An Investigation of Power System Reliability Problem in Distribution Network (The Case of Bale Robe Town Distribution Sub Station)

Jemal Adem Abda

A Thesis Submitted to

The Department of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Masters of Science Degree in Electrical Power and Control Engineering (Electrical Power)

Office of Graduate Studies

Adama Science and Technology University

July, 2020

Adama, Ethiopia

An Investigation of Power System Reliability Problem in Distribution Network (The Case of Bale Robe Town Distribution Sub Station)

Jemal Adem Abda

Advisor:

Milkias Berhanu (PhD)

A Thesis Submitted to

The Department of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Masters of Science Degree in Electrical Power and Control Engineering (Electrical Power)

Office of Graduate Studies

Adama Science and Technology University

July, 2020

Adama, Ethiopia

Approval Sheet

This is to certify that the thesis prepared by **Jemal Adem Abda** entitled '***An Investigation of Power System Reliability Problem in Distribution* Network: The Case of Bale Robe Town Distribution Sub Station**' and submitted in the fulfillment of the requirements for the Degree of Master of Science in Electrical Power Engineering compling with the rules and regulations of the University by meeting the accepted standards with respect to original quality.

Jemal Adem	____________	____________
Name of Student	Signature	Date
Dr. Milkias Berhanu (Ph.D.)	____________	____________
Advisor /Supervisor/	Signature	Date
____________________	____________	____________
External Examiner	Signature	Date
______________	____________	____________
Internal Examiner	Signature	Date
______________	____________	____________
Chair Person	Signature	Date
____________________	____________	____________
Head of Department	Signature	Date
______________	____________	____________
School Dean	Signature	Date
________________	____________	____________
Postgraduate Dean	Signature	Date

Declaration

I hereby declare that this thesis entitled '***An Investigation of Power System Reliability Problem in Distribution*** **Network: The Case of Bale Robe Town Distribution Sub Station'** was composed by myself, with the guidance of my advisor, that the work contained here is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or professional qualification.

Jemal Adem	____________	____________
Name of Student	Signature	Date
Dr. Milkias Berhanu (Ph.D.)	____________	____________
Advisor /Supervisor/	Signature	Date

Acknowledgements

First of all, I would like to express thank ALLAH, the lord of the universe, for his mercy and limitless help and guidance.

Secondly, I would like to express my profound appreciation to my advisor Dr. Milkias Berhanu for his support and guidance that contributed to the successful completion of this thesis.

And also, I would like to thank those workers of EEU at Robe town of distribution substation help me to collect the data from the organizations. The others are Dr. Molla Biweta and Mr. Ashaber Berhanu (Staff member at Adama Science and Technology University) for supporting me.

Finally, I would like to give special thanks to my beloved family specially my mother, father, my brothers Umar Adem, Awol Adem (Ph.D. Candidate), Dr. Kemal Adem and all of my friends who always help me by giving motivation, financial supports, comments, technical supports and sharing me their ideas. They have great contribution for the preparation of this study in desired way.

Table of Contents

Approval Sheet i
Declaration ii
Acknowledgements iii
Table of Contents iv
List of Tables vi
List of Figures vii
Abbreviations ix
List of Symbols xi
Abstract xii
CHAPTER ONE 1
INTRODUCTION 1
1.1 Background of the Study 1
1.2 Electrical Distribution System 3
1.3 Statement of the Problem 4
1.4 Objectives of the Study 5
1.4.1 General Objective 5
1.4.2 Specific Objective 5
1.5 Significance of the Study 6
1.6 Scope (delimitation) of the Study 6
1.7 Operational Definition of Key Terms 6
1.8 Organization of the Study 6
CHAPTER TWO 7
REVIEW OF RELATED LITERATURE 7
2.1 Theoretical Background 7
2.2 Literature Review 8
2.3 Power Distribution Network System 10
2.4 The Classification of Electrical Distribution Systems Based on Construction 10
2.4.1 Overhead Distribution Line Systems 11
2.4.2 Underground Line of Distribution System 11
2.5 Elements of the Distribution System 12
2.5.1 Distributed Feeders 12
2.5.2 Distributor 15
2.5.3 Service mains 15
2.6 Sub-Division of Power System Reliability 16
2.7 The Structure of Electrical Power System 18
2.7.1 Power Generation 18
2.7.2 Transmission Line 18
2.7.3 Distribution Substations 19
2.8 Power System Reliability Evaluation 23
2.9 Power Quality, Reliability and Availability 24
2.9.1 Power Quality 25
2.9.1.1 Problem Associated with Power Quality 26

2.9.1.2 From Where power quality problems come from 28
2.9.2 Reliability of Power System 28
2.9.3 Power Availability 29
2.10 The Basic Distribution System Reliability Indices Calculation 30
2.11 Practices of Reliability and Power Quality of Distribution Systems Network 34
2.11.1 The Practice Reliability of Power Distribution System 34
2.11.2 The Practice of Power Quality of Distribution Systems Network 35
2.12 The Challenges of Reliability Distribution Network Town Line Feeder Interruption 35
2.13 Interruption Factors 37
CHAPTER THREE 40
METHODOLOGY 40
3.1 Research Methods of Collection Data 40
3.2 Data Source 41
3.2.1 Primary Sources of Data 41
3.2.2 Secondary Sources of Data 41
3.3 Research Design 41
3.4 Feasibility Study on Reliability Analysis 42
3.5 Design of Distribution Network 43
3.6 The Design Procedures in Electric Distribution 43
3.6.1 Design of Medium Voltage Network System 43
3.6.2 Design of Conductors and Cables 44
3.7 Design of Low-voltage network 44
3.7.1 Design Low-voltage network Required information 45
3.7.2 Location of the Transformers 46
3.7.3 Determination of Line Routes 46
3.8 Loads and Measurements 46
3.9 Line Route Selection 46
3.10 Description of the Study Area 47
CHAPTER FOUR 48
DATA COLLECTION ANALYSIS AND INTERPRETATION 48
4.1 Background of Data Collection 48
4.2 Monthly Interruption Frequency and Duration of Interruption 48
4.3 Depending on Data Collected the Analytical Method of Reliability Indices Evaluation and Analysis 51
4.4 The Loss of Revenue Before and After Improvement in Bale Robe Town Distribution Substation due to Power Interruption 63
4.5 The Technique of Reliability Improvement of the Distribution system 64
CHAPTER FIVE 72
CONCLUSIONS AND RECOMMENDATIONS 72
5.1 Conclusions 72
5.2 Recommendations 73
References 74
Appendixes 79

List of Tables

Table.4. 1: The average reliability indixes of south east (Robe town) substation with out Recloser and other protective device. 67
Table.4. 2: The average reliability indixes of south east (Robe town) substation with Recloser and other protective device 67
Table.4. 3: Reliability indices standards of different countries [19] 67

