circuit once an upstream breaker or recloser has interrupted the fault current and is usually installed downstream of a recloser. Since sectionalizers have no capacity to break fault current, they must be used with a backup device that has fault current breaking capacity. Sectionalizers count the number of operations of the recloser during fault conditions. After a preselected number of recloser openings, and while the recloser is open, the sectionalizer opens and isolates the faulty section of the line. This permits the recloser to close and reestablish supplies to those areas free of faults. If the fault is temporary, the operating mechanism of the sectionalizer is reset.

Sectionalizers are constructed in single or three phase arrangements with hydraulic or electronic operating mechanisms. A sectionalizer does not have a current/time operating characteristic and can be used between two protective devices whose operating curves are very close and where an additional step in coordination is not practicable [8].

Sectionalizers with hydraulic operating mechanisms have an operating coil in series with the line. Each time an overcurrent occurs the coil drives a piston that activates a counting mechanism when the circuit is opened and the current is zero by the displacement of oil across the chambers of the sectionalizer. After a prearranged number of circuit openings, the sectionalizer contacts are opened by means of pretension springs. This type of sectionalizer can be closed manually. Sectionalizers with electronic operating mechanisms are more flexible in operation and easier to set. The load current is measured by means of CTs and the secondary current is fed to a control circuit which counts the number of operations of the recloser or the associated interrupter and then sends a tripping signal to the opening mechanism. This type of sectionalizer is constructed with manual or motor closing.

The following factors should be considered when selecting a sectionalizer:

- System voltage.
- Maximum load current.
- Maximum short-circuit level.
- Coordination with protection devices installed upstream and downstream.

The nominal voltage and current of a sectionalizer should be equal to or greater than the maximum values of voltage or load at the point of installation. The short circuit capacity (momentary rating) of a sectionalizer should be equal to or greater than the fault level at the point of installation. The maximum clearance time of the associated interrupter should not be permitted to exceed the short-circuit rating of the sectionalizer. Coordination factors that need to be taken into account include the starting current setting and the number of operations of the associated interrupter before opening.

Fuses: - A fuse is an overcurrent protection device; it possesses an element that is directly heated by the passage of current and is destroyed when the current exceeds a predetermined value. A suitably selected fuse should open the circuit by the destruction of the fuse element, eliminate the arc established during the destruction of the element and then maintain circuit conditions open with a nominal voltage applied to its terminals, (i.e. no arcing across the fuse element).

The majority of fuses used in distribution systems operates on the expulsion principle, i.e. they have a tube to confine the arc, with the interior covered with de-ionizing fiber, and a fusible element. In the presence of a fault, the interior fiber is heated up when the fusible element melts and produces de-ionizing gases which accumulate in the tube. The arc is compressed and expelled out of the tube; in addition, the escape of gas from the ends of the tube causes the particles that sustain the arc to be expelled. In this way, the arc is extinguished when current zero is reached. The presence of de-ionizing gases, and the turbulence within the tube ensures that the fault current is not re-established after the current passes through zero point. The zone of operation is limited by two factors; the lower limit based on the minimum time required for the fusing of the element (minimum melting time) with the upper limit determined by the maximum total time that the fuse takes to clear the fault.

The following information is required in order to select a suitable fuse for use on the distribution system [8]:

- Voltage and insulation level.
- Type of system.
- Maximum short-circuit level.
- Load current. The above four factors determine the fuse nominal current, voltage and short circuit capability characteristics.

The required characteristics necessary for protective equipment to perform its function properly are sensitivity, selectivity, speed and reliability.

- **Sensitivity** applies to the ability of the relay to operate reliably under the actual condition that produces the least operating tendency.

- **Selectivity** is the ability of the relay to differentiate between those conditions for which immediate action is required and those for which no action or a time-delayed operation is required. The relays must be able to recognize faults on their own protected equipment and ignore, in certain cases, all faults outside their protective area. It is the purpose of the relay to be selective in the sense that, for a given fault condition, the minimum number of devices operate to isolate the fault and interrupt service to the fewest customers possible.

- **Speed** is the ability of the relay to operate in the required time period. Speed is important in clearing a fault since it has a direct bearing on the damage done by the short-circuit current; thus, the ultimate goal of the protective equipment is to disconnect the faulty equipment or system as quickly as possible.

On designing protection system coordination, it may differ from system to system because of economic considerations, equipment availability, system topology and others. The economic costs and the benefits of a protection device should also be considered to arrive at a suitable balance between the requirements of the scheme and the available financial resources. In most modern relays the time dial settings can start from values as low as 0.1second, and go to as high as 20 seconds. In distribution systems where it is possible to increase the loading on feeders under emergency conditions, the minimum pickup current setting is usually two times the nominal circuit current. And in order to make sure that the relay is able to trip under a fault condition, the maximum pick up current is usually chosen to be half of the smallest single phase to ground fault current [7].

All relays are assumed identical and approximated by IEEE standard inverse-time characteristic equation as:

$$\mathrm{T\,i,j} = \left(\frac{Ak}{\left(\frac{Iij}{Ipi}\right)ck-1} + Bk\right) * TDSi \qquad 2.17$$

Where Ti,j is the operating time of the relay i for a fault at location j, TDSi is the time dial setting for rely i, IPi is the pickup current of the relay i, Iij is the fault current passing through the relay i for a fault at place j, and A, B and C are constant values to provide selected curve characteristics. It can be seen from the equation that the non-linearity comes from the pickup current term.

According to IEEE Standard C37.112-1996, the IEEE standard Inverse-Time Characteristic Equations for overcurrent relays, the constant and exponents in Table 2.1 define the shape of the standard Moderately Inverse, Very Inverse, and Extremely Inverse trip characteristics, which are very common and applicable in most relays of modern time [7].

Table 2.1: Constants and exponents for standard characteristics of over current relays.

Characteristics	A	B	C
Moderately Invers	0.0515	0.114	0.02
Very Invers	19.61	0.491	2
Extremely Invers	28.2	0.2117	2

2.6. Reliability Cost/Worth

When a power is interrupted, both the utility and customers face interruption costs. When a customer faces such interruption, there is an amount of money that the customer is willing to pay to avoid the interruption and this amount is referred to as the customer cost of reliability. Such costs are tangible and intangible types and also there is an opportunity cost. But assessing the interruption cost from the customer side is difficult.

So to maximize the reliability, the utility should balance their reinforcement cost for reliability improvement and the customer cost for poor reliability. Therefore, the optimal level of reliability is said to be achieved when the sum of utility cost and the customer cost are minimum [10].

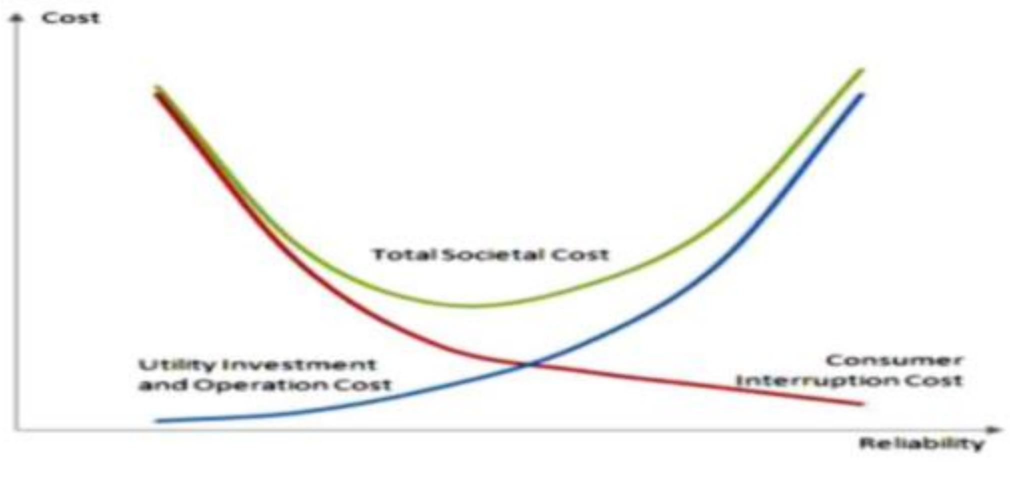

Figure 2.4: Reliability worth and reliability cost

The above Figure 2.4 shows the cost of both customer and utility and it tells us that high reliability achieved by investing high cost

2.7. Literature Review

Electric power is a vital element in any modern economy. The availability of a reliable power Supply at a reasonable cost is crucial for the economic growth and development of a country. Electric power utilities throughout the world, therefore endeavor to meet customer demands as economically as possible at a reasonable service of reliability. To meet customer demands, the power utility has to evolve and the distribution Substation system has to be upgraded, operated and maintained accordingly [12]. To fulfill and meet customer demands currently the following Researches are going on, on the electric power distribution Substation system some of these listed as follows:

A Paper [13] presents a comparative analysis of distribution reliability improvements that can be achieved by using various outdoor distribution devices. First, it discusses the application of the most common types of devices, including line Reclosers, automatic sectionalizes and manual switches. And analysis the quantifies the reliability improvements that can be achieved by using each or a combination of these devices. The paper concludes all devices offer an improvement in reliability. Switches will improve SAIDI. Midpoint switches also possess significant value for tie-point applications where feeder ties are possible. Sectionalizes and Reclosers perform relatively closely for the various configurations except that the Reclosers offer more improvement for MAIFI. The highest possible across the board improvement is achieved by using single-phase Recloser and single-phase Reclosing loop schemes.

A Paper [14] provides the development of the new reliability and security index that reflects both on direct and indirect characteristics. Direct characteristics deal with the risk to not fully supply load in various contingencies. Indirect characteristics address such undesirable conditions as circuit overloads, voltage problems, low stability margins, area interchange violations, and insufficient generation reserves, unfeasible power flows, etc. Although indirect characteristics do not necessarily cause load losses they nevertheless signal about a reduce security/reliability margin. This reduce margin may lead to sometimes hardly predictable and quantifiable load losses (via remedial actions, islanding and, instability), unforeseen events (cascading outages), sever system failures (voltage collapse) etc. The new index gives a more comprehensive answer regarding the general degree of both reliability and security in the system by combing diverse contributing factors using a fuzzy logic like approach. It is designed to flexibly accommodate various priorities and admittance of power utilities regarding particular characteristics integrated into the index. The existing indices such as unexpected unsaved energy, system minutes, stability margins and others can be linked to or derived from the general index. The index meets the need in practical, flexible and effective security and reliability index.

A Paper [15] explains the implementations of reliability improvement solutions to test system have been evaluated from a socio-economical point of view. For each of the alternative solutions implemented in the test system, the average annual supply interruption cost to the customers supplied from the test system has been estimated. Furthermore, the maximum annual capital cost associated with the implementation of each solution has been estimated. Then, a reliability improvement solution is considered justified socio-economically if the capital cost associated with its implementation is less than the resulting reduction in the interruption cost to the customers.

A Paper [16] focuses on aging power systems. Aging of components is an important fact in power system reliability assessment. It results from a number of different reasons; deterioration, erosion or damage of equipment. Regardless of reasons, most equipment may develop aging trend over time. As a result, aging may become the cause of load curtailments because of higher system failure probability. So, it is necessary to examine aging characteristics in system reliability or in economic evaluation. Power systems with high reliability at low-cost offer may benefit in competitive. This thesis illustrates the effect of aging on composite power system reliability evaluation.

A Paper [17] explain the technique for assessing the reliability of alternative conceptual design architectures. The method is based on the identification of criticality and sensitivity of system components, and the simulation model that incorporates probability and failure rates of individual components such that system level reliability measures can be computed. This analysis at the system level supports decision making early in the design process and assists the designers to evaluate and identify critical elements of different conceptual architectures and to select among or integrate different architectural solutions to ensure improved reliability.

A Paper [18] mainly focuses on the reliability problems of the existing power grid of Adama city and the smart grid has been proposed as a solution. Therefore, the appropriate components of the smart grid are selected to design the overall system. Smart Reclosers are the key components of the smart grid, which are used for fault detection, isolation and restoration programs in the distribution systems and the result of this fact has been an unprecedented increase of global demand for this product. Smart Reclosers offers a complete design solution with integrated smart grid capabilities offering not only remote control but automation and analog data measurement and logging capabilities to achieve the utility business drivers. The designed system is simulated using the software’s Dig-Silent and windmill that are used to analyze the reliability of the overall system. The simulation of the designed model shows that the application of smart Reclosers can improve the reliability of the overall system from 50% to 70%.

A Paper [19] presented a basic new restoration methodology for distribution system configurations that maximize the amount of load that can be restored after a grid blackout, substation outage and distribution feeder line section outages and evaluates the cost of load point interruptions considering feeder islanding and substation capacity constraints. Several case studies with restoration procedures are presented and discussed to clearly reveal the impact of distribution system capacity constraints on load point reliability indices and the cost of load point interruptions.

A Paper [20] proposed a branch and bound type heuristic method to determine the network configuration to enhance distribution system reliability and for minimum line losses. Its solution scheme starts with a meshed network by initially closing all switches in the network. The switches are then opened one at a time until a new radial configuration is reached. In this process the switch to be opened at each stage is selected in order to enhance distribution system reliability and to minimize line losses of the resulting network.

A Paper [21] proposed an evaluation technique for distribution reliability that uses the improved failure rate of all protective devices in a network, depending on the location of the superconducting fault current limiter. As a result, it is expected that the SFCL makes the reliability of adjacent equipment on an existing network improve, and these changes are analyzed.

A Paper [23], discussed that a distribution recloser is designed to interrupt fault current. It is designed to "reclose" on the fault repeatedly in a predefined sequence in an attempt to clear the fault. One of the philosophies for the use of reclosers is to increase reliability.

A Paper [24] has presented the potential use of reclosers for power reliability improvements. In their discussion, if a fault is of a momentary nature, the recloser helps to restore the service quickly; and hence enables the reduction of the outage time.