List of Figures

Fig.1. 1: Single Line Diagram of Bale Robe Substation Layout 4
Fig.2. 1: Elements of Distribution System 16
Fig.2. 2: Tie Feeder 17
Fig.2. 3: Loop Feeder 18
Fig.2. 4: Radial Feeder 18
Fig.2. 5: Parallel Feeder 19
Fig.2. 6: Subdivision of System Reliability 22
Fig.2. 7: The block diagram Functional zones of a power system 25
Fig.2. 8: The grading of power quality, reliability, and availability was shown in [27]. 29
Fig.2. 9: The block diagram of Major Causes of interruption 44
Fig.3. 1: The block diagram of thesis methodology... 45
4. 1: Monthly interruption frequency and duration of interruption for the year 2007 E.C /2015 G.C 54
Fig.4. 2: Monthly interruption frequency and duration of interruption for the year 2008 E.C/2016 G.C 54
Fig.4. 3: Monthly interruption frequency and duration of interruption for the year 2009 E.C/2017 G.C 55
Fig.4. 4: Monthly interruption frequency and duration of interruption for the year 2010 E.C/2018 G.C 56
Fig.4. 5: Monthly interruption frequency and duration of interruption for the year 2011 E.C/2019 G.C 56
Fig.4. 6: Monthly interruption frequency and duration of interruption for the year 2012 E.C/2020 G.C 57
Fig.4. 7: Five years SAIFI (int/cust/yrs) and SAIDI (hr/cust/yrs) value of Goba Feeder Line. 58
Fig.4. 8: Five years CAIFI (int/cust) and CAIDI (hr/int) value of Goba Feeder Line 59
Fig.4. 9: Five years ASAI and ASUI value of Goba Feeder Line 59
Fig.4. 10: Five years SAIFI (int/cust/yr.) and SAIDI (hr/cust/yr.) value of Agerfa Feeder Line 60
Fig.4. 11: Five years CAIFI (int/customer) and CAIDI (hr/int) value of Agerfa Feeder Line 61
Fig.4. 12: Five years ASAI and ASUI value of Agerfa Feeder Line 61
Fig.4. 13: Five years SAIFI (int/cust/yr.) and SAIDI (hr/cust/yr.) value of Sinana Feeder Line 62
Fig.4. 14: Five years CAIFI (int/customer) and CAIDI (hr/int) value of Sinana Feeder Line 62
Fig.4. 15: Five years ASAI and ASUI value of Sinana Feeder Line 63
Fig.4. 16: Five years SAIFI (int/cust/yr.) and SAIDI (hr/cust/yr.) value of Gasera Feeder Line 63
Fig.4. 17: Five years CAIFI (int/customer) and CAIDI (hr/int) value of Gasera Feeder Line

.... 64
Fig.4. 18: Five years ASAI and ASUI value of Gasera Feeder Line 65
Fig.4. 19: Two years SAIFI (int/cust/yr.) and SAIDI (hr/cust/yr.) value of Madda Walabu University Feeder Line 65
Fig.4. 20: Two years CAIFI (int/customer) and CAIDI (hr/int) value of Madda Walabu University Feeder Line 66
Fig.4. 21: Two years ASAI and ASUI value of Madda Walabu University Feeder Line. 66
Fig.4. 22: The block diagram Design of system reliability improvement 70
Fig.4. 23: Robe Town Distribution of Sinan feeder on ETAP software with Recloses…. 72
Fig.4. 24: Simulation result of Sinana feeder on ETAP software with Recloses 73
Fig.4. 25: Robe Town Distribution of Agerfa feeder on ETAP software with Recloses 74
Fig.4. 26: Simulation result of Agerfa feeder on ETAP software with Recloses 75
Fig.4. 27: Robe Town Distribution of Goba feeder on ETAP software with Reclose 75
Fig.4. 28: Simulation result of Goba feeder on ETAP software with Recloses 75

Abbreviations

AC	Alternate current
AENS	Average Energy Not Supplied Index
ASAI	Average Service Availability Index
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
CB	Circuit breaker
CII	Customer Interrupted per Interruption Index
DF	Diversity Factor
DPEF	Distribution Permanent Earth Faults
DPSC	Distribution Permanent Short Circuit
DTEF	Distribution Transient Earth Faults
DTSC	Distribution Transient Short Circuit
E.C	Ethiopian Calendar
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
ENS	Energy Not Supplied Index
ETAP	Electrical Transient Analyzer Program
EPR	Ethylene Polymer Rubber
Hr	Hour
HTL	High Tension Line
IEEE	Institute of Electrical and Electronics Engineers
KM	Kilo Meter
KV	Kilo Volt
KVA	Kilo Volt Ampere
KWH	Kilo Watt Hour
La(i)	Average Load at Load Point i
LF	Line Feeders

MVA	Mega Volt Ampere
MWH	Mega Watt Hour
OP	Operational
LTL	Low Tension Line
R	Recloser
RMS	Root Mean Square
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
XLPE	Cross Line Polyethylene

List of Symbols

Nci	Individual feeders number of customer interrupted
Ni	Total number of customer interrupted
NT	Total number of customer served
No	Total Number of Customer Interruptions/Affected
ri	Restoration time
T	Time period
Ui	Annual Outage Time at Load Point
Yr	Year
$\sum$	Summation Function

Abstract

A power system is a system which requires high reliability and power quality due to high system infrastructure investment and failure cost. Even though the reliable and quality electric power supply is essential to modern society, the extensive use of electricity is led to a high sensitivity to power failures. More than 85% of all customer interruptions occur due to failures in the distribution system. Based on the results of this thesis, the reliability of the Bale Robe town power distribution system does not meet the requirements set by the Ethiopian Electric Agency (EEA). As per the thesis result analysis, the average frequency of interruptions per customer per year (int/cust/yr.) of Bale Robe town at the current feeders for Goba, Agerfa, Sinana, Madda Walabu University (MWU) and Gasera is found to be 259 int/cust/yr., 253 int/cust/yr., 217 int/cust/yr., 3 int/cust/yr. and 557 int/cust/yr. respectively. In connection, the average duration of interruptions (hr/cust/yr) of Goba, Agerfa, Sinana, MWU and Gasera feeders were found to be 175.56 hr./cust/yr., 209.92 hr./cust/yr., 230.90 hr./cust/yr., 1.1 hr./cust/yr. and 1011.8 hr./cust/yr. respectively. In this regard, it can be seen that a Bale Robe town distribution system reliability violates the requirements set by EEA in which System Average Interruption Frequency Index (SAIFI) is supposed to be below 20 and System Average Interruption Duration Index (SAIDI) is below 25 hr./cust/yr. This interruption indexes are also validated against other countries requirements. In addition, the thesis models the power distribution system network under the case study and carries out its analysis with brief discussions. Furthermore, the reliability indices improvement techniques reliability for the proper protection coordination was recommended.

Mainly, the distribution system network planning and its design are done in the thesis work in order to minimize and improve the indices so that the effect on customers connected to the feeders can be minimized.

Finally, by implementing the developed model using ETAP software, the overall reliability of the first three feeders of the Goba, Agerfa and Sinana power distributions were improved by 99.5%, 71.75% and 47.4% for SAIFI, SAIDI and ENS respectively.

Key words: ETAP, Electrical Distribution System, Reliability, Reliability indices

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

The performance and reliability study in power systems is very important to the utilities as well as to the country as it could be used for many decisions making in the development of the system and increasing the end user satisfaction. Improving reliability and quality of supply in a demanding and competitive business environment is one of the most challenging tasks for power utilities today. Reducing the number and duration of power outages and limiting the number of affected customers were important steps toward this goal [1].

The economic and social effects of loss of electric service in Ethiopia have significant impacts on both the utility supplying electric energy and the customer of electric service. The cost of a major power outage confined to one distribution system can be on the order of millions of dollars. If a major power outage affects multiple distribution systems of customer services, then the expected interruption cost can exceed million dollars. Ethiopia electric power system is vulnerable to system abnormalities such as control failures, protection or communication system failures, transmission line failures, poor maintenances and disturbances, such as lightning, grounding, system overload and human operational errors. Therefore, maintaining a reliable power supply to the customer service is very important issue for power systems design and operation of Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU) [1].

Power distribution network system established mainly to provide adequate electricity supply to customers as economically as possible with reasonable assurance of reliability. Nowadays, the power distribution networks have grown exponentially in term of size and technology over the past few years. As a result, utility must strive to ensure that the customer’s reliability requirements are met with optimum strategic planning and the lowest possible cost. The ability of the system to provide adequate supply of electricity energy determine by the term reliability. Reliability analysis of distribution network is not a new topic in electric power [2].