It is known that the length of feeder has a direct significant effect on the value of reliability indices, i.e. the variation in length of feeder (due using new substation) leads to the change in failure rate thereby causing a variation on the value of reliability indices. However, research works/or review articles reported so far on power reliability improvement did not give a great emphasis to the effect of variation in feeder length on the value of reliability indices.

This thesis therefore, gave due attention to the mentioned gap above by considering the variation in failure rate as a crucial factor.

CHAPTER THREE

DATA COLLECTION AND ANALYSIS

3.1. Introduction

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

Reliability analysis needs interruption duration, interruption frequency, a total number of customers served, customers interrupted, loads connected and so on. So, under this chapter, the collected failure data and basic electrical data of power system equipment which are necessary for reliability analysis are presented. These data are analyzed to identify the current reliability status of the substation and to distinguish the main problems of interruption

Generally, the following methodology has been followed in conducting the thesis work:

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

Data Collection: Data collection plays a very crucial role in the statistical analysis. In this thesis work, the primary data type has been used which is collected for the first time by the researcher from the case study area. In this thesis work, the data can be collected through various methods like surveys, observations, personal interviews and case study.

- Three years (2009 -2011 E.C) the interruption, data has been collected from Bule hora substation which helps to carry out reliability analysis.
- The rating of Transformers, number of customers and feeder length have been collected from the distribution in Bule hora Substation.
- Load of the existing system has been gathered.
- The collected data has been used to clearly analyze the problems of the Bule hora city feeder.

During analysis of power reliability, basic elements such as interruption duration, interruption frequency, a total number of customers served, customers interrupted and loads connected are taken into consideration. In this chapter, the collected failure data and basic electrical data of power system equipment which are necessary for reliability analysis are presented.

These data are analyzed to identify the current reliability status of Bule hora sub-station assess the main problems of interruption.

3.2. Descriptions of site Locations

This study would be done in Bule Hora Town, West Guji Zone of Oromia Regional State. The Town lies between 5026'-5052'N latitude and 37056'38052'E longitude. Located on the paved of Addis Ababa Moyale highway and the Town far from Addis Ababa about 476 km to the Southern part of the country. The Bule Hora Woreda has 20 kebeles of which Bule Hora Town is one Woreda of the Zones

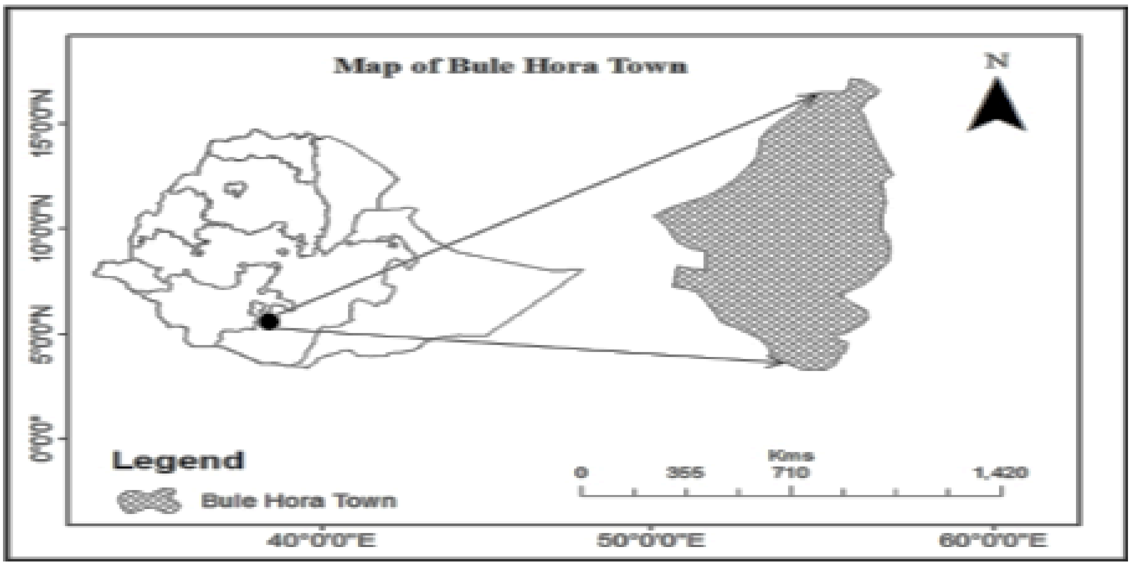

Figure 3.1: Topography of Bule Hora Town

Bule-hora Substation

Bule-hora substation receives electrical power as an input from Dilla that supplies 132KV/25MW with transmission line to the two power transformers. The first 25MVA 132/33KV transformer is the old one which take 132KV as input and take out the four outgoing 15KV feeder lines which are chelektuLine-1, burji Line-2, hageramariam Line-3 ad main Feeder. The second 132/33KV power transformer is the new which installed in the nearest few years which is not old as the first transformers. This 33KV feeder lines for rural Guji Zone towns are used far flung rural areas and other Guji zone which is far from Bule hora town which has to be extended farther in order to cover all the rural electrification activities, whereas the towns near to Bule hora towns by rural areas are served by 15KV medium voltage line from the first 132/15KV transformer.

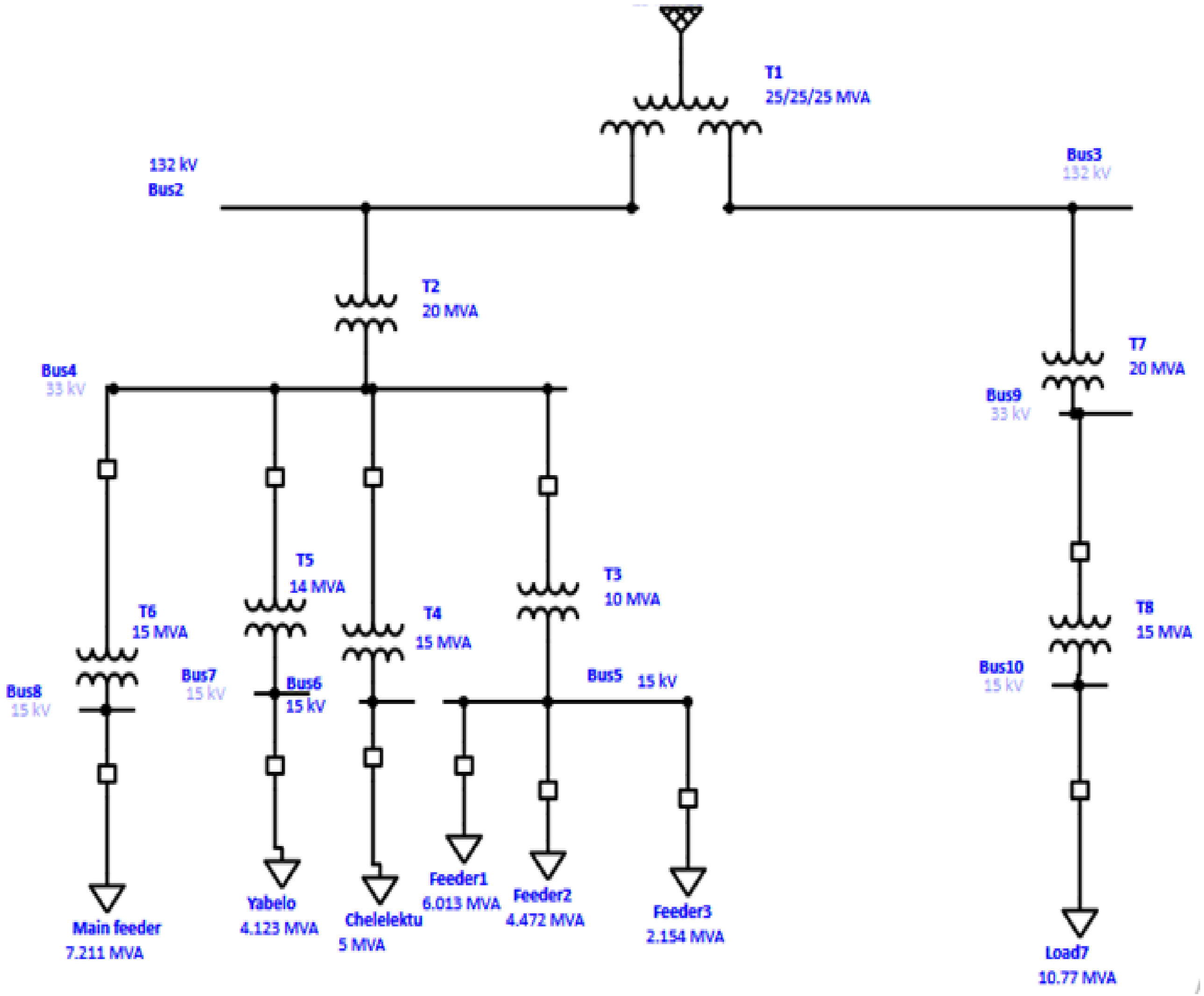

Figure 3. 2 : Single Line diagram of Bule-hora Substation

Figure 3.3 Bule hora Substation [Source: study area]

The Case Study of Bule –hora Feeder Line-3

The case study of this thesis is limited to Bule-hora feeder Line-3. Bule-hora feeder Line-3 is a radial distribution system which delivers electrical power to the customers from Bule-hora substation in a straight forward fashion. Bule-hora utility providing service center has a total of 15316 customers. Out of this is 9656 customers get service from Bule-hora Line-3. Customers are the owners of big hotels and small restaurants, small micro industry, most of all Bule hora governmental administrative office, school, colleges, university, hospitals and clinics, some factory,

Bule-hora feeder Line-3 is divided into in to various laterals which is again divided into several sub-laterals of feeders to distribution transformers. The main feeders are before the distribution transformers are three phase three wires which is 15kv and low voltage side after the distribution transformers are three phase four wire or single phase two wire circuit.

Figure 3.4: 132/15KV Power Transformer Photo in Bule hora Substation

3.3. Data collection

Primary Data

Primary data has been collected by the direct involvement of the researcher and workers of Bule-hora electrical utility service center. This is intended for keeping evaluation reliable. During the site survey, the primary data necessary for this study is concerned with the length of the feeder, rating and type of each transformer, topology and layout of the system, conductor type and size, topography and environmental conditions.

Line length

One basic parameter considered for design of the existing system making use of software

(ETAP 16) is length line. The total length of the feeder which is up to 45.96km is segmented based on the location of tap points and transformers.

Table 3.1: Partial Line Data for Bule hora feeder line -3 from Appendix-D

Equipment ID	From Element ID	To Element ID	Cable Length in meter
Cable12	Bus 162	Bus140	300
Cable20	Bus134	Bus137	100
Cable21	Bus241	Bus247	50
Cable22	Bus125	Bus132	90
Cable24	Bus252	Bus250	200
Cable25	Bus254	Bus245	100
Cable26	Bus245	Bus248	20
Cable27	Bus257	Bus245	420
Cable28	Bus258	Bus263	100
Cable29	Bus162	Bus168	80
Cable30	Bus259	Bus264	35
Cable31	Bus260	Bus262	500
Cable32	Bus350	Bus352	410
Cable33	Bus351	Bus354	250
Cable34	Bus227	Bus224	280
Cable35	Bus228	Bus226	75

Transformer and Load

The second data required for ETAP 16 for distribution system analysis is transformer ratings and its caring capacity and the load of the transformer. The total numbers of transformers with their total loads are collected for Bule hora Feeder line-3.

Table 3.2: Partial Transformer data with its load rating of Bule hora Feeder Line-3 from Appendix-E

Equipment ID	Primary Element ID	Secondary Element ID	Rated Power in MVA	Primary Voltage in KV	Secondary Voltage in KV	Load in MVA
T14	Bus24	Bus23	100	15	0.38	80
T15	Bus26	Bus25	315	15	0.38	252
T16	B-25	Bus28	200	15	0.38	160
T17	Bus30	Bus29	630	15	0.38	504
T18	Bus32	Bus31	50	15	0.38	30
T19	Bus35	Bus34	315	15	0.38	251
T20	B-28	Bus36	315	15	0.38	252
T21	Bus38	Bus37	315	15	0.38	252
T22	Bus40	Bus39	50	15	0.38	30
T23	Bus42	B-30	100	15	0.38	80
124	B-32	Bus43	315	15	0.38	252

Table3. 3: Name, Voltage Levels and Current ratio of Bule hora Substation outgoing feeders

Feeder Name	Voltage level	Current ratio of CT	Circuit breaker type
Feeder Line-1	15KV	200/5A	Fixed
Feeder Line-2	15KV	400/5A	
Feeder Line-3	15KV	400/5A	

Secondary Data

The secondary data has been collected from Bule hora substation which has been recorded for last three years from 2009-2011 E.C. of interruption data from 25MVA, 132/15KV transformers three outgoing 15KV feeder Lines that is Feeder Line-1, Feeder Line-2 and Feeder Line-3 that they have a number of frequency and duration of interruption for each feeder line as shown in table3.4 and table3.5 which show total frequency and duration of sustain interruption at Bule hora substation respectively.

Table3. 4: Total frequency interruption of Bule hora substation from 2009-2011E.C.for each year from Appendix-A

Feeder Name	2009E.C.	2010E.C.	2011E.C.
Feeder line 1	446	364	351
Feeder line 2	495	597	480
Feeder line 3	330	394	300

Table3. 5: Total duration interruption of Bule hora substation from 2009-2011E.C.for each year from Appendix-A

Feeder Name	2009E.C.	2010E.C.	2011E.C.
Feeder line 1	610.22hrs	562.5512hrs	482.117hrs
Feeder line 2	569.68hrs	794.694hrs	452.537hrs
Feeder line 3	420.903hrs	469.863hrs	338.63hrs

3.4. Cases of power interruptions

Bule hora substation has recorded data about the fault type based on frequency and duration of interruption. The technicians have recorded the frequency and duration of power interruption and load of each feeder per hour. This information is taken from the reading of instrument and utility workers during total outage. To know the cause of power interruption interviews line mans and technical managers, head managers of the utility and some of employers who have experiences and information on distribution system are interviewed. Ten workers have participated in the interview that is intended for gathering data on the cause of the fault. These ten workers included two experienced professionals, one electrical engineer, five workers graduated from TVET holding diploma and two workers having high school level education with ten years' experience. The interviews were prepared to describe the common cause of interruption in Bule hora feeder 15KV lines. From the interview response, the cause of power interruptions are: - aging of poles, equipment and wires, tree contacts, tree failing, pole failing, over loading, insulation cracking, animals, large birds., winds, rains and lighting which cause power interruption in Bule hora distribution system and also distribution line are interrupted for maintenances purposes.