Over the past, distribution network system has received less attention devoted to reliability studies compared to generation and transmission system [1]. The reasons being the generation and transmission systems are capital intensive and the inadequacy can have wide spread consequences for both society and environment. However, a distribution system is slightly cheaper compare to the generation and transmission is localized. Analysis of the customer failure statistics of most utilities shows that distribution system makes the greatest individual contribution to the unavailability of electrical supply to customer [2].

It is very important to assess and evaluate the reliability of power system networks in order to obtain the most accurate and effective way in decision making especially in planning, construction, operation, and maintenance. Historical assessment and predictive methods are normally used to evaluate the reliability of a distribution network. Most utilities focus more on historical assessment rather than predictive methods. Reliability evaluation method for distribution system fall in to two classes: simulation and analytical [2].The Simulation is the most flexible method but require extensive time in computational and also uncertainty in precision. Analytical method can be further divided into network modeling and Markov modeling. Network modeling has been the most popular technique for distribution system reliability analysis due to the simplicity of the method and natural similarities between network model and the distribution topology. The difference between simulation and analytical method is the way in which the system reliability indices are evaluated. By applying both analytical and simulation method, the reliability indices for distribution systems have been determined such as System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI). The probability distribution of SAIFI and SAIDI which give information about the variability of the indices also need to obtain in order to improve in decision making [4].

When a utility reaches every customer with an electrical path of sufficient strength to satisfy the customer's demand for electric power, that electrical path must be reliable so that it provides an uninterrupted flow of stable power to the utility's customer. Reliable power means delivering all of the power demanded and doing so all of the time. Beyond the need to deliver power to the customer, the utility must also deliver it without having under-voltages, over-voltages or over-currents that were not tolerable by any piece of equipment in the system including customer equipment. Further, the voltage at the customer premise is required not to be below the nominal utilization voltage by more than a specified amount because most electrical equipment is designed to operate properly when supplied with acceptable voltages and currents [3].

Having a high power factor is almost as favorable as having in-range voltages and currents with regard to attaining good performance measures. Movement of power through any electrical device, will be it a conductor, transformer, regulator, etc., produces a certain amount of electrical loss due to impedance (resistance to the flow of electricity) of the device. These losses which are a result of the inevitable laws of nature create a cost to the utility. Electrical losses can be measured, assessed, and minimized through proper engineering, but never eliminated completely. The lower the loss, the more efficiently the system is said to be operating [2,3].

1.2 Electrical Distribution System

The distribution system is an important part that provides the final links between the utility and the customers. Most distribution systems in practice have a single circuit main feeder and are radially configured [3]. The radial distribution system is widely used because of it is simple design, generally low cost and supportive protection scheme. But the drawback of radially configured system is a reliability problem. For radial system the reliability in a distribution system can be improved by network reconfiguration, which is accomplished by closing normally open switches and opening normally closed switches [3,4].

The power distribution system is made up of transformers, poles, insulator, hook, wire and electrical protective devices. Distribution substations monitor and adjust circuits within the system. The distribution substations in Ethiopia medium distribution line voltages to 33 kV and 15 kV or less. The basic function of an electric power system is to supply customers with electricity. The continuity of energy supply can be increased by improve system structure, increased investment during the planning phase, operating phase or both [4].

The reliability is not enhanced without incurring additional cost. So it is evident the reliability of distribution system has been directly related cost invested on distribution system upgrading and periodical monitoring. Different country has been their own reliability standard, and our country Ethiopia has been also the reliability index for reliability improvement. Due to different cases distribution reliability decreases and customers are subjected to power interruption. Electric power distribution in Robe town is also not free from this problem. Even there are times that electric power interruption occurs several times a day, not only at the low voltage but also at the medium voltage distribution systems. This problem impacts social, economic development and individuals' life. In addition to this Robe town has a cold weather condition. The mean annual temperature of Robe town was about 23.5 °C. A single diagram of a 66 kV transmission line from Melkawekena Power Station to Bale Robe Town Distribution Substation where the study has been focused is shown in Fig.1. 1.

66 KV Line from Melkawekena Substation to Robe Town Distribution Substation

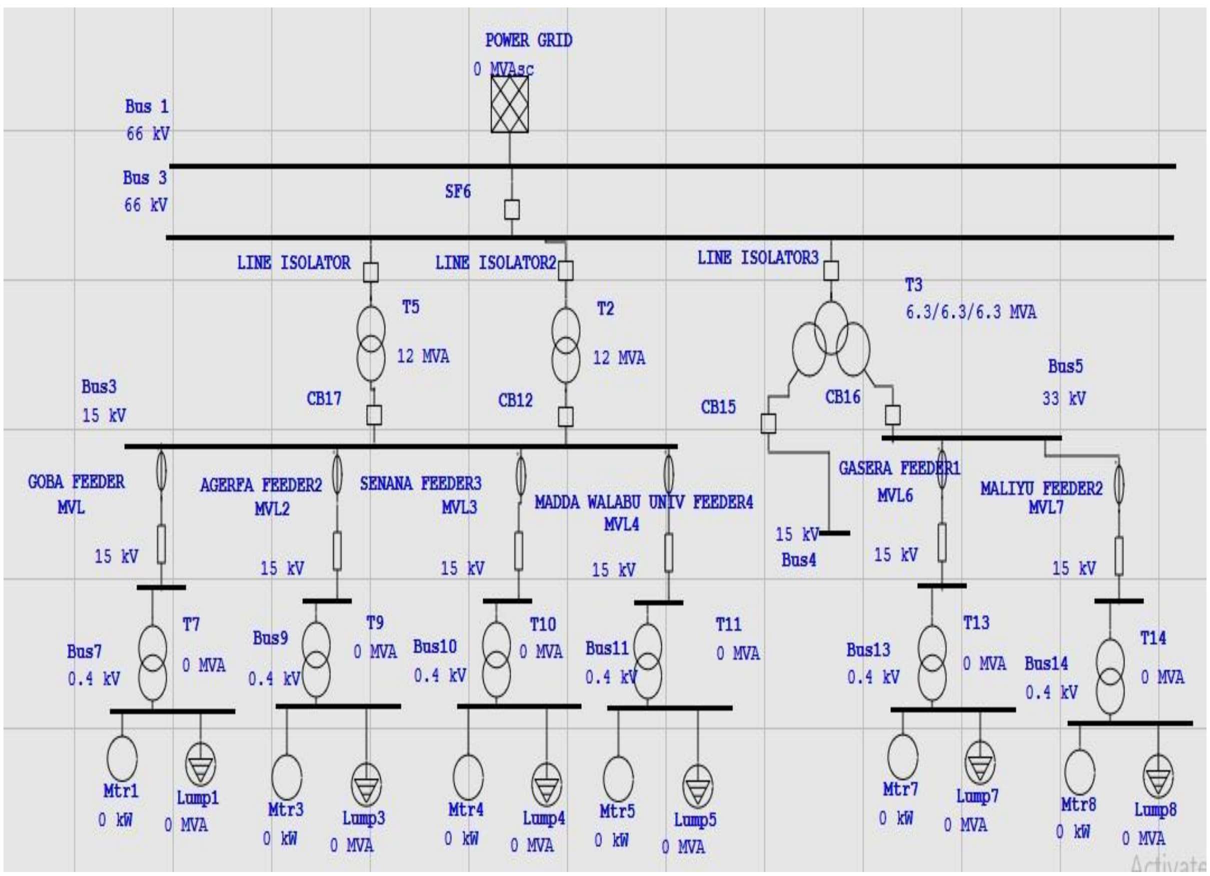


Fig.1. 1: Single Line Diagram of Bale Robe Substation Layout

1.3 Statement of the Problem

The reliability of electric distribution systems is critically important for both utilities and customers. Electric reliability affects public health and safety, economic growth and development, and societal well-being.