Some causes of the power outage explained by the workers

Aging of pole and equipment

According to the information obtained from the interview and site visit 15KV Bule hora feeder line-3 installation have very old distribution system. Therefore, almost all equipment and poles are very old.

Poles

From site visit and interview response, almost all are old wooden poles and few iron poles. The wooden poles are vulnerable to aging. The aging of the poles mainly affects the support towers especially when the poles are falling. This happens because root of wooden poles are putrefied since most of the soil of Bule hora carry moisture which cause the root of the pole become deteriorated. This condition is very serious in low level areas where poles are repeatedly falling.

In some of the rural area near to Bule hora town feed from Bule hora Line_3. The poles of these feeder pas through the farming soil. The farmers do not care for the soils that hold the root of the pole during tilts the farm which causes the water penetrated to enter to the root of the poles that cause the roots get putrefied. As per discussion, total interruption of power is occurred due to failing pole of the feeder from either of areas because the distribution system has no feeder section or zone that divide the customer according to areas, length or size of customers and environmental and topology of the Bule hora towns.

Equipment aging

Power distribution system equipment aging results in major customer's interrupt, in this section from response of interview, wire become broken and fail to ground, to the arm of the insulator or to other phase line which form grounding or short circuit accordingly. The other problem is aging of insulators in each pole which become crack and make grounding problems.

Tree

Bule hora areas have tree plants which large in number and in size and some length of the feeder pas near to these trees. The tree near to feeders grow in length of branch or its height which make contact with phase or make short two or more phases. Or falling trees on feeder line due to wind or an inappropriate or carelessly terminating of tree by customer's interrupt power from the substation by tripping feeder circuit breakers due to tree either making short circuit or grounding.

Animals

According to the information obtained from the utility workers, there are cases in which from animals create body contact for rubbing with electrical pole structures. As the results, these poles either fall down or these could be short circuit that can cause power interruptions.

3.5. Types of fault recorded in Bule Hora substation

Distribution permanent Earth fault

DPEF is the type of fault which occurs due to the contact in one of the three phase lines with directly or indirectly grounding. This is called permanent as it persists from long time after occurrences. From the interview responses, this earthling fault occurs due to tree contact with phase, broken conductor fail to ground, making contact with other low voltage pole or Tele poles, phase line lose and fail on the arm of insulator holders, Cracking of insulators and broken insulators by children and raining and wind make contact with tree.

Distribution permanent short circuit fault

Permanent short circuit fault is occurred when two or more different feeder phase lines come in contact with each other. When this happen, there is excessive current that travels along a path that is different from the intended one in an electrical circuit, which can lead to circuit damage, fire and explosion. Short circuit is the most commonly used terms to describe the cause of power failures.

As per interview, the cause of DPSF in the Bule hora distribution systems are aging pole fails, Winds, broken wire fails on phase lines due to aging, loose of distribution lines fail on nearby lines, loses of fixation of two or more insulations due to deteriorated poles edge, carelessly cutting of tree fails on lines, broken tree branches and rubbing animals on aging poles

Distribution Temporary Earth Fault (DTEF)

The term DTEF is to indicate that the fault doesn't persist long. As result it causes circuit breaker to trip. DTEF occurs during rainy season because of the supporting few steel structures get in contact with distribution line and water leak to crack old insulator that results in interruption. Wind blow forces feeder lines against tree or poles near to lines like Tele poles and low voltage poles. In Bule hora, in some areas high voltage lines and medium voltage lines are condensed in closely placed towers even high voltage line and low voltage lines found up and lower in one pole. Possibility of a line getting pushed or pulled to due to wind exists. Separation between lines gets close and forces of attraction /repulsions are created. This event produces contact with tree, towers, etc. thereby creating contact to the earth.

Distribution Temporary short circuit (DTSC)

As per interview response DTSC occurs in short time. It doesn't persist long. Contacts between distribution lines occur because of windy season, Large birds, monkey. These make short two or more phase at the moment directly or indirectly. The lines contact and separate causing the breaker to trip. But these contacts do not stay long. It creates momentary short circuits. Similar event occurs during tree movement by wind and monkey jumping creating contact with distribution lines. The tree touches two-line same time forming line to line fault. Moreover, contact of birds dead on lines and stormy rain season caused interruption.

Distribution Line Overload (DLOL)

DLOL is an overload of the distribution line when the current flow through the line is exceeding that of the rated current. The overloads occur in the distribution line when the current through the line increases beyond its rated capacity. This raise the temperature which cause fuse element melt or blows and the insulation of the line melt, the conductors disconnect. Hence most of the low voltage sides of distribution transformer in Bule hora have over loading effect. From this point of view, most of the low voltage side of the distribution transformer was directly connected to load without fuse or protective devices because of this, fuse is always blow due to the over loading effect. According to information gathered from interview responses, DLOL is one of the causes of power outage in Bule hora. The conception of high electrical powers can cause over load in the existing power grid. Excessive overload causes high tension on the distribution line which forces line conductor that result in disconnection of power networks. From the response of crew/other, most of the central area of the towns, around each distribution transformer, there are large number of business center in addition to residential customers like, big hotels, different small and medium micro production enterprises and residential customers. All of these customers use electric power simultaneously and their power consumption is unknown.

Power Transformer Over load

The Service life of transformers is influenced by the temperature rise of winding and temperature rise of oil due to the KVA loading. Overloading cause excessive temperature rise and deterioration of the insulation and the oil overload reduce service life of the transformers. The over loaded transformer beyond its rated name plate can lead to failures. From site visit and interview response, the overload effect of transformers causes power outage, the worker explains as example that Transformer are 400MVA which are a new. It is changed by 315MVA the old transformer which failed due to the over load effect.

Bule hora feeder line-3 passes through the center of the town. Around the central area, there are small and medium production centers, Hotels, colleges, different organization and especially residential customers which distribute “Enjera” and other customers which make their own business. Hence all these customers have a probability to use power at the same time from this point of view most of transformer affects because of the overloading effect the major cause of loading the transformer beyond the name plat rating is due to the risk associated with the premature aging cumulative deterioration with an increase of temperature.

Operational Interruption

It is necessary to interrupt customer service when performing work on the radial distribution systems. As per Bule hora substation worker's explanation, Bule hora substation workers interrupt the feeder line voluntarily when utility technician asks to interrupt the feeder line for maintenances, load transfer and new transformer erecting and new feeder line installation for new areas. Because the feeder has no any section division or zone and also in few transformers directly connected to 15KV feeder and low voltage side without Isolators and fuse. As site visiting and interview responses, low voltage lines are directly connected to the transformers due to overload effect without fuse because of this, for low voltage side maintenances and installation, the line man ask substation operator to interrupt the power of the hole feeder without notification to the customers.

Transmission Line Fault /TLP

Transmission line is used to transport generated power from Dilla with 132KV to Bule hora substation. Transmission Line Fault/TLP are the fault that occurred on the transmission line which cause total power interruption in Bule hora towns. Therefore, any fault, inability to transmit or any constraints violated in the transmission line which caused inadequate problems in Bule hora distribution system.

System overloads (SOL) and Generation Unit Problem/GUP

This interruption type does not frequently occur and it's general to all substations. It's in distribution system level. Faults in some Generation plants cause power shortage to supply all loads. There has been a record of total blackout of system. Some generation plants faced technical problem and power access had been short. System overload also occurs due to imbalance of power demand and power generated during peak customer demand. In some seasons water levels of hydropower plant decrease and generating capacities are limited. Moreover, system overload occurs. When Generated Power is below the total demand decrease and generating capacities are limited. Moreover, system overload occurs as a result of poor load forecasting. If the available generation cannot supply the loads or if any constraints are violated, the system is inadequate. In case of Bule hora all loads are interrupted.

Types of fault in Bule hora Substation outgoing feeders

These data have been collected as secondary data which is recorded for last three years from 2009E.C.-2011E.C at Bule hora substation. The different types of power system faults have been frequently occurring at Bule hora substation. Appendix - B shows the duration and frequency of the three year faults. From Appendix – B average evaluation for frequency and duration of interruption for three years has been done on the number of interruption. In Table3.6 and Table3.7 below can calculate the percentage of frequency and duration by taking the contribution of each type of fault respectively and total sum.

Table3. 6: Three years' average interruption Frequency of faults from Appendix-B

No	Fault type	Feeder Line-1		Feeder Line-2		Feeder Line-3	
		Aveg.Freq	Ave.Freq%	Aveg. Freq	Aveg.Freq%	Aveg. Freq	Aveg.Freq%
1	DPEF	26.66	7.069	47	8.61	18	5.2735
2	DPSC	42	11.132	58.66	10.75	28.667	8.3986
3	DTEF	25.66	6.802	91.33	16.74	23.667	6.3986
4	DTSC	83	21.99	100.67	18.45	28.33	8.299
5	TLP	3	0.795	3	0.55	3	0.8789
6	SOL	39.667	10.51	47	8.61	42	12.305
7	GUP	32	8.48	32	5.864	32	9.375
8	OP	125.33	33.215	166	30.42	165.66	48.535
TOT		377.33	100%	545.66	100%	3341.33	100%

Table3.7: Three years' average interruption duration of faults types from Appendix-B

No	Fault type	Feeder Line-1		Feeder Line-2		Feeder Line-3	
		Falt dur Aveg Dur	Cont int Dur %	Falt dur Aveg Dur	Cont int Dur %	Falt dur Aveg Dur	Cont int Dur %
1	DPEF	86.756	15.74	93.94	14.85	41.93	10.305
2	DPSC	149.81	27.184	144.078	22.7	77.125	18.95
3	DTEF	6.235	1.132	11.183	1.769	2.85	0.701
4	DTSC	7.612	1.138	54.941	8.689	5.773	1.41
5	TLP	18.883	3.426	18.883	2.891	18.88	4.64
6	SOL	103.15	18.718	125.258	19.81	109.54	26.922
7	GUP	46.82	8.49	46.825	7.405	46.825	11.502
8	OP	131.82	23.92	137.171	21.694	103.95	25.54
TOT		551.113	100%	632.13	100%	406.88	100%

3.6. Reliability Evaluation and Analysis Methods

Reliability evaluation of a distribution system is associated with the continuity of supply of energy from the supply points to the individual customer load points. Reliability of a distribution system is measured using reliability indices Reliability analysis needs interruption duration and frequency, total number of customers served, customer interrupted and load connected. Under this chapter the collected failure data and basic electrical data of the power system which are necessary for reliability analysis are presented. These data are analyzed to identify the current reliability status of the substation and to distinguish the main problem of interruption.

Reliability evaluation of distribution systems consist of two main approaches [4].

- Simulation methods based on drawings from statistical distributions
- Analytical methods based on solution of mathematical models.

The Monte Carlo techniques are normally very time consuming due to large number of drawing necessary in order to obtain accurate results. The fault distribution from each component is given by a statistical distribution of failure rates and outage times.

The analytical approach is based upon assumptions concerning statistical distribution of failure rate and repair times. The most common evaluation techniques are using a set of approximate equation of failure mode analysis.

3.7. Data analysis

Analytical approach calculates the average reliability indices using a set of mathematical equations. This procedure is relatively simple and requires a reasonably small amount of computer time. The analytical approach is based on assumptions relates to the statistical distributions of failure rates and repair times [4].

In this thesis, the primary as well as secondary data have been collected from Bule hora utility and Bule hora substation respectively. The secondary data as frequency and duration of power interruption of Bule hora feeder line-3 distribution system for three years (2009- 2011 E.C.) have been analyzed and interpreted. The primary data of the total length of 45.596 KM of the feeder has taken for load point indices interpretation. The frequency and duration of interruption and the length of the feeder are used to calculate failure rate and mean time to repair of each failure [25]. The data obtained from Bule hora substation are required to calculate the failure rate and mean time to repair. These data obtained are used to analysis of the reliability indices of the existing system of Bule hora feeder line -3 which are selected feeder in this thesis as a case study.

The performance of Bule hora feeder line-3 has been evaluated using commonly used reliability indices. These indices provide customer risk dimension accordingly this thesis present the result of the reliability indices obtained by analytically for Bule hora feeder line-3 distribution system only. In this thesis the reliability analysis of electrical distribution system in Bule hora feeder line-3 has been carried out. The system reliability is evaluated for systems feeder determining its performances indices. The reliability is evaluated for system feeder line-3 load point. While calculating the reliability indices of Bule hora feeder line-3 only sustained interruptions are considered. The collected secondary data from Bule hora substation as sustained interruption in frequency and duration the whole analysis is made only as system average indices of sustained interruption, no momentary indices are considered additionally interruption recording method is not only on basis of how many customers are affected by fault occurrence but also many delivery points are monitored to clear the fault.

The reliability indices of Bule hora feeder line-3 of the Distribution system have calculated with the help of ETAP 16 software package, to predict the reliability indices with ETAP 16 software. The value of failure rates and mean time to repair for each component are necessary.

Failure rate

To estimate the failure rate of the line per kilometer, the total number of outages should be divided by the feeder length (km) as indicated in the following equation [24].

$$\mu A = \frac{\text{Total number of interruption}}{\text{Total feeder length (km)}*\text{year}} \quad \frac{int}{km.yr}$$

Table 3.8 2009-20011E.C. Frequency of power interruption

	2009	2010	2011
Feeder line 3	300	394	300

Average of frequency interruption is 341.33

Total length of Bule hora feeder line-3 is 45.596KM

Where μA = active rate of any component

$$\mu a= \frac{300+394+300}{45.596*3} = 6.09 \text{ interuption/km.year}$$

Table3.9: 2009-20011E.C. Duration of power interruption

	2009	2010	2011
Feeder line 3	420.903	469.863	338.63

Average frequency interruption = 341.333

Average duration of interruption = 409.778

$$\text{MTTR} = \frac{Total\ repair\ time}{Total\ number\ of\ interuption} = x = \frac{409.778}{341} = 1.2\text{hr/interruptions}$$

From the above equation, the calculated average failure rate of the line and repair times per km of the existing feeder are 6.09(Interruptions /km. year) and 1.2 (Hrs. /interruption) respectively.