The frequent power interruption of Robe town is become a serious problem due to many factors. These factors that cause failures in the Robe town distribution system such as Human error factors, External factors and Intrinsic factors. The rapid increase in the population of people migrating from the rural areas to the urban areas. However, the power system facilities, particularly the distribution network has not experienced a proportionate expansion adequate enough for maintenance thus leading to; overloading of the system, system losses due to mismatches between the power supply and demand received, unreliable power supply to consumers, transient behavior of the systems, overloading of feeder (conductors, resulting to over-heating and insulation breakdown), constant power outages leading to shutdown of production activities and eventual loss of revenue and gross profits, overloading of the system result to overheating of the system which has caused deficiency of the system to supply a reliable power to the consumer.

In order to overcome and minimize these effects, investigation of reliability in power system problem as power quality in distribution network is vital. The investing of extra money for maintenance, construction, operation and extra money for energy substitution have been ceased.

1.4 Objectives of the Study

1.4.1 General Objective

The general objective of this study is to investigate the power system reliability problem in distribution system network at Robe town, by applying analytical and Simulation method using the ETAP software tool.

1.4.2 Specific Objective

The specific objectives of this study were: -

- To assess the practices of power system reliability problem in power distribution network of the study area.
- To identify challenges of evaluating the reliability of distribution center of the city line feeder of the study area.
- To collect and analyze data from Bale Robe town substation and calculate the most powerful reliability indices and design model simulation.
- To minimize the factors that affect reliability problem in distribution network.

1.5 Significance of the Study

This study through investigation of power system reliability as power quality problem in power distribution network must be useful for which are; improve of productivity, the most efficient and cost effective way of supplying electricity from industrial areas up to until residential consumers, minimizing of cost of production, increasing of power efficiency, without effect environmental pollution pure electricity for customer. In addition, another researcher who want to conduct study are also take as a reference source for their study.

1.6 Scope (delimitation) of the Study

This study is focused on the investigations of the reliability and power quality enhancement in power distribution network: In the case of Robe town. Because of time and budget constraints, this study is delimited to Robe town.

1.7 Operational Definition of Key Terms

Reliability: refers to how consistently a method measures something. If the same result can be consistently achieved by using the same methods under the same circumstances, the measurement was considered reliable.

Electrical Distribution Systems: it is the important part that provides the final links between the utility and the customers.

Quality: involves voltage, frequency, and waveform. Good power quality can be defined as a steady supply voltage that stays within the prescribed range, steady alternating current (AC). Frequency close to the rated value, and smooth voltage curve waveform (resembles a sine wave).

1.8 Organization of the Study

This study is comprising five chapters. The first chapter deals with background of the study, statement of the study, objective of the study, and delimitation of the study. The second chapter focuses on review related literature. The third chapter focuses on research method and design of the study. The fourth chapter focuses on data analysis and interpretation. The last chapter focuses on the conclusions and recommendations of the study.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Theoretical Background

Electric power system is the largest and the most complex system made by the mankind. It consists of countless number of structures and facilities, equipment's and components, systems and subsystems and the sophisticated connections among all those. The fundamental function of electric power system is to transfer electrical energy to it consumers, it is always the priority of utility companies to ensure it is consumers gets adequate and secure electric power supply within some economic constraints [4].

A transmission and distribution system can be expensive to design, build, and operate. Equipment at every level involves two types of costs: capital costs and operating costs. Capital costs include the equipment and land, labor for site preparation, construction, assembly and installation, and any other costs associated with building and putting the equipment into operation. Operating costs include labor and equipment for operation, maintenance and service, taxes and fees, as well as the value of the power lost due to electrical losses. Usually, capital cost is a one-time cost (once it was built, the money has been spent). Operating costs are continuous or periodic. Obviously, the utility aims to maintain these costs at the minimum level possible [4].

The voltage is then further reduced by distribution transformers to the utilization voltages of 380 volts three-phase or 220 volts' single-phase supply required by most users. Substations are fenced yards with switches, transformers and other electrical equipment. Once the voltage lower at the substation, the electricity flows to industrial, commercial, and residential centers through the distribution system. Conductors called feeders reach out from the substation to carry electricity to customers [5].

Due to the size and complexity of the power system, investigation of reliability of power system in distribution system of high tension and low tension is typically only practical for small systems. A common solution is to utilize the results from a HTL and LTL evaluation as input for a separate evaluation of a specific distribution system. In such procedure the effects that the distribution system may have on the reliability and power quality of the transmission and generation systems were neglected [4,5]. Each functional zone is made up of several subsystems. Generation consists of generation plants and generation substations. Transmission consists of transmission lines, transmission switching stations, transmission substations, and sub transmission systems. Distribution systems consist of distribution substations, primary distribution systems, distribution transformers, and secondary distribution systems [5].

Rapid changes in modern life, especially in population, economy, and technology, have created a high demand for energy. Electricity is the most aspects of modern life because modern society considers it an indisputable right [6]. Maintaining a continuous power supply is an indicator of prosperity and national development. Therefore, providing customers with secure and reliable power was a priority of decision makers [5,6].

Fully reliable power systems do not exist due to many factors, such as random failures of system components, intermittent power sources, and uncertain load profile. System blackout may result from one or more of these factors in a conditional sense [6]. Electrical power are vital important to our modern society nowadays in line with the challenges to provide the most efficient and cost effective way of supplying electricity from industrial areas up to until residential consumers. The availability of a reliable power supply at reasonable cost was crucial for the economic growth and development of a country [7]. Power Utilities Company now a days try to enhance and develop their own strategies based on experience, trending, research and studies to meet customer demands as economically as possible at reasonable service of reliability. An analysis throughout shows that around 90% of all customer reliability problems were due to the problem in distribution system. Thus, improving distribution reliability is the key to improving customer reliability [6][7]. The concept of power-reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements.

2.2 Literature Review

Several authors and researchers have studied the reliability and Power quality are certainly a major concern in the recent area; it becomes especially important with the introduction of sophisticated devices whose performance in Electrical Utility for automated distribution systems. There are different power quality problems like voltage sag, voltage swell, voltage interruption, harmonic distortion, under voltage and over voltage. There is different reliability problem like frequency interruption and duration interruption. The increased awareness on reliability and power quality has resulted in the need to quantify the performance of a distribution system. Different authors have contributed to study and mitigate reliability as power quality problems from various ideas. Thus the literature reviews in this distribution system is collected from several places around the world. Different thesis that have been done and finding their lack to investigate in this thesis.

In [2]**,** reliability assessment of radial distribution system with distributed generation. It was describing mathematical analysis of reliability indexes and compare with standards. But it was mitigation technique improved by Distributed Generation. However, the authors did not discuss about recloser and other switches. And also there is no identification of which secondary distribution transformer needs upgrade and rehabilitation of the phase line.

In [5], Reliability assessment of radial distribution system with distributed generation. The researcher discussed different existing distribution systems performance and reliability. However, the researcher did not give the major focus to the causes of reliability problem and constrains. And also the improvement technique was distributed generator.

In [7], Reliability Analysis of Power Distribution Network, in this paper the key technologies of building smart grid was explained. But it is lack causes of interruption does not explain.

In [48] Reliability Improvement of Power Distribution System using Auto recloser Case was studied it was describing the relationship between reliability verses cost and how recloser done in distribution system. But the authors do not explain mathematical analysis of reliability indices.

Based on this review aims to give explanations on approaches done by previous researchers in order to find ultimate combinations for investigation of power system reliability and power quality and also technical aspect. Finally, the available software's, simulation software's that used as designing tools and analysis is going to discuss in this thesis.

2.3 Power Distribution Network System

Power distribution networks are recognized as the constituent part of power systems with the highest concentration of failure events. Even though the faults in distribution networks have a local effect when compared to the generation and transmission sides, major contingency escalation events are being more frequently reported from this section [10]. Power distribution networks developed and expanded over the years driven by overall power demand and network capacity requirements due to an increasing number of customers [11].