ETAP 16 software use µA and MTTR equation to predict the basic reliability parameters for reliability analysis. To estimate the failure rate of a component ETAP 16 uses combination of active µA and passive µp failure rates together. µA, the active failure rate in number of failures per year per unit length. The active failure rate is associated with the component failure mode that causes the operation of the primary protection zone around the failed component and can therefore cause the removal of the other healthy components and branches from service, after the actively failed component is isolated, and the protection breakers are reclosed. This leads to service being restored to some or all of the load points. It should be noted, however, that the failed component itself (and those components that are directly connected to this failed component) could be restored to service only after repair or replacement. While µp is the passive failure rate in number of failures per year per unit length. The passive failure rate is associated with the component failure mode that does not cause the operation of protection breakers and therefore does not have an impact on the remaining healthy components. Repairing or replacing the failed component will restore service [25], [Software Library]. µp is assumed as zero in the model Table3.10below show the value of the Bule hora feeder line-3 reliability indices which are calculated with the help of ETAP 16 software.

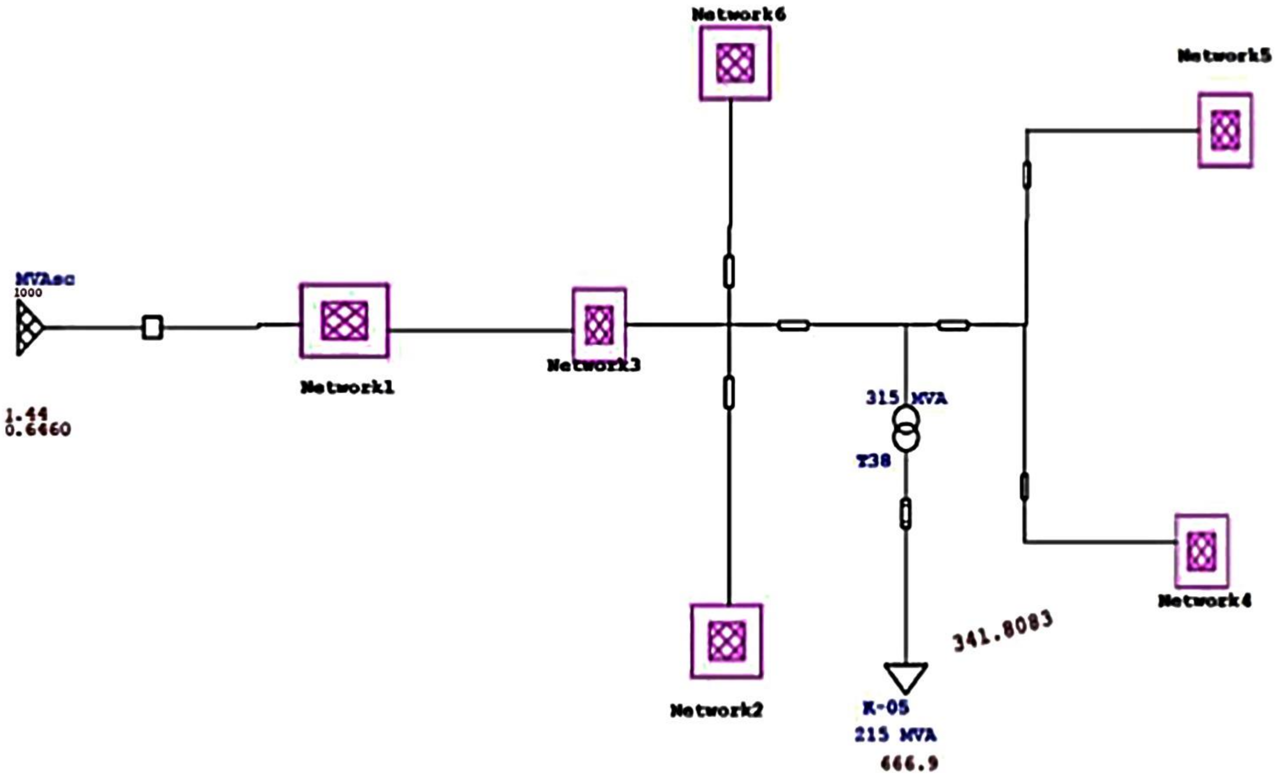

Figure 3.5 Composite network Single Line diagram of the existing system of Bule hora Line-3 with SAIFI and SAIDI

Table 3.10: Reliability indexes for Existing system

SUMMARY System indexes	
Reliability Indices	Result of Analysis
AENS	120933.3 MWhr/customer.yr
ASAI	0.9239pu
ASUI	0.07613pu
CAIDI	1.195hr/customer interruption
EENS	10,037,460MWhr/yr.
SAIDI	666.890hr/customer.yr
SAIFI	341.8082f/customer.yr

The Existing system data analysis work described system availability metrics and metrics regarding unreliability. The results of the reliability indices from the data analysis of the existing system compared with the bench marking of the computed reliability indices of different countries, it is obvious that the Bule hora feeder line-3 distribution system has been worse performance and need to be improve up on to increases its reliability indices from table3.11. The reliability indices from calculate values is used to measure the performance of the distribution system/ Bule hora feeder line-3 / for sustained interruption.

The results of reliability indices are explained as followed: -

- SAIDI measures the total duration of an interruption for the average customers during given time period which is equal to 666.8905hr per customers per year. This index shows that every customer's experiences 666.8905hrs per year that is customer was out for 666.8905hrs per year. This SAIDI result compared to the bench marking. It is extremely large. Hence this provides that there is great reliability problem in the existing Bule hora feeder line-3.
- SAIFI is the average number of time that a feeder line-3 customers experiences an outage during the year from this point of view, the result of SAIFI is equal to 341.8082f per customer per year. That is, per year customers at Bule hora feeder line-3 has 341.8082 probability of experiencing a power outage. The value of this SAIFI is compared with the bench marking values. It is much greater than the maximum value of the bench mark. This clearly indicates that there is serious reliability problem in the Bule hora feeder line-3.
- CAIDI, once an outage occurs the average time to restore service is found from the customer. The value of CAIDI of Bule hora feeder line-3 is 1.951hrs per customer interruptions, i.e. on average, any customer who experienced an outage on a year was out of services for 1.951hrs.
- ASAI, It is the average services availability index that services was available during a given time period to the total customer hours demanded. i.e. it shows the fraction of times that a customer has received power during the reporting period. The power supply of the over all of Bule hora feeder line-3 is 0.9239pu (92.39%) available in table.
- EENS: It indicates the un-served or unsold energy of each feeder. For the overall system, the total unsold energy was 10,037,460.0 MWhr /yrs.

- AENS: This index represents the average energy not supplied per customer by the system. The overall system has an AENS value of 1220,933.3MWhr / customer.yr.

In general, based on the data analysis the following points can be drawn:

- The reliability of the Bule hora feeder line-3 does not meet the requirements as compared to the bench marking country and the reliability of this feeder is not good enough as compared to the international reliability indices of best experienced countries.
- There is high unavailability of services in the network.
- There is also much loss of Unsupplied Energy due to both planned and unplanned outages in the present power grid of Bule hora feeder line-3.

3.8. Bench Marking for Distribution System Reliability Indices

The standard with reliability of a distribution system in measured against is known as reliability bench mark. The standards are given in order to provide a justification and given acceptable margin for the reliability performance of distribution network [29]. Based on IEEE guide, refer to [24] highlighted the bench marking for ten countries computed for power distribution reliability in table3.16. The annual value of SAIFI and SAIDI for each of the participating countries shown in the table3.11. The countries give emphasis to the power quality and reliability. From the table3.11 Germany has high reliable power delivery compared to other developed country, the Germany has lower SAIDI which Germany has lower sustained interruption duration/ shorter in duration of power outage in a year/ but as considering USA compared to other nine countries. It is considered as unreliable. The idea of power reliability is tremendously large which covers all parts of the ability of the system to satisfy the customer's requirements without the overburdening the tariff [24]. The commonly used reliability indices for distribution system that must use to assess the previous performance and predict the next performances of power system.

Table 3.11: International comparison of reliability indices

Countries	SAIFI (Int./Year/Customer)	SAIDI (Hr./Year/Customer)
United States of America	1.5	4
Italy	2.2	0.967
France	1.0	1.03
Denmark	0.5	0.4
Australia	0.9	1.2
Spain	2.2	1.73
Canada	3.4	6.9
United Kingdom	0.8	1.5
Germany	0.5	0.383
Netherland	0.3	0.55
Ethiopia	20	25
Bule hora feeder line3	341.802	666.890

3.9. Reliability cost and worth

Introduction

Electrical power system in the distribution system is used to deliver electrical energy to the customers as economical and as reliable as possible. In modern society the life depend on the electrical energy because of all activities is performed by the electrical equipment and machines but this daily routing activities or operation of the electrical equipment and machines became paralyzed when the power of electrical energy interrupted due to different factors [28]. When power is interrupted both utility and customers face interruption costs.

The majority of the outages seen by customers are caused by failure in the distribution system. The reliability of planning approach is based on cost of un-served energy. This is the economic loss the customers experienced due to un-served energy as a result of planned or unplanned interruptions. The approach balances the coast of improving service reliability for customers and the economic benefits of such improvements. The importance of the power grid depends on the customers being supplied. It is known truth that the reliability of a system can be increased by increased investment. At the same time the outage costs of the system will decrease and this lead to the concept of an optimum reliability [25]. The essential problem in applying the concept of optimum reliability is lack of knowledge of the true outage cost and the feature that should be included. The outage cost has seen by utility and the customers. The utility outage costs include: loss of revenue from customers not served; loss of customer goodwill; increased expenditure due to maintenance and repair. Costs seen by the customer and most of these are extremely difficult, if not impossible, to quantify. They include: costs imposed on industry due to lost manufacture, spoiled products, damaged equipment, extra maintenance and costs imposed on residential customers due to spoiled deep frozen foods, alternative heating and lighting costs, etc [25].

Power Interruption Cost Evaluation in the Distribution system

Electricity supplies in Ethiopia are at reasonable cost. If it supplies with quality levels, it becomes basic condition for development economic growth and welfare. Customer Interruption cost is simply revenue lost by the utility companies due to power interruption to the connected customers. This revenue may be in the form of system failure, ruin process, over time pay and loss of production. When customer faces interruption, there is an amount referred to as the customer cost of reliability. Such costs are of tangible and intangible types and also there is an opportunity cost.

But assessing the interruption cost from the customer side is difficult. Power interruption costs are in both utility side and the customer side.

Power Interruption Cost from Utility Side

Power interruption cost from utility side is estimated on customer data, interruption data and cost outage data. Bule hora substation record interruption data that are usually recorded in the form of interruption duration, interruption frequency and load reading of each feeder on each hours. The Bule hora utility has data of customers. The energy is a very important terms to estimate the interruption cost of system for a typical year. The basic factor used for cost estimation is the tariff (price in birr) for different type of customers

Expected interruption cost/ EIC/ is calculated for each delivery point in the area by computation of the contribution to EENS and EIC for each and every interruption expected to occur during a year. The expected frequency and duration of each failure giving interruption to the delivery point, in combination with the expected load and the specific interruption cost for each interruption duration are used to obtain the delivery point EIC.

$EIC = EENS * Tariff\ per\ KWH$

The average Equivalent Flat Rat of the utility is 0.5233centin

The Electrical Energy not supplied is

EENS =10,037,460.00MWhr/yrs

$EIC = 10{,}037{,}460.00\text{MWhr/yrs} * 0.5233 = 5{,}252{,}602.818\,birr$

In general, Bule hora utilities loss 5,252,602.818*birr* per year because of power

unavailability or power outage in the Bule hora feeder line-3 systems.

Table 3.12: Ethiopian Electricity Tariff from utility

	Monthly Consumption (KWh)	Price Rate (Birr/KWh)
Residential	Equivalent Flat Rate	0.4735
	0-50	0.2730
	51-100	0.3564
	101-200	0.4993
	201-300	0.5500
	301-400	0.5666
	401-500	0.5880
	Above 500	0.6943
Commercial	Equivalent Flat Rate	0.6723
	0-50	0.6088
	Above 500	0.6943
Low Voltage Time of Day Industry @15 KV		
Equivalent Flat Rate		0.5778
Peak		0.7426
Off Peak		0.5354
High Voltage Industry @132 KV		
Peak		0.4736
Off Peak		0.3664

3.10. Mitigation Technique for Distribution System power Interruption

The main target to improve reliability and power quality to customers are to eliminate faults and then to minimize the effect of faults on customers even if it occurs [33].

From Bule hora utility employer's response for the cause of power interruptions are aging of pole, equipment and wire, Tree contact, tree failing to line, pole failing, over loading, insulator cracking, animals, winds, rains and lighting which case power interruption in the Asella distribution system and also the distribution lines are interrupted for maintenance operations. Hence identifying the root cause of the outages is the first step in maximizing the reliability of DS. It is important to apply the interruption mitigation techniques in order to obtain better results. Hence it is important to analyses the root cause and apply mitigation techniques. The distribution power outage mitigation technique can be basically classified in to two categories [33].

- Electrical Mitigation Technique
- Non- Electrical Mitigation Technique

Electrical Mitigation technique

It directed impact on the distribution system analysis. This technique includes [33]

- Placement of protective devices in the DS like- recloser, Fuse, Circuit breakers
- Placement of switching devices (manual or automatics switches)
- System reconfiguration and feeder re-conducting

This thesis selects reclosers as addition of protective devices in the distribution feeder line due to its reliability and over current protection but mainly for reliability reasons.

The DS can be reconfigured by changing the location of normally open switch effectively change the allocation of the customers and the flow of power for the effective feeders. It not only improves reliability. It also minimizes the losses, operation cost, and over loading effect [33. The main goal of an automatic service restoration is the operation of Tie switches to restore the energy supply to the maximum number of possible area having been affected by the fault [4]. Basically, the feeders to be transfer customers presently receiving poor reliability to a nearby healthy feeder with better reliability and the effectiveness of this technique on the system.

Non Electric Mitigation Techniques

Non electric mitigation techniques do not have any impact on other engineering analysis tools and can be evaluated solely with reliability studies. Types of non-electric mitigation technique include: [33]

- Vegetation management and installation of lightning arresters,
- Animal protection guards,
- Placement of crews and human factors.

Maintenance strategies for mitigation of power outage

The main aim of maintenance is to extend equipment life time and reduce the probability of failure. Periodically maintenance decreases interruption frequencies and duration of interruption. Maintenance may be divided in to two namely: -

- Preventive maintenance
- Corrective maintenance

Preventive maintenance is a proactive approach to improve the condition of an unfiled component that may be deteriorated to some degree. The utility experts must be assessed about DS main equipment for instant transformer oil, deteriorated pole, loos insulators which are the cause of power outage in the DS. Predictive maintenance and planned maintenance can be carried out according to the critically of the system failure. Precaution maintenance is done to equipment to prevent any failure occurring in the future while Corrective maintenance replaces or repairs failed component. Electrical equipment wears out due to various aging causes. Insulation degradation, heating due to current flow, mechanical damage and corrosion from chemical reactions bring about shortening of equipment life time. Life extension and repair practice are preferable to replacing with new equipment. Damages on equipment have to be addressed by life extension programs. Life extension of distribution equipment must be carried out timely and on regular basis depending on condition of the equipment. Repair of equipment is more preferable to replacement of equipment in terms of cost and equipment durability. Replacement is done after ascertained data of failure frequency and operation incapability. [14]

In this thesis a 15 KV Recloser has been selected based on the capacity of the Bule hora city feeder line. Place and a number of automatic Reclosers are chosen by considering a number of customers, feeder length, the sensitivity of the area and economic benefits. The reliability indices SAIFI, SAIDI and cost benefits would be the main drivers for comparison of the alternatives using heuristic technique.

The switches placement techniques consist of the following steps:

STEP 1: Determining the feeder line and number of switches to be installed.

STEP 2: Division of the main feeder line into sections, where the size of each section is based on nearly the same number of customers or randomly determined in case of multiple repetitions of the techniques – initial placement of switches and objective function calculation.

STEP 3: Random determination of a sequence of switches, the location of which will be verified.

STEP 4: Establishing two new placements of the switch (ordered as in STEP 3) – the successive possible placement towards main feeding point (MFP) and in the opposite direction (however not further than other switch).

STEP 5: Determining objective function values for new switch placements and selecting the most advantageous one as compared to the original one. The improvement of the objective function values signifies a new position of the switch, otherwise – the switch is relocated to its original site.

STEP 6: If the placement of all switches has not been verified (ordered as in STEP 3), go back to STEP 4 or to STEP 3 until procedure (STEP 3÷STEP 6) is repeated (the number of cycles is the assumed parameter of a techniques).

STEP 7: The placement of the switches are optimal.

In this study, a Nu-Lec 15 KV outdoor pole mounted automatic circuit Recloser is selected for simulation. The Recloser allows for protection with other devices and is applicable in the real world. Nu-Lec industries are Schneider electric core business unit for recloser technology

CHAPTER FOUR

Result and Discussion

4.1 Introduction

This chapter presents the explanation of the modeling and simulation of the existing system with different mitigation alternative techniques to improve the system reliability of the Bule hora city feeder line at a reasonable cost. Different techniques have been analyzed by ETAP 16 Software simulation. The simulation focuses on evaluating the impact of using different techniques such as reclosers, reconfiguration, sectionalizing, using circuit breaker and other techniques.

Recloser is a device that is used in overhead distribution systems to interrupt the circuit to clear faults. Automatic reclosers have electronic control sensors and vacuum interrupters that automatically reclose to restore service if a fault is temporary. There are several attempts that may be made to clear and energize the circuit and if the fault still exists the recloser locks out. In this thesis three-phase Reclosers are used for enhancement of power distribution reliability. The Reclosers incorporated protective relaying equipment can be set to trip at specific overcurrent conditions and reclose at specific time intervals. After a circuit trip and settled time delay, the Recloser automatically re-energizes the circuit. Reclosers are typically set to trip and reclose two or three times before a lockout condition occurs. The Lockout means that a person working on the line must manually reset the recloser for power to be restored. If the fault condition clears before the recloser locks-out, the protective relaying resets back to the start of the sequence. Reclosers can also be tripped manually. This allows the recloser to be used as a load-break switch [27].

Recloser allows utilities to implement automatic back feed restoration (loop automation) and fault finding. Automatic circuit reclosers are designed for use on overhead distribution lines as well as distribution substation applications for different voltage classes like 15 KV, 27 KV and 38 KV [27].

In this thesis a 15 KV Recloser has been selected based on the capacity of the Bule hora city feeder line. Place and a number of automatic Reclosers are chosen by considering a number of customers, feeder length, the sensitivity of the area and economic benefits.

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4.2. Procedure for Distribution Reliability Analysis by ETAP Software

The reliability analysis is conducted by performing the following procedures in ETAP 16.0 software.

- Modeling of one-line diagram of the existing system using the software.
- Identify and input relevant parameters for the simulation.
- Specify type and operation characteristics of the protection devices.
- Conduct Load flow, short circuit and reliability assessment simulations

4.3. System Modeling

In this thesis, Electrical Transient Analysis Program (ETAP 16.0 version) software has been used as a design, simulation and reliability assessment analysis tool. Load flow and short circuit analysis used for the study has been calculated.

To predict the reliability indices of Bule hora distribution system, values of failure rates and mean time to repair for each component of static loads are necessary. To estimate the failure rate of the line per kilometer, the total number of outages should be divided by the feeder length (kilometers) as indicated in equation (4.1). The average mean time to repair (MTTR) each failure is computed using equation (4.2).

$$\mu A = \frac{\text{Total number of interruption}}{\text{Total feeder length (km)}*\text{year}} \quad \frac{int}{km.yr} \qquad 4.1$$

$$MTTR = \frac{\text{Total repair time}}{\text{Total number of interruption}} \qquad hr/int \qquad 4.2$$

By using equation (4.1) and equation (4.2), the basic reliability parameters used in ETAP software for reliability analysis are calculated as follows: -

$$\mu a = \frac{300+394+300}{45.596*3} = 6.09 \text{ interruption/km.yr}$$

$$MTTR = \frac{409.778}{341} = 1.2 \text{hr/interruption}$$

To estimate the failure rate of a component ETAP 16.0 uses a combination of active (μA) and passive (μp) failure rates together. The active failure rate in the number of failures per year per unit length. The active failure rate is associated with the component failure mode that causes the operation of the primary protection zone around the failed component. It causes the removal of the other healthy components and branches from service, after the actively failed component is isolated, and the protection breakers are reclosed. This leads to service being restored to some or all of the load points. It should be noted, however, that the failed component itself (and those components that are directly connected to this failed component) could be restored to service only after repair or replacement. The passive failure rate (μp) is the number of failures per year per unit length of the feeder. The passive failure rate is associated with the component failure mode that does not cause the operation of protection breakers and therefore does not have an impact on the remaining healthy components. Repairing or replacing the failed component will restore service [ETAP Software Library]. As there is no means of isolating specific faulty areas in the system, μp is assumed as zero in the model.

The Bule hora city feeder (15 KV) has been constructed by 50 mm2, seven stranded, Aluminum Conductor (ALC). This almost equals with ICEA three phase AL Conductor or Code AL 50 mm2, which is found in ETAP Library.

In order to modeling the existing city distribution line and to analyze the current distribution reliability status, the following assumptions have been considered as an input in ETAP 16.0 software.

- ✓ The city line data,
- ✓ Cable length,
- ✓ Number of customers,
- ✓ The connected load
- ✓ Number of the transformer for each load point with the rating,
- ✓ Active Failure rate
- ✓ Duration of interruption in hours
- ✓ Frequency of interruption

Bule hora feeder line-3 is protected by circuit breaker of CT 400/5A rated at the outgoing of the transformer at the substation. This feeder line has no section or division of zone and has no any protective devices other than substation circuit breaker. When the fault occurs at one point far from substation or in one lateral feeder line, the total feeder lines are become out. All customer on this feeder experienced power interruption. Power interruption stay for long duration of time until the lateral faulted line are located and isolated manually. This thesis divided the Bule hora feeder line-3 into different six zones. The zone concept refers to a systematic method of dividing DN in to manageable area/zone/ based on loads, load criticality and disturbance vulnerability. This thesis proposes automatic recloser which makes DS automatic to enhance reliability improvement. All division zones are equipped with automatic electron control recloser and Tie switching technology. Placements of number of automatic recloser on different point of Bule hora feeder line-3 are chosen by considering the different criteria based on the utility faces the challenge of fault identifying and restoration manually and economic benefit of Bule hora town.

These criteria explained as following;

The first criteria consideration for placement of reclosers are sensitivity and economic benefits for Bule hora town situation in which the town activities depend on this feeder that is hotel, small restaurant, small micro industry enterprise, most of Bule hora governmental office, school, colleges, university, hospital and clinics, private hospital, banks, different governmental finance offices, a few industry and almost all service providers get electricity power supply from this Bule hora feeder line-3 in addition to the above customer there is large number of residential customer are considered or included in this feeder line-3.

The second considerations for placement of Automatic recloser are based on the topology of the landscape. The lateral feeder line pass through this topology to the nearest rural area of Bule hora town are most time valuable to wind, tree branches, farming animals which cause the failures of the power. There for this area is challenged areas for crew/line man’s when the fault occurred. Because when the fault occurred, in this lateral feeder line which cause total power line outage of the Bule hora feeder line-3.

The other third consideration for placement of recloser is the environmental factors that is the lateral feeder line pass through forest are valuable to fault, which have wild animals like monkey and large size birds which cause fault to the feeder lines.

Every necessary parameter (connected load, number of customers, cable length and active failure rate are the major ones) used for distribution system reliability analysis is entered in the ETAP software. The interruption, data of years from 2009 to 2011 E.C are used as a base year. As per the data found from the customer service center, a total number of customers currently connected to the

Bule hora city feeder are about 9656. The protection devices have been used to place on the lines are shown in Figure below.

Table 4.1: Input Reliability parameters to ETAP Software

Input Reliability parameters to ETAP Software Substation component	Source	Type	Active Failure Rate (f/yr.)	Passive Failure Rate (f/yr.)	MTTR (hr.)	Switch time (hr.)	Replace time (hr.)
Transformer	IEEESd493-1990	Liquid Fill 15 KV	0.0130	0.0130	367.00	367.0	71.50
Circuit Breaker	IEEESd493-1997	Fixed	0.0030	0.0045	54.20	54.20	3.90
Reclosers	IEEESd493-1997	3phase Oil Fill 15 KV	0.0037	0.003	149.3	34	10

4.4. Case Sudy-1 Placement of the number of reclosers in Feeder Line-3

Reclosers are designed to operate like station breaker. The reclosers incorporated protective relaying equipment which can be set to trip specific over current conditions and reclosed at specific time interval [25]. It used on the main feeder of the circuit and are generally used on lateral branches. The Bule hora feeder line-3 could be divided in to six zone/area for easily manage the zone during the utility fault management case apply six automatic reclose to protect each zone to the down side. The simulation focuses on evaluating the impacts of using all reclosers at the same time on reliability of the system.

From Table4.2 illustrates the reliability improvement because of inserting reclosers for each division of zones of protection which are formed based on topology and environmental factor, length of feeder, economical benefit and sensitivity for town as explained in the introduction of this chapter.

From this table, the reliability indices are improved. As the reliability indices shown in the table4.1, SAIDI is reduced from 666.8905 to 268.9207 hr. per customer per year i.e.

SAIDI is improved by 59.67% from the existing status and also SAIFI is reduced from 341.8082 to 124.7221 f per customers per year. I.e. SAIFI is improved by 63.51% from the existing status, EENS is reduced from 10037460.00 to 3901796 Mw hr. per year. The Utility EIC /loss of earning Ethiopian birr due to EENS is also reduced from 5,252, 602.818E.bir to 2,041, 807.2302E.bir i.e. the utility get profit about 3,210, 795.5878E.bir per year in addition to ordinary profit from sold electric consumption if this methodology applied.