A distribution substation transfers power from the transmission system to the distribution system of an area. Distribution voltages is typically medium voltage, between 15 kV and 33kV depending on the size of the area served and the practices of the local utility. Besides changing the voltage, the job of the distribution substation was to isolate faults in either the transmission or distribution systems. Distribution substations may also be the points of voltage regulation, although on long distribution circuits (several km/miles), voltage regulation equipment may also be installed along the line. Complicated distribution substations can be found in the downtown areas of large cities with high-voltage switching and backup systems on the low-voltage side [11,12].

2.4 The Classification of Electrical Distribution Systems Based on Construction

Distribution system reliability investigation is able to predict the interruption profile of a distribution system based on system topology and component reliability data. Unfortunately, many utilities do not have enough historical component reliability data to perform such an investigation, and are not confident that other sources of data are representative of their particular system. As a result, these utilities do not incorporate distribution system reliability investigation into their design process and it was significant advantages. This thesis presents a way of gaining confidence in a reliability model by developing a validation method. This method automatically determines appropriate default component reliability data so that predicted reliability indices match historical values. The result is a validated base case from which incremental design improvements can be explored [15].

In distribution line, sending end power and receiving end power is not same. It goes on decreasing due to consumption at each load center. The voltage at each node (load center point) is different and also power flow in each branches between two nodes is different and hence power loss is different in different branches [16].

Low cost, simplification, and standardization were all important design characteristics of distribution systems. Few components or installations are individually engineered on a distribution circuit. Standardized equipment and standardized designs were used wherever possible [16].

Distribution planning is the study of future power delivery needs. Planning goals are to provide service at low cost and high reliability. Planning requires a mix of geographic, engineering, and economic analysis skills. New circuits (or other solutions) must be integrated into the existing distribution system within a variety of economic, political, environmental, electrical, and geographic constraints. The planner needs estimates of load [17].

2.4.1 Overhead Distribution Line Systems

Overhead circuits consist of aerial cables or open-wire conductors carried on poles or towers. Aluminum conductors have, to a large degree, replaced copper in overhead installations. Conductor sizes most commonly used Aluminum Cable Steel Reinforced (ACSR) or stranded aluminum alloy. An aluminum cable stranded around a steel core sized to give the required strength as ACSR. Other cables were aluminum conductor alloy reinforced (ACAR) and all aluminum-alloy conductor (AAAC) [17].

An overhead line are the structure of distribution system that transmits the electrical energy over a large distance which consists of one or more conductors suspended by towers or poles. The overhead (OH) lines is mainly bare conductors [16,17].

2.4.2 Underground Line of Distribution System

In older areas, transmission circuits are often 3-conductor lead-covered cables. Cross-linked polyethylene and ethylene-propylene rubber were replacing lead. Ordinarily, a 3conductor copper cable varying is installed in underground conduits. Aluminum cable is seldom used in underground installations because these cables is larger than copper cables of equal ampacity [17].

The underground (UG) systems mainly uses power cables to transmit electrical energy. The UG lines are used due to the reasons; Extreme weather condition (snow, wind) in distribution areas, densely populated urban areas having right of way problem, can be used near submarine crossings [17].

2.5 Elements of the Distribution System

In general, the distribution system is derived from electrical system which is Substation ally fed by the consumers' premises and the transmission system. It generally consists of feeders, laterals (circuit-breakers) and the service mains [18]. Figure2.1 shows the single line diagram of a typical components of distribution system.

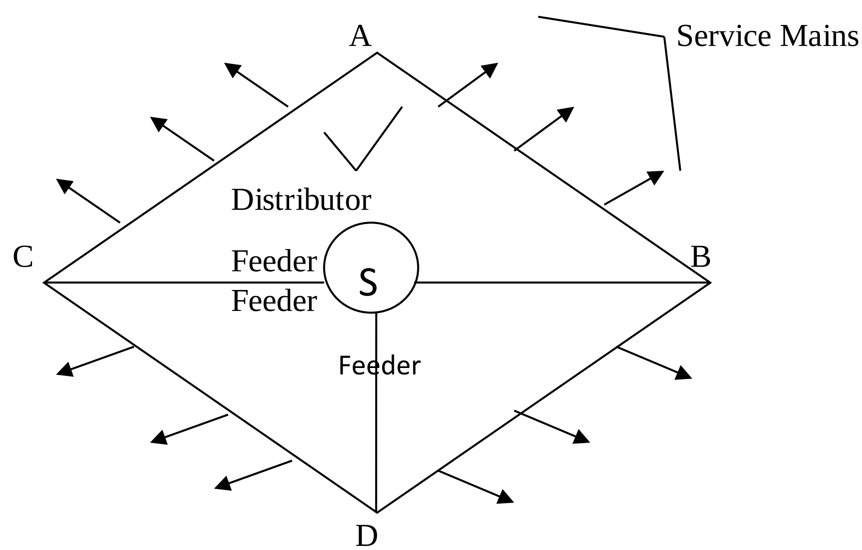


Fig.2. 1: Elements of Distribution System [54]

2.5.1 Distributed Feeders

The most common equipment found on primary distribution feeders are fuses, distribution transformers, recloses, load break switches, and voltage regulators. Most common distribution feeder configurations include feeder splitting, loop, radial and parallel. These configurations may be implemented closer to the substation side or downstream depending on what constraints are present when designing the feeder to meet customers 'needs and embedding the required level of reliability [17].

A feeder is a conductor, which connects the sub-station (or localized generating station) to the area where power is to be distributed. Generally, no tapping is taken from the feeder so that the current in it remains the same throughout. The main consideration in the design of a feeder is the current carrying capacity [17].

Tie Feeder: The main function of a tie feeder is to connect two sources. It may join two substation buses in parallel to provide service continuity for the load supplied from each Bus [18].

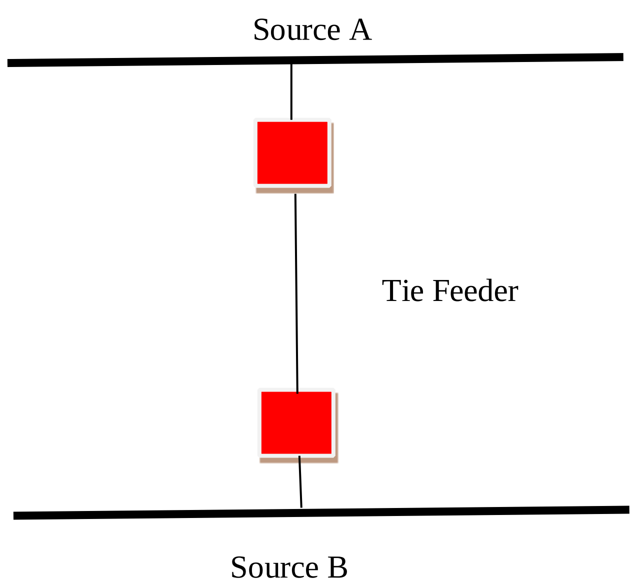


Fig.2. 2: Tie Feeder [18]

Loop Feeder: - A loop feeder has it is ends connected to a source (usually a single source), but it is the main function is to supply two or more load points in between. Each load point can be supplied from either direction; so it is possible to remove any section of the loop from service without causing an outage at other load points. The loop can be operated normally closed or normally open. Most loop systems are, however, operated normally open at some point by means of a switch. The operation is very similar to that of two radial feeders [18].