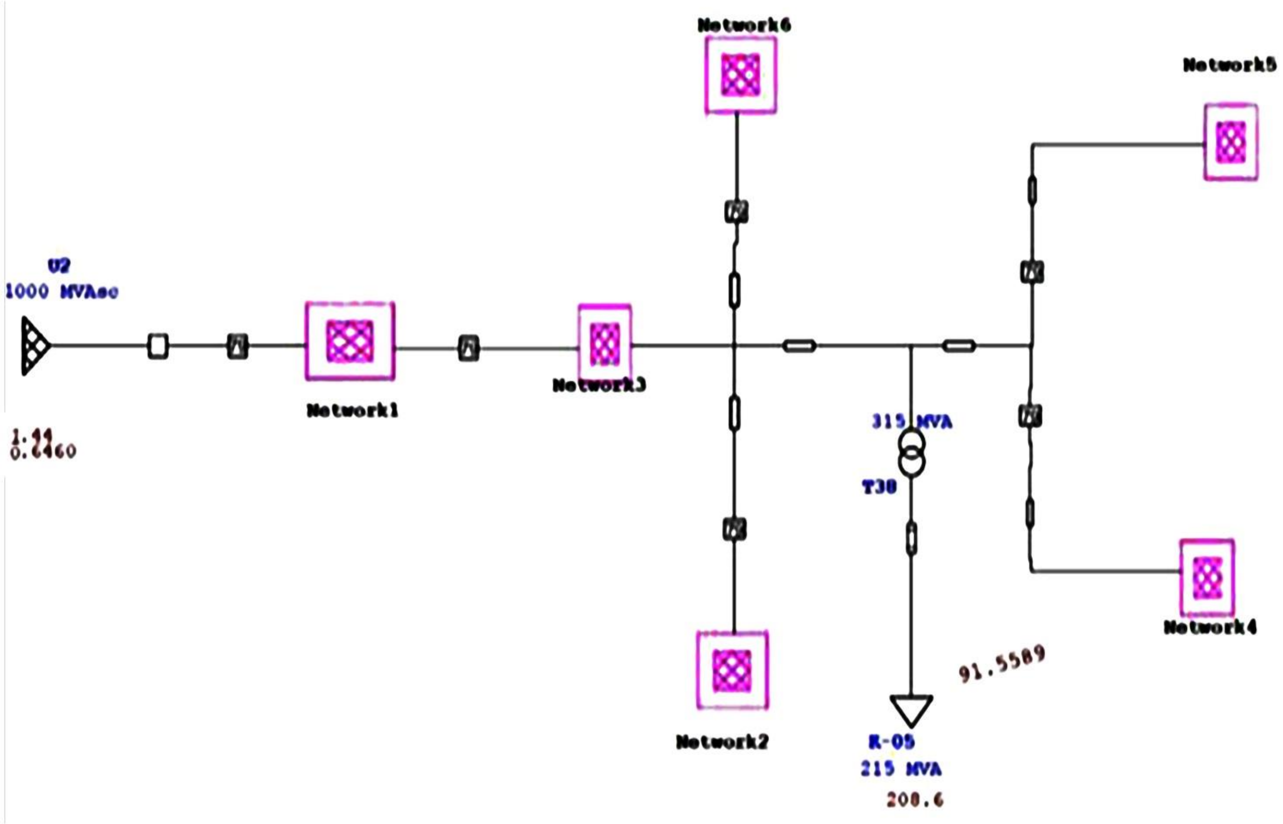


Figure 4. 1: Single Line diagram of the of Bule hora feeder line-3 with each zone protected reclosers

Table 4. 2: Result of Reliability indices for Case one

Summary System indexes	
Reliability indices	Result of analysis
AENS	47009.5900 MWhr/customer.yr
ASAI	0.9693pu
ASUI	0.03070pu
CAIDI	2.156hr/customer interruption
EENS	3901796.000MWhr/yr
SAIDI	268.9207hr/customer.yr
SAIFI	124.7221f/customer.yr

Generally, the distribution reliability is improved but as compared to different country in the bench marking case, still, the improved result of these reliability indices does not meet the requirement as compared to the bench marking country and the reliability of this feeder is not good enough as compared to the international reliability indices of best experienced countries. And applied the alternative supply through Tie switching from adjacent other unloaded feeder line as case study as followed.

4.5. Feeder Reconfiguring with the system using normally open Tie Reclosers

The system reliability is also further improved by implementing Automatic source transfer scheme using Tie recloser switching system.

In the case study one, the Bule hora feeder line-3 has been divided the feeder in to six zone based on topology of the towns, environmental factors, length of the feeder, sensitivity and economic benefits of the towns. Each division of zone is protected or equipped with automatic reclosers integrated with Tie switch system in order to detect the fault occurred in that zone and it isolate the fault. This protect the total outage of the power of Bule hora feeder line-3 i.e. it maximizes the number of the customer satisfaction.

In addition to the divided zone and each zone is protected, this thesis propose alternative sources supply of the power for each zone of the feeder in order to restore in the event of fault or the interruption of the main supply from the substation for the purpose of enhancement of the distribution reliability improvement. The DS configure by changing the normally opens switch, effective change the allocation of the customers and the flow of power for the effective feeders. It is not only improving reliability but it also minimizes the losses, operating cost and over loading effect [33]. The healthy load zone that have lost power will be restored through their boundary Tie switching devices beyond the Tie devices will be considered the back-feed restoration should not over load any part of the back-feed network [4]. The divided zone of the feeder reconfigures with the adjacent healthy feeder using normal tie reclosers. It closes in the response to power outage from the main supply by command signal sent from the control center in to other alternative supply. The Tie point recloser can be set to employ different fault thresholds i.e. which is downstream [25].

In general Tie reclosers pave the way to transfer the load of the zone from the main supply to the alternative other supply in case of power outage. The basic strategy is to transfer customer's present received poor reliability to a nearby feeder with better reliability and the effectiveness of system configuration technology primarily depends up on the number of Tie-switches on the system [33]. The following case study show improvement of the feeder reliability

Case-2. <u>Tie circuit added on the network 4 and network-5</u>

The laterals feeder in this zone vulnerable to different cause of fault like tree contact, edging of equipment and pole, moisture soil etc. If fault occur due to this cause of fault, the fault is detected and isolated by automatic reclosers additional to the recloser alternative supply is given through normally open Tie recloser in case the main supply become out in order to enhance the reliability improvement therefore due to this Tie reclosers supply power, the distribution reliability improved as following.

As the reliability indices shown in the table4.2, SAIDI is reduced to 140.3578hr per customer per year i.e. SAIDI is improved by 78.95% from the existing status and also SAIFI is reduced to 67.4682f per customers per year. I.e. SAIFI is improved by 80% from the existing status, EENS is reduced to 1999223Mwhr. per year and EENS is improved by 80%.

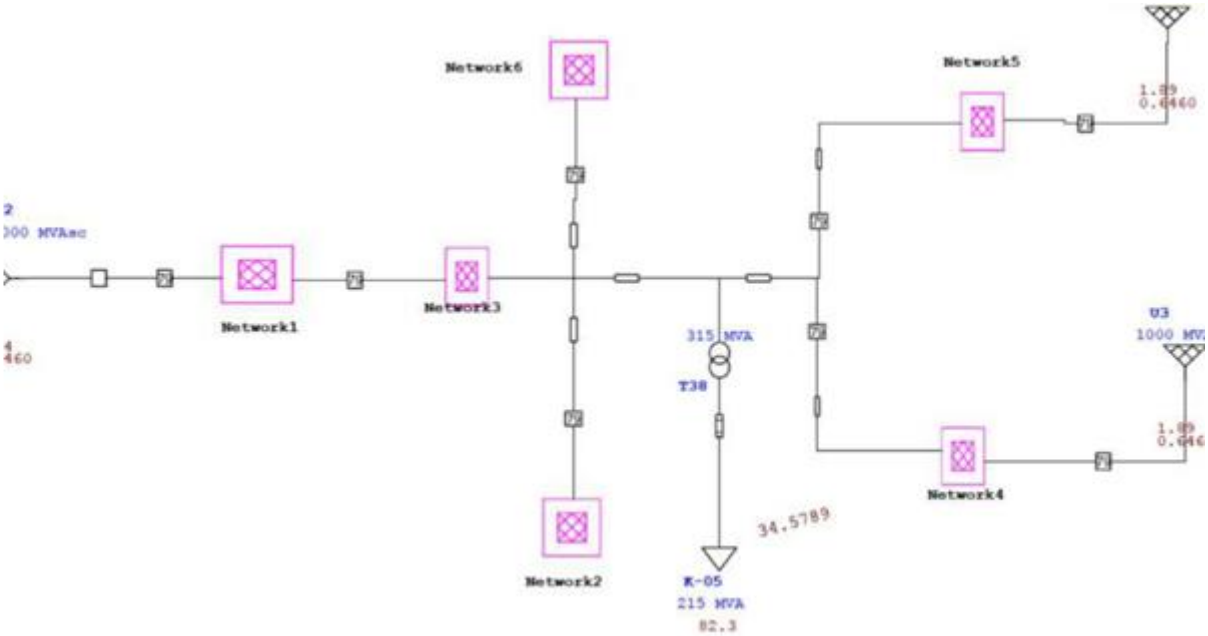


Figure 4.2Single line diagram of Bule hora feeder line 3 with each zone protected and Tie recloser for network-4 and 5

Table 4.3: Result of Reliability indices for Case 2

Summary System indexes	
Reliability indices	Result of analysis
AENS	24087.200 MWhr/customer.yr
ASAI	0.9840pu
ASUI	0.01602pu
CAIDI	2.080hr/customer interruption
EENS	1999223.000MWhr/yr.
SAIDI	140.3578hr/customer.yr
SAIFI	67.4682f/customer.yr

Case-3. <u>Tie circuit added on network 2 and on the network-6</u>

This zone of division found in the other direction of town, the feeder in this zone supply to different production Centre, small enterprises, healthy center and different organization. The feeder to this zone pas to uphill and also it is lengthy. The zone also protected by automatic recloser and supply alternative power through normally open Tie recloser to the feeder in order to enhance the feeder reliability improvement. The over all of the Bule hora feeder line 3 reliability indices are improved in this way and the improved result as following ways

As the reliability indices shown in the table4.3, SAIDI is reduced to 89.48hr per customer per year i.e. is improved by 86.58% from the existing status and also SAIFI is reduced to 58.101 f per customers per year. I.e. SAIFI is improved by 83% from the existing status, EENS is reduced to 1,308,381Mwhr. per year and EENS is improved by 86.97%.

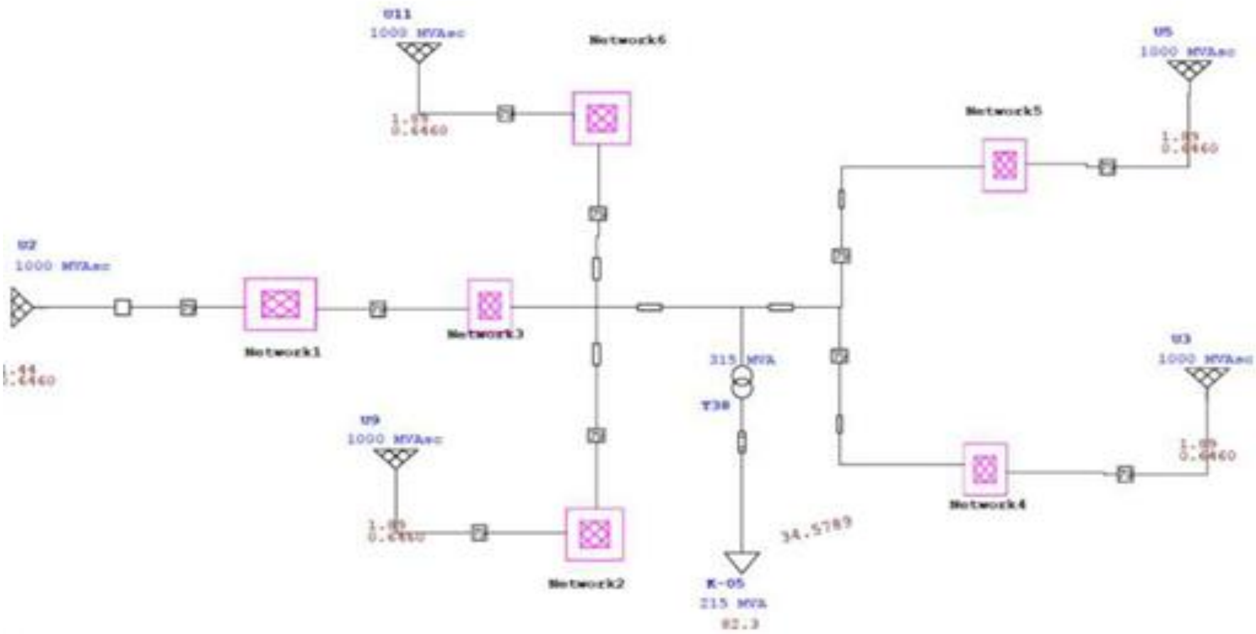


Figure 4.3 Single line diagram of Bule hora feeder line 3 with each zone protected and Tie recloser for network-2 and 6

Table 4.4: Result of Reliability indices for Case 3

Summary System indexes	
Reliability indices	Result of analysis
AENS	15575.7300 MWhr/customer.yr
ASAI	0.9898pu
ASUI	0.01021pu
CAIDI	1.540hr/customer interruption
EENS	1308361.00MWhr/yr
SAIDI	89.4822hr/customer.yr
SAIFI	58.1011f/customer.yr

Case-4 Applying Tie Switch in the all side of the division of zone and rural feeder

The Bule hora feeder Line-3 is divided in to six section/ zone and each zone is protected and controlled by electronic controlled reclosers. The switch placement in the DN of the zone on the downside lateral feeder has the advantage to reduce the impact of power outage to the customer in the zone instead of total power outage of the zone.

The switch placement to the lateral feeder and rural feeder line have the following effect. As the reliability indices shown in the table4.4, SAIDI is reduced to 48.857hr per customer per year i.e. SAIDI is improved by 92.66% from the existing status and also SAIFI is reduced to 38.96 f per customers per year. I.e. SAIFI is improved by 88.64%.