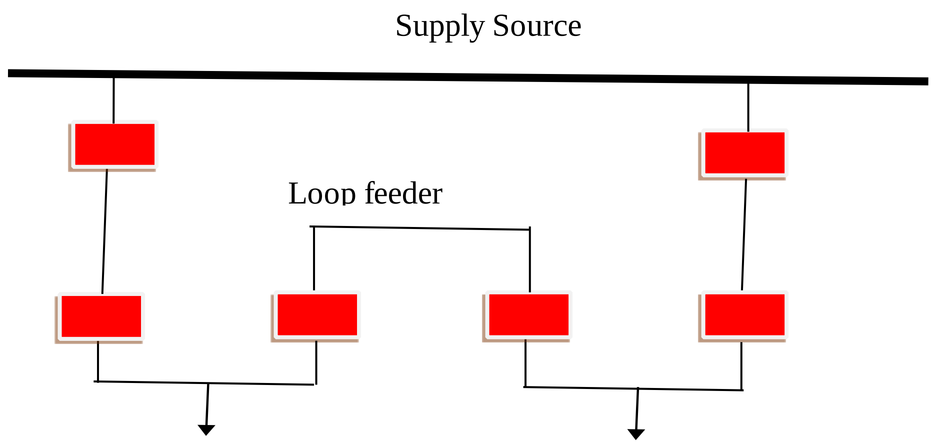


Fig.2. 3: Loop Feeder [18]

Radial Feeder: A radial feeder connects between a source and a load point, and it may supply one or more additional load points between the two. Each load point can be supplied from one direction only. Radial feeders are most widely used because the circuits are simple, easy to protect, and low in cost [18].

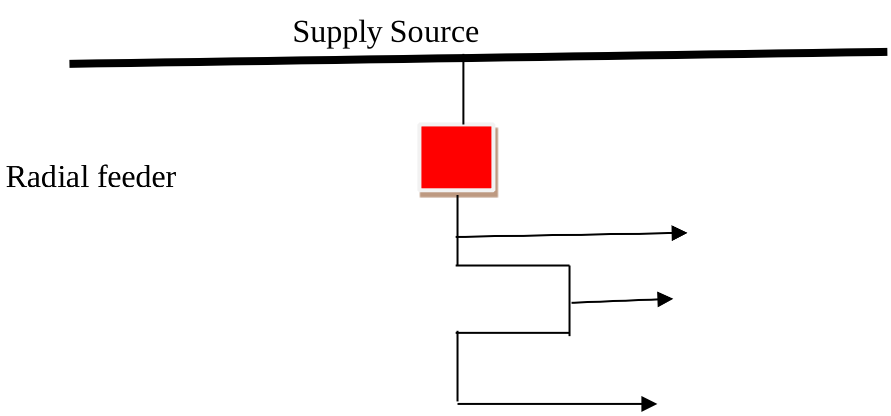


Fig.2. 4: Radial Feeder [18]

Parallel Feeder: Parallel feeders join the source and a load which provides the capability of supplying power to the load through one or any number of the parallel feeders. Parallel feeders provide for maintenance of feeders without interrupting service to loads and quick restoration of service when one of the feeders fails [18].

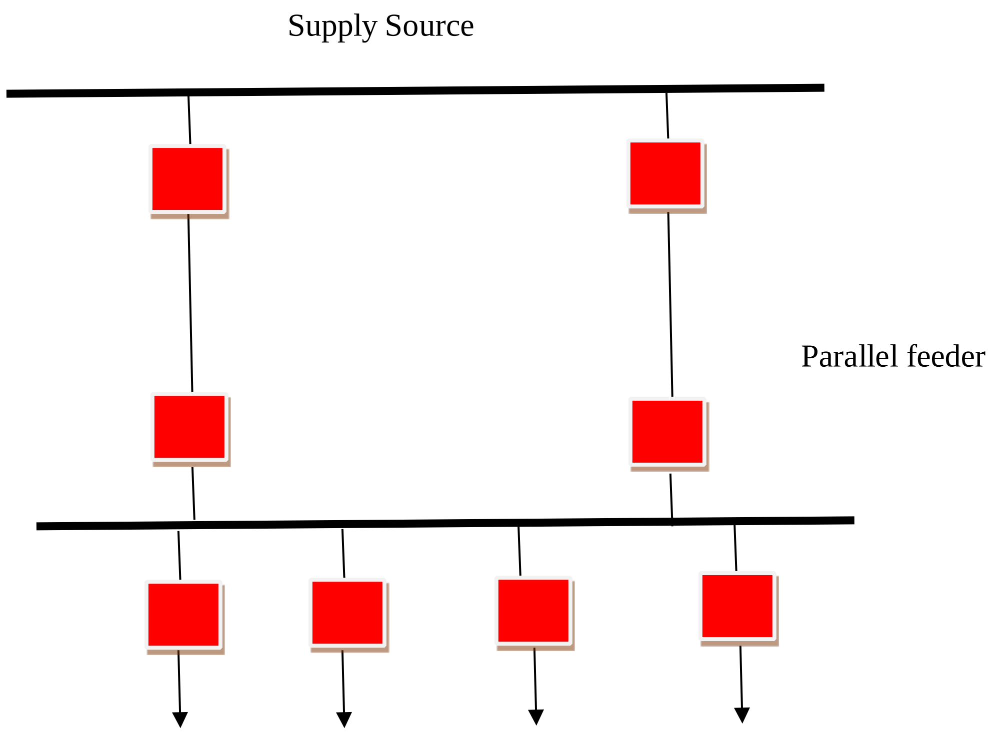


Fig.2. 5: Parallel Feeder [18]

2.5.2 Distributor

A distributor is a conductor from which tapping are taken for supply to the consumers. In Figure 2.1, AB, BC, CD, and DA are the distributors. The current through a distributor is not constant because tapping was taken at various places along it is length. While designing a distributor, voltage drop along it is length the main consideration since the statutory limit of voltage variations was 10% of rated value at the consumer's terminals [17].

2.5.3 Service mains

A service main is generally a small cable which connects the distributor to the consumer's terminals. The secondary distribution system is that section of the network between the primary feeders and utilization equipment. The secondary system consists of step-down transformers and secondary circuits at utilization voltage levels. Residential secondary systems are mainly single-phase, but commercial and industrial systems generally use three-phase power. The voltage levels for a particular secondary system were determined by the loads to be served. The utilization voltages are generally in the range of 230 V to 400 V [17,18].

2.6 Sub-Division of Power System Reliability

Electrical power is vital important to our modern society now a day in line with the challenges to provide the most efficient and cost effective way of supplying electricity from industrial area up to until residential consumers. The availability of a reliable power supply at reasonable cost is crucial for the economic growth and development of a country [18].

Power Utilities Company now a days try to enhance and develop their own strategies based on experience, trending, research and studies to meet customer demands as economically as possible at reasonable service of reliability. An analysis throughout the world shows that around 90% of all customer reliability problems are due to the problem in distribution system. Thus, improving distribution reliability is the key to improving customer reliability [19]. The concept of power-reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements. There is a reasonable subdivision of the concern designated as system reliability which is shown in Figure 2.2. The concept of reliability in the power system can be interpreted using three different categories below;

System Adequacy- Adequacy means the ability of sufficient generation and the capability of transmission and distribution system to meet customer demand. It is related to the static reliability of the power system in which the system design structure and installed capacity are more focused for the evaluation of the reliability of the system without considering the system dynamic behavior [19].

It relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. These include the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities required to transport the energy to the actual consumer load points. It is referring to the power system has enough power generation capacity and enough transmission capacity, at any time can satisfy the requirement of the user on peak, characterization of the steady state performance of power grid. the capability of the system to meet it is demand at all times considering scheduled and expected unscheduled outage of the elements. The ability of the electric system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements [18,19] .

System Quality: Regarding voltage condition, and harmonic characteristics. It should be noted that the definition of reliability may vary from different perspectives. The two main perspectives for reliability consideration of a power system are customer perspective and utility perspective. The customers care about quality of service and being able to use their appliances any time needed during a day. Therefore, any interruption in service is undesirable from the customer's perspective. The utility's perspective of reliability considers both the service reliability at the load points and reliability of the supply side which may include the reliability of generation, transmission and distribution assets, as well [18,19].

System Security: System security is the capability of the system to counter disturbances or faults which arises within system. It is related to the dynamic reliability of the power system in which the transient disturbances such as short circuit faults, unexpected failure system components were taken into consideration [19].

It relates to the ability of the system to respond to disturbances arising within the system. Security is therefore associated with the response of the system to whatever perturbations it is subject. The ability of the system to with stand disturbances such as a short circuit [19].

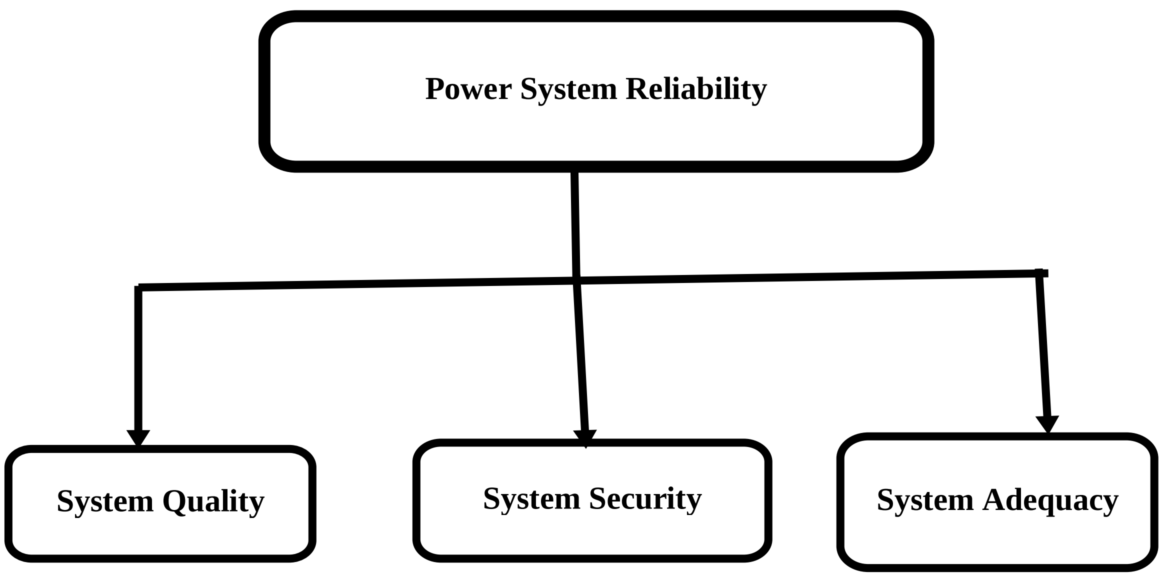


Fig.2. 6: Subdivision of System Reliability [18,19]

2.7 The Structure of Electrical Power System

The fundamental purpose of Electrical Power System is to provide an adequate electric power supply to all points of utilization at an economically acceptable rate with reasonable level of reliability. Reliability of power supply has always been an important issue in the electric utility systems. Electricity supply involves a very complex and highly integrated system. Failures in any part of it can cause interruptions which range from in convenience a number of local residents, to major and widespread disruptions of supply. The economic impact of these outages is not restricted to loss of revenue by the utility or loss of energy utilization by the customer but include indirect costs imposed on the society and the environment due to the outage [20].

A power system consists of a generation, transmission and a distribution system. Traditionally, reliability analysis and evaluation techniques at the distribution level have been far less developed than at the generation or transmission levels since distribution outages are more localized and less costly than generation and transmission level outages. However, analysis of the customer failure statistics of most utilities shows that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer [19,20].

2.7.1 Power Generation

A generator is a machine that transforms mechanical energy into electric power. Prime movers such as engines and turbines convert thermal or hydraulic energy into mechanical power. Thermal energy is derived from the fission of nuclear fuel or the burning of common fuels such as oil, gas, or coal. The alternating current generating units of electric power utilities generally consist of steam turbine generators, gas combustion turbine generators, hydro (water) generators, and internal-combustion engine generators. Electricity is produced at central power plants (also referred to as generating stations) by converting mechanical energy into electrical energy. A prime mover such as engines and turbines convert thermal or non-thermal sources such as hydraulic, wind and steam turbine that is used to bring the mechanical power to a generator [12].

2.7.2 Transmission Line

The transmission system is divided into two parts: transmission and sub transmission systems. The transmission system is the bulk power transfers electric power from a generation plant to a sub-transmission system through generation substations at voltage levels of 66kv,132kv,230 kV and higher. The transmission system is usually part of the electric power network. The sub-transmission system then transfers the electrical power at voltage levels between 66 kV to 132 kV to the distribution substation and on to the distribution networks. The transmission of large quantities of power over long distances is more economical at higher voltages. Power transmission at high voltage can be accomplished with lower currents which lower the I^2R power losses and reduce the voltage drop. The consequent use of smaller conductors requires a lower investment. Standard power transmission systems are 3-phase, 3-conductor, overhead lines with or without a ground conductor. Transmission lines are classed as unregulated because the voltage at the generating station is controlled only to keep the lines operating within normal voltage limits and to facilitate power flow [20].

Sub-transmission stages are used to enable a more practical or economic transition between transmission and distribution systems in order to produce electricity. The generation plants are connected to transmissions networks via generation substations which is interconnection node between generation plant and transmission lines, where electric power is stepped up to a higher voltage (normally between 132 kV to 500 kV) to be transported over long distance [19,20].

2.7.3 Distribution Substations

Distribution substations supply MV power to the distribution system. The substation contains one or more power transformers, voltage and current regulating equipment, bus bars and switchgear. As substation is one of the most important infrastructure in electric power system and has the great impact on the distribution system reliability, reliability evaluation of the substation and it is impact on the distribution system reliability can be a great interest for this thesis. Substation is one of the important part of the power system to transfer reliable electricity to the customer adequately. It is also an interface where voltages are transformed from higher voltage level to lower voltage level or vice versa either between the generation and transmission systems or between the transmission and sub-transmission systems or between the sub-transmission systems and distribution systems [20,21].

The reliability of substation has great impact on the overall reliability of the power system and can be measured in terms of the frequency and duration of substation-related equipment outage events that violates the system reliability criteria such as equipment overloads or unacceptable voltages [21,22]. It has been step-down power transformers, a few incoming high voltage sub-transmission lines and several outgoing medium voltage overhead lines or underground cables.

Step down power transformers in the substation step down sub-transmission voltage levels to primary distribution levels. First, the distribution substations step down the voltage from 132 kVor 66Kv to 33Kv or 15 kV. Then, the primary distribution system transfers the electric power from the substation to the distribution transformers. Some industrial customers are served directly from the primary distributions. The distribution transformers step down the voltage again to utilization levels, namely: 120/230 V for single phase, 400 V for three phases. Lastly, the secondary distribution systems distribute the power to the customers' service entrance equipment. The distribution networks are either overhead lines or underground cables [20,21].