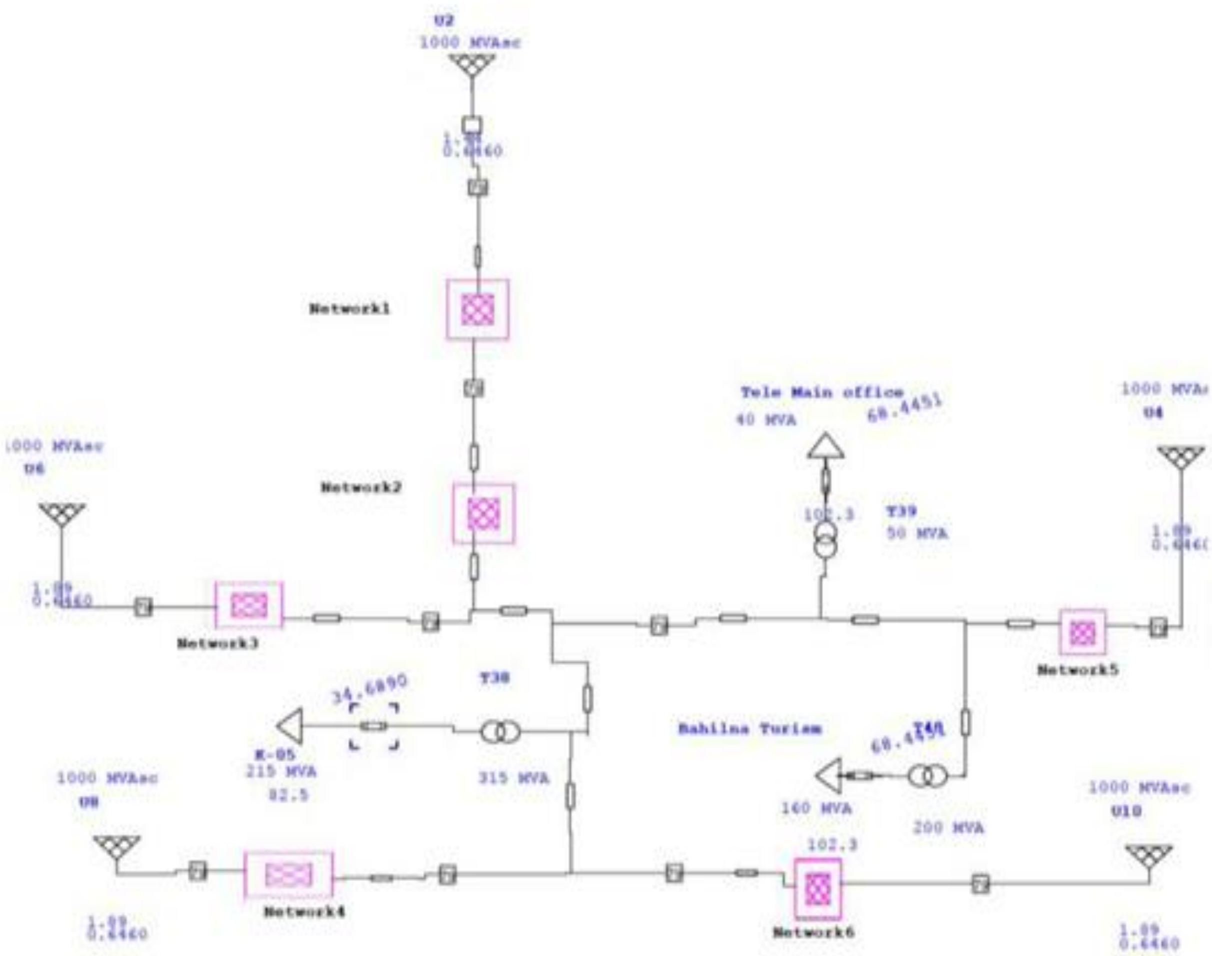


Figure 4. 4: Single Line diagram of Bule hora Line-3 with each zone protected reclosers and applying switches in each zone and Tie reclosers for network

Table 4.5: Result of Reliability indices for Case -4

Summary System indexes	
Reliability indices	Result of analysis
AENS	3.7418 MWhr/customer.yr
ASAI	0.9944pu
ASUI	0.00558pu
CAIDI	1.254hr/customer interruption
EENS	284,380MWhr/yr
SAIDI	48.8575hr/customer.yr
SAIFI	38.9464f/customer.yr

As can be seen from the Table 4.5, the Reclosers together with the tie switch enhanced significantly the reliability of the system. The expected number of outages per year per customer has been reduced from 666.890.0 to 38.9464(. SAIFI is improved by 88.64%} and the annual outage duration has been reduced from 341.808 to 48.857 hours (SAIDI is improved by 92.66%) has been improved as compared with the selected base years.

Table 4.6: Summary of the results of reliability enhancement for all Cases

Customer Oriented Reliability Indices	Cases				
	Existing System	Case 1	Case 2	Case 3	Case 4
SAIFI (f/customer/yr))	341.8082	124.7221	67.4682	58.101	38.96
SAIDI (hr/customer/yr.)	666.8905	268.9207	140.3578	89.48	48.85
CAIDI (hr/customer/Int.)	1.95	2.156	2.081	1.540	1.254
ASAI(pu)	0.9239	0.9693	0.9840	0.9898	0.9944
% Reduction in SAIFI	0	63.51	80	83	14
% Reduction in SAIDI	0	59.67	78.95	86.581	92.66

From the above Table 4.6, it was determined and concluded that the most effective alternative (case-4) for improving the power reliability of the study area was installing by Reclosers with tie switch at critically selected locations and permanently isolating the long and faulty line goes to another woreda from the Bule hora city feeder.

Table 4.7: Summary of the result of system energy oriented reliability enhancement for all Cases

Energy Oriented Reliability Indices	Cases				
	Existing System	Case 1	Case 2	Case 3	Case 4
EENS (MWhr/yr	10,037,460.0	3,901,796	1,999,223	1,308,381	284,380
ECOST (Ebirr/yr)	5,252,602.81	3,210,795.58	1,044,194.1729	683,367.3	148,531.674
% Reduction in EENS	0	61.12	80	86.96	97.16

In addition to the system configuration Scheduled preventive protection, additional rehabilitation works on entire parts of the system, enhancing manpower problems, control strategy and solve other related problems will have a great role in the system reliability enhancement.

4.6. Interlocking and Switching Sequence Operation of Protective Devices

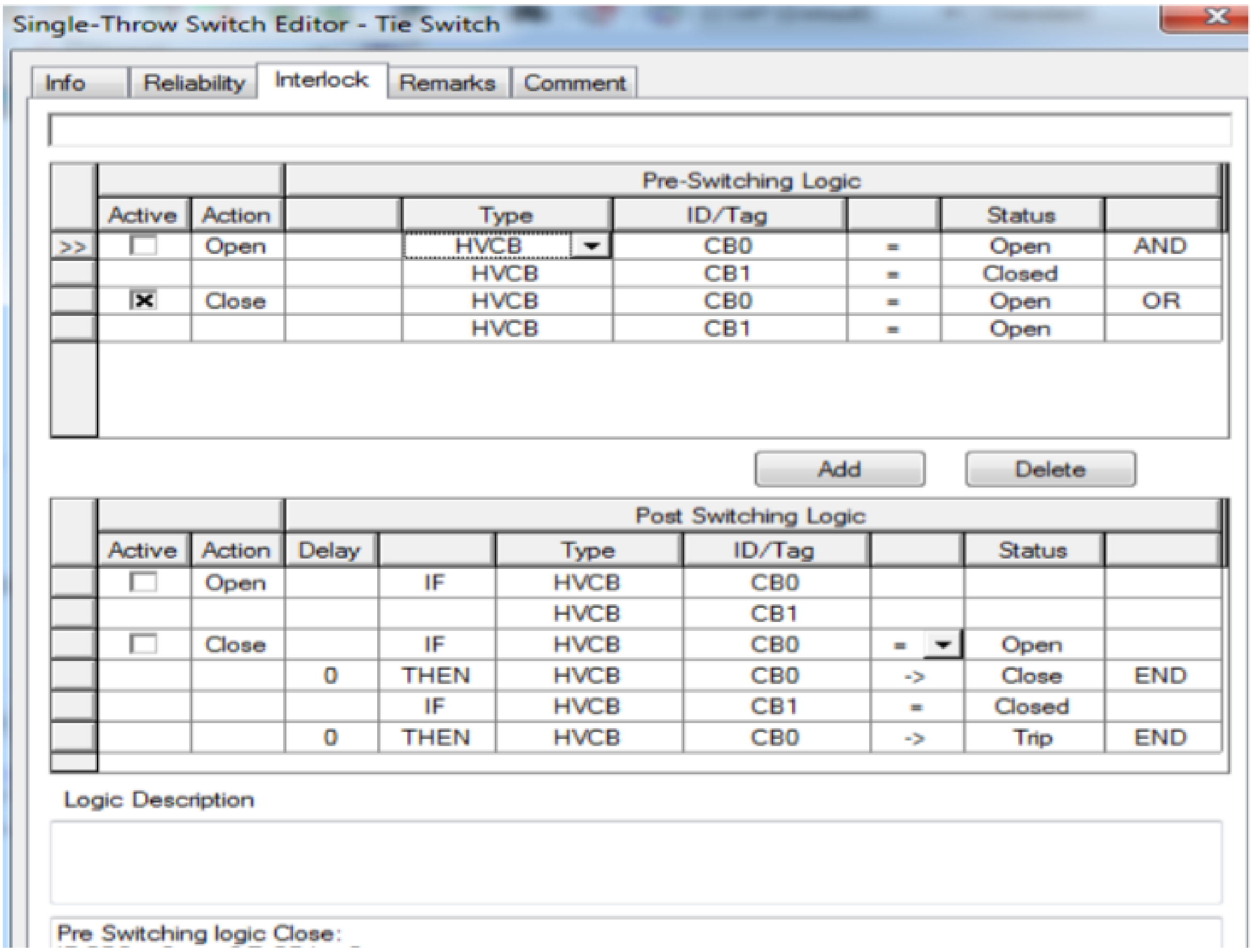
Interlocking among protection devices may be implemented mechanically, electrically or in other ways. These are mainly used to keep service continuity and maintain the overall safety of the system.

For a fault occurred anywhere in the system, each circuit breaker that has the same fault current flowing through it may detect different amounts of fault current as a result of varying sensitivities and tolerances. When the fault occurs, the protection device closest to the fault should operate first to stop and isolate the faulty circuit.

To accommodate for the varying tolerances and to ensure that multiple protection devices do not unnecessarily trip based on the same fault current, the protection devices should be interlocking to each other based on their settled currents and time [17].

A switching sequence is a series of status changes of switching devices (switches and circuit breakers) to accomplish a specific task, such as transferring loads from one source to another, energizing/de-energizing loads, de-energizing a piece of electric equipment (i.e. transformers or bus) for maintenance. With this tool, you can simulate system behavior and study the effect of the switching sequence before it is actually implemented in the real world.

Table 4.8: Interlocking between CB1, CB1 and Tie switch



	Active	Action		Type	ID/Tag		Status	
>>	☐	Open		HVCB	CB0	=	Open	AND
				HVCB	CB1	=	Closed	
	☒	Close		HVCB	CB0	=	Open	OR
				HVCB	CB1	=	Open	

Pre-Switching Logic

	Active	Action	Delay		Type	ID/Tag		Status	
	☐	Open		IF	HVCB	CB0			
					HVCB	CB1			
	☐	Close		IF	HVCB	CB0	=	Open	
			0	THEN	HVCB	CB0	->	Close	END
				IF	HVCB	CB1	=	Closed	
			0	THEN	HVCB	CB0	->	Trip	END

Post Switching Logic

From the Table 4.8, it is clearly observed that the interlocking among the substation circuit breakers and the Tie switch; so that the tie switch should not close unless one of the two breakers are open. This implies that the three switches never be closed at the same time as the two substations are not synchronized to feed the same load at a time.

4.7 Economical Cost Analysis

In this thesis, an economical cost analysis has been done based on the interruption cost only related to the utility side by using Expected Energy Not Supplied (EENS) of each Cases. For case-1, annual average unsold energy is reduced from 10,037,460 to 3,901,796 MWh per year as shown in Table below. Therefore, the revenue saved due to reliability improvement can be estimated as follows.

The Revenue loss before improvement due to unsold energy is:

10037460.0Kwhr/yr.*0.5233birr/kwh= 5,252,602.81Birr

For Case-1; The Revenue saved after enhancement due to unsold energy is:

$$\frac{(10037460 - 3901796)KWh}{\text{year}} * \frac{0.5233\text{birr}}{\text{kwh}} = \frac{3210792.971\text{birr}}{\text{year}}.$$

The investment cost can be calculated by using the cost of one outdoor high voltage recloser used to design the system in Case-1. The average cost of one Recloser is 15,000 (USD) [29]. Based on the exchange rate of the Commercial Bank of Ethiopia (CBE) on 24-Feb2021, (l USD= 46.01 ETB), the cost of one 15 KV, 800A pole mounted outdoor Recloser is: 15,000 x 46.01 = 690,150ETB.

Investment cost= 6*690,15=4,140,900ETB

The Payback period is used as an important factor to evaluate the economic competiveness of the respective Cases. The Payback period is the period or length of time required to recoup the cost expended in an investment. It is the ratio of the cost of investment to the annual saving by using that investment

$$\text{Payback period} = \frac{\text{Investment Cost}}{\text{Annual Revenue saved cost}}$$

Thus, For Case-1; the payback period is:

$$\text{Payback period} = \frac{4141440}{3210792.971} = 1.23 \text{ years payback time}$$

For Case-2: Annual Revenue saved cost after improvement is

$$\frac{(10037460-1999223)KWh}{\text{year}} * \frac{0.5233\text{birr}}{\text{kwh}}=4206409.422\text{ETB/year}$$

Investment cost= 8 x 15,000 x 46.01= 5521920 ETB

Payback period= $\frac{5521920}{4206409.422}$=1.31years payback time

In Case-2, the payback period shows that it takes 1.98 years to get back the investment cost and the reliability indices SAIFI and SAIDI have been reduced by 80% and 78.95% respectively.

For Case-3: Annual Revenue saved cost after improvement is

$$\frac{(10037460-1308381)KWh}{\text{year}} * \frac{0.5233\text{birr}}{\text{kwh}}=4567927.041\text{ETB/year}$$

Investment cost= 10 x 15,000 x 46.01= 6902400 ETB

Payback period= $\frac{6902400}{4567927.0411}$=1.51years payback time

Hence, the payback period indicates that it takes 1.51 years to get back the investment cost. In this case, the reliability indices SAIFI and SAIDI have been reduced by about 83%and 86.5% respectively.

For Case-4: Annual Revenue saved cost after improvement is

$$\frac{(10037460-284380)KWh}{\text{year}} * \frac{0.5233\text{birr}}{\text{kwh}}=5103786.764\text{ETB/year}$$

The average cost of recloser and tie switch is equal, means (15000 USD) and also

Investment cost= 11 x 15,000 x 46.01= 6902400 ETB=7592640ETB

Payback period= $\frac{7592640}{5103786.764}$=1.48years payback time

Hence, the payback period indicates that it takes 1.48 years to get back the investment cost. In this Cases, the reliability indices SAIFI and SAIDI have been reduced by about 88.58%and 92.66% respectively.

Table 4.9: Summary and comparison of payback periods for all the cases

Energy Oriented Reliability Indices	Cases				
	Existing system	Case-1	Case-2	Case-3	Case-4
EENS (MWhr/yr	10,037,460.0	3,901,796	1,999,223	1,308,381	284,380
Interruption Cost (ETB)	5,252,602.81	2041809.847	1,044,194.1729	683,367.3	148,531.674
Investment Cost (ETB	0	4141440	5521920	6902400	7592640
Annual Revenue Saved (ETB		3210792.971	4206409.422	4567927.041	5103786.764
Payback Period (year)	0	1.23	1.31	1.51	1.48

Table 4.9 reveals that the payback period of Case-1, 2, and 3 is small as compared with the scenario-4, but as clearly shown in above, the percentage reduction for SAIFI and SAIDI compared with the selected base years is minimum.

When coming to scenario four the percentage reduction for SAIFI and SAIDI is about 80 percent as compared to the existing system, but the payback period is not good as case 4. Case-4 has enhanced the reliability of the system very well and the payback period is only 1.48 years.

Table 4.10 below shows the comparison of the most commonly used reliability indices (SAIFI and SAIDI) of Bule hora city feeder, with the requirements of the Ethiopian Electric Agency (EEA) and the best-experienced countries in the world. As it is observed from Table 4.5, the SAIFI and the SAIDI have been improved by 86% and 85.4% respectively as compared with the base year's values.

Table 4.10: Summary and comparison of reliability indices values with benchmark country

Country		SAIFI	SAIDI
United State		1.5	4
Australia		0.9	1.2
France		1	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
Bule hora Feeder line 3	Existing	314.8082	666.896
	Case:-1	124.7	268.9207
	Case:2	67.46	140.3578hr
	Case:-3	58.1.1011	89.48
	Case:-4	38.96	48.857hr

CHAPTER FIVE

5. Conclusion and Recommendation

5.1. Conclusion

Based on the results of this research work, the reliability of the Bule Hora city power distribution system does not meet the requirements set by the regulatory body that is, Ethiopian Electric Agency (EEA). The average frequency of interruptions of Bule Hora city present feeder is 666.890 interruptions per customer per year and the average duration of interruptions is 341.8082 hours per customer per year. And also, the reliability of Bule Hora city power distribution system is not good enough as compared to the international reliability indices of best experienced countries such as Germany.

In this thesis different Distribution model proposed and analyzed. As above simulation result shows all Distribution models have different Reliability improvement contributions with 1.23 to 1.48 payback investment cost. All cases are tolerable in terms of investment cost. The existing Bule hora feeder line 3 data analysis gives SAIDI, SAIFI, EENS, etc. which are equal to 666.8905hr/cust/yrs, 341.8082f/cust. /yrs., and 10,037,460Mwh/yrs. respectively. This results have been compared to the bench marking, it is extremely large hence this provides that there is great reliability problem in the Bule hora feeder line 3. In general, the result shows that the Bule hora feeder line 3 is unreliable.

This thesis has been dividing the existing DN in to manageable area/zone and apply DA technology for protection of each zone using automatic recloser integrating with Tie switching recloser to the zone of the feeder node and use manual switch for different lateral feeder and rural feeder line in the zone for location of fault feeder and also restored by alternative supply through Tie switching mechanism from adjacent healthy feeders. These enhance the distribution reliability improvement and satisfy the customer by reducing outage impact, duration and frequency of power interruption.

This thesis considered four case studies, from these case study, using Number of reclosers, Tie switching circuit, and switching load isolation method in the case fault occurred in the division zone enhance the reliability of the Bule hora feeder line 3. From this point of view, SAIFI, SAIDI, is reduced to 38.96 f/cust/yrs, 48.4822hrs/cut/yrs i.e. they improved 83% and

86.58% respectively and also EENS is reduced to 1,308,361Mwhrs/yrs i.e. it also improved by 86.97%. In other word, the utility will get 8729,099 MWhrs/yrs is available for soled because of this method of improvement in addition to the ordinary sold. This increases the income of the utility.

5.2. Recommendations

The Ethiopian Electric Utility (EEU) should work to improve the reliability of the power distribution system at Bule Hora city. The existing DN should be modernized to meet the reliability standards. Based on this thesis result, it is possible to assured that using protection device along the feeder line can enhance the reliability of the existing power distribution system. But, it is not enough to meet requirement of the Ethiopian Electric Agency (EEA). To meet this requirement, it is necessary to reduce causes of faults in this city. This can be done by tree trimming, scheduled Inspection of Poles and Conductors clearance, scheduled preventive maintenance to poles and conductors, inspection of distribution transformers and conduct regular changing of oil.

5.3. Future Works

Here the thesis work is done for the reliability improvement with only Bule hora feeder line. The reliability assessment can be extended to:

- The reliability assessment of the whole part of the outgoing feeders.
- Technical and non-technical losses.
- Maintenance optimization of the distribution system.
- On the design aspect of the distribution system.
- Distribution automation separately by different researchers.

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APPENDIX A

Bule hora substation interruption frequency and duration in 2009E.C.

Month	Outage in number	Feeder Name		
		Feeder line 1	feeder line 2 2	Feeder line 3
September	Freq.	39	73	47
	Dur(Hr.)	66.68	68.865	42.875
October	Freq.	34	47	25
	Dur(Hr.)	24.462	50.625	38.641
November	Freq.	29	32	36
	Dur(Hr.)	44.618	47.6	47.798
December	Freq.	44	49	55
	Dur(Hr.)	48.272	71.688	84.299
January	Freq.	27	47	30
	Dur(Hr.)	53.733	47.698	47.605
February	Freq.	23	53	33
	Dur(Hr.)	15.772	36.53	33.917
March	Freq.	31	59	29
	Dur(Hr.)	23.384	72.149	26.884
April	Freq.	23	46	36
	Dur(Hr.)	49.269	52.059	35.511
May	Freq.	29	72	27
	Dur(Hr.)	17.466	56	15.4
June	Freq.	32	44	28
	Dur(Hr.)	181.852	186.887	37.733
July	Freq.	27	37	25
	Dur(Hr.)	16.843	86.063	25.67
August	Freq.	26	38	23
	Dur(Hr.)	20.2	18.53	33.53
Total		364	597	394
		562.5512	794.694	469.863
Total interruption frequency				
Total interruption duration				

Bule hora substation interruption frequency and duration in 2010 E.C.

Month	Outage in number	Feeder Name			
		Feeder line 1	Feeder line 2	Feeder line 3	
September	Freq.	36	32	29	
	Dur(Hr.)	70.935	35.06	23.633	
October	Freq.	26	24	29	
	Dur(Hr.)	58.47	21.322	30.016	
November	Freq.	16	30	18	
	Dur(Hr.)	22.783	36.636	17.493	
December	Freq.	26	22	28	
	Dur(Hr.)	28.817	31.9	11.83	
January	Freq.	14	21	21	
	Dur(Hr.)	3.015	7.758	19.483	
February	Freq.	34	33	32	
	Dur(Hr.)	21.137	17.9	22.2	
March	Freq.	54	48	31	
	Dur(Hr.)	69.004	71.15	60.828	
April	Freq.	73	61	39	
	Dur(Hr.)	122.711	113.05	93.95	
May	Freq.	57	51	18	
	Dur(Hr.)	71.567	57.484	34.784	
June	Freq.	39	53	31	
	Dur(Hr.)	48.532	71.783	27.783	
July	Freq.	39	61	34	
	Dur(Hr.)	44.89	48.77	49.09	
August	Freq.	32	59	20	
	Dur(Hr.)	49.012	50.868	29.813	
Total	Freq.	446	495	330	
	Dur(Hr.)	610.224	563.681	420.903	
Total interruption frequency		1602			
Total interruption duration		2113.003			

APPENDIX B

***Frequency of interruption of type of faults* in 2009**

No	Fault type	Feeder Line-1		Feeder Line-2		Feeder Line-3	
		Aveg.Freq	Ave.Freq%	Aveg. Freq	Aveg.Freq%	Aveg. Freq	Aveg.Freq%
1	DPEF	26.66	7.069	47	8.61	18	5.2735
2	DPSC	42	11.132	58.66	10.75	28.667	8.3986
3	DTEF	25.66	6.802	91.33	16.74	23.667	6.3986
4	DTSC	83	21.99	100.67	18.45	28.33	8.299
5	TLP	3	0.795	3	0.55	3	0.8789
6	SOL	39.667	10.51	47	8.61	42	12.305
7	GUP	32	8.48	32	5.864	32	9.375
8	OP	125.33	33.215	166	30.42	165.66	48.535
TOT		377.33	100%	545.66	100%	3341.33	100%

***Duration of interruption of type of faults* in 2010**

No	Fault type	Feeder Line-1		Feeder Line-2		Feeder Line-3	
		Falt dur Aveg Dur	Cont int Dur %	Falt dur Aveg Dur	Cont int Dur %	Falt dur Aveg Dur	Cont int Dur %
1	DPEF	86.756	15.74	93.94	14.85	41.93	10.305
2	DPSC	149.81	27.184	144.078	22.7	77.125	18.95
3	DTEF	6.235	1.132	11.183	1.769	2.85	0.701
4	DTSC	7.612	1.138	54.941	8.689	5.773	1.41
5	TLP	18.883	3.426	18.883	2.891	18.88	4.64
6	SOL	103.15	18.718	125.258	19.81	109.54	26.922
7	GUP	46.82	8.49	46.825	7.405	46.825	11.502
8	OP	131.82	23.92	137.171	21.694	103.95	25.54
TOT		551.113	100%	632.13	100%	406.88	100%

Three years' average interruption Frequency of faults

No	Fault type	Feeder Line-1		Feeder Line-2		Feeder Line-3	
		Aveg.Freq	Ave.Freq%	Aveg. Freq	Aveg.Freq%	Aveg. Freq	Aveg.Freq%
1	DPEF	26.66	7.069	47	8.61	18	5.2735
2	DPSC	42	11.132	58.66	10.75	28.667	8.3986
3	DTEF	25.66	6.802	91.33	16.74	23.667	6.3986
4	DTSC	83	21.99	100.67	18.45	28.33	8.299
5	TLP	3	0.795	3	0.55	3	0.8789
6	SOL	39.667	10.51	47	8.61	42	12.305
7	GUP	32	8.48	32	5.864	32	9.375
8	OP	125.33	33.215	166	30.42	165.66	48.535
TOT		377.33	100%	545.66	100%	3341.33	100%

APPEDIX- C

Questionnaires about causes of power interruptions on Bule hora utility Power distribution network

The purpose of this document is to provide an outline of preliminary information that will be used by the thesis work done in the School of Electrical and Computer Engineering, -Hawass University**.**

This study is a part of partial fulfillment of the requirements for the Degree of Masters of Science in Electrical and Computer Engineering program in Hawassa Institute of Technology Hawassa University. The area of the research is selected on studies of power system reliability Assessment and Enhancement in Bule hora utility.

The aim of this questionnaire is for gathering relevant data in relation to Assessment of Power Interruption in Bule hora distribution system specially on Bule hora feeder line 3, for the purpose of identifying the root cause of power interruptions and to propose proper mitigation solutions for those potentially identified problems and to suggest recommendations to the concerning bodies.

Interview questionnaires for Bule hora Utility workers

1. In which areas of responsibility you involved?
2. What is your educational level?
3. How many your work experiences on the current responsibility of work you involved?
4. What is the main cause of power interruption on the Bule hora feeder line 3?
5. Explain each cause of power interruption and put the degree of the difference in their cause level.

6. How you are relates the cause of power interruption with a types of fault recorded in Bule hora substation example

- DPEF
- DPSC
- DTEF
- DTSC
- DLOL
- OP
- TLP
- SOL

7. What are your reasons for prolongation of the power outage durations?

8. If you have any suggestion about the solutions of the power interruption problems in Bule hora town power distributions system, Bule hora feeder line 3, please specify it

APPEDIX- D

Line Data for Bule hora Feeder Line-3

Equipment ID	From Element ID	To Element ID	Cable Length in meter
Cable12	Bus 162	Bus140	300
Cable20	Bus134	Bus137	100
Cable21	Bus241	Bus247	50
Cable22	Bus125	Bus132	90
Cable24	Bus252	Bus250	200
Cable25	Bus254	Bus245	100
Cable26	Bus245	Bus248	20
Cable27	Bus257	Bus245	420
Cable28	Bus258	Bus263	100
Cable29	Bus162	Bus168	80
Cable30	Bus259	Bus264	35
Cable31	Bus260	Bus262	500
Cable32	Bus350	Bus352	410
Cable33	Bus351	Bus354	250
Cable34	Bus227	Bus224	280
Cable35	Bus228	Bus226	75

APPEDIX- E

Transformer data with its load rating of Bule hora Feeder Line-3

Equipment ID	Primary Element ID	Secondary Element ID	Rated Power in MVA	Primary Voltage in KV	Secondary Voltage in KV	Load in MVA
T14	Bus24	Bus23	100	15	0.38	80
T15	Bus26	Bus25	315	15	0.38	252
T16	B-25	Bus28	200	15	0.38	0.38 160
T17	Bus30	Bus29	630	15	0.38	504
T18	Bus32	Bus31	50	15	0.38	30
T19	Bus35	Bus34	315	15	0.38	251
T20	B-28	Bus36	315	15	0.38	252
T21	Bus38	Bus37	315	15	0.38	252
T22	Bus40	Bus39	50	15	0.38	30
T23	Bus42	B-30	100	15	0.38	80
124	B-32	Bus43	315	15	0.38	252