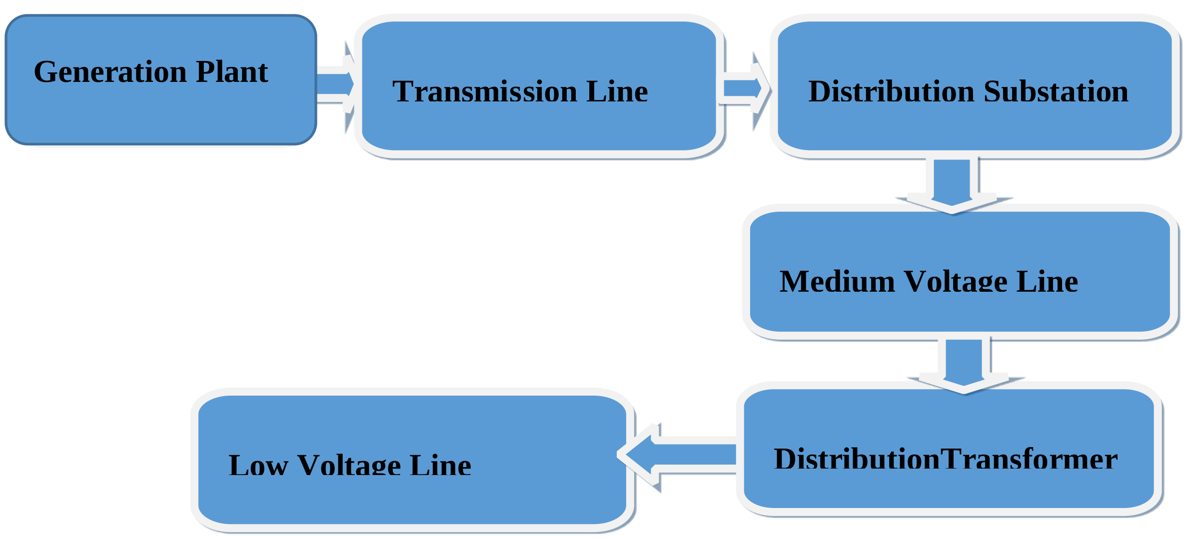


Fig.2. 7: The block diagram Functional zones of a power system

The safe operation of a power distribution system requires much dedicated equipment; this equipment is installed throughout the distribution system and it includes elements, such as power transformers, circuit breakers, and control and monitoring apparatuses. The most important elements and a brief definition are presented as follows.

Lines: - Line are responsible for transporting electrical energy between two distant points; overhead line are typically made of bare aluminum (being ACSR a commonly used type), where as underground lines commonly use cables with polymer-insulation, such as XLPE and EPR. Cables and conductors used for distribution line are characterized by their current capacity and rated voltage [12].

Distribution Transformer: -A transformer is an electric device that consists of two or more windings coupled by their electromagnetic fields; it transfers power from one winding to another without changing the frequency and is capable of performing voltage level transformation (reduction or increment). Transformers are used to perform successive voltage reductions along the distribution system in order to adjust the voltage level to an adequate value for every system section [22,23].

Circuit Breaker: - A circuit breaker is a switching device designed to open and close a circuit by non-automatic means and to open the circuit automatically on a predetermined overcurrent in order to avoid damage to itself and other equipment [22,23].

Potential Transformer: -A potential transformer is a conventional transformer with primary and secondary windings on a common core. Standard potential transformers are single-phase units designed and constructed so that the secondary voltage maintains a fixed relationship with primary voltage [23]. They are used to reduce the primary circuit voltage to a safe value (120 V), so it can be used as an input signal for monitoring and protection devices; these transformers only have the capacity to serve low rating meters and relays [22,23].

Current Transformer: -A current transformer transforms line current into values suitable for standard protective and monitoring devices, and isolates the relays from line voltages. A current transformer has two windings, designated as primary and secondary, which are insulated from each other. The primary winding is connected in series with the circuit carrying the line current to be measured, and the secondary winding is connected to protective devices, instruments, meters, or control devices. The secondary winding supplies a current in direct proportion and at a fixed relationship to the primary current [22,23].

Relay: -A relay is an electronic, low-powered device used to activate a high-powered device. In distribution systems, relays protect feeders and system equipment from damage in the event of a fault by issuing tripping commands to the corresponding circuit breakers in order to interrupt the current produced by the fault [22,23].

Recloser: -The automatic circuit recloser is a protective device with the necessary intelligence to sense overcurrent's and interrupt fault currents, and to re-energize the line by reclosing automatically. In case of a permanent fault, the recloser locks open after a present number of operations (usually three or four), isolating the faulted section from the main part of the system [22,23].

Fuse: -A fuse is a protective device used in distribution systems to protect laterals, secondary circuits, and low power transformers; it consists of a strip of wire that melts and clears an electric circuit when an overcurrent or short-circuit current passes through it.

Melting and clearing times depend on the fuse's time-current curves [22,23].

Sectionalize*:* -The sectionalized is a circuit-opening device used in conjunction with source-side protective devices, such as reclosers or circuit breakers, to automatically isolate faulted sections of electrical distribution systems. The sectionalized senses current flow above a preset level, and when the source-side protective device opens to de-energize the circuit, the sectionalized counts the overcurrent interruption [22,23].

Switch: -A switch is a switching device used to isolate a system element for repair or maintenance. It must be capable of carrying and breaking currents during normal operating conditions; a switch may include specified operating overload conditions and also carrying for a specified time current under specified abnormal circuit conditions such as those of a short circuit. A switch, therefore, is not expected to break fault current, although it is normal for a switch to have a fault making capacity [22,23].

Capacitor Bank: -A capacitor bank is a local source of reactive power. By correcting power factor, it can perform voltage regulation and reduce system losses. Capacitor banks are generally three-phase and were installed within the distribution substation or at intermediate points of a primary circuit line [22,23].

2.8 Power System Reliability Evaluation

Reliability is the analysis of failures, their causes and consequences. It is the most important characteristic of product quality as things have to be working satisfactorily before considering other quality attributes. Reliability is the probability that the system will perform it is intended function under specified working condition for a specified period of time [24].

Quantitatively, reliability is expressed as a mathematical function of time: $R(t)$ = Probability that the system still works correctly at time t. Reliability is a real number between 0 and 1; that is, at any time $0 \le R(t) \le 1$. The continuity of energy supply can be increased by; improved system structure, Effective and efficient Operation. It is evident therefore that the reliability and economic constraints were related [25].

Hence, ways of sustaining an adequate level of system reliability and methods for improving it are topics of extreme significance and have key social impacts. More aspects from this topic specific to the discussion here, such as subdivisions in distribution grid reliability, failure modes and respective probabilities, load point failure rate, system indices for reliability evaluation, configuration variations in power distribution, load demand and transfer capacities. Reliability and economic constraints might interfere with each other, and hence require an agreed balance. This balance should be achieved not only by the interest in making savings from the network and cost-effectiveness, but also by considering the societal requirements of high quality of uninterrupted energy requirements [24,25].

The system cost will generally increase with higher investment cost in equipment & facilities which provide higher reliability. On the other hand, the customer interruption costs due to higher reliability will decrease. The total cost to society is the sum of these two costs that means utility cost and customer cost. There is a minimum point in the resulting total cost curve which indicates the optimal target level of reliability [25].

The majority of customer reliability problems are from distribution systems;85% of power interruption is due to distribution system outages (poles and wires, cables, switchgear.),9% from substations,4% from transmission and 2% was caused by generation [23,24,25].

2.9 Power Quality, Reliability and Availability

Power quality problem from a customer perspective might be defined as any electric supply condition that causes appliances to malfunction or stops their use. Power quality problem from a utility perspective might be perceived as non-fulfillment of various standards such as RMS voltage or harmonics. Power is equivalent to the instantaneous product of current and voltage, and formulating a meaningful definition of power quality is difficult. The best a utility can do is to supply customers with a perfect sinusoidal voltage source with constant frequency and amplitude [26]. Less than perfect power quality occurs when a voltage waveform was distorted by transients or harmonics, changes it was amplitude, or deviates in frequency [26].

Reliability is primarily concerned with customer interruptions, therefore a subsection of power quality [26]. Sustained interruptions have continuously been categorized as a reliability issue, but many utilities have categorized momentary interruptions as a power quality issue [26,27]. Momentary interruptions are an important customer issue and most distribution engineers consider them a reliability issue. Therefore, reliability is all aspects of customer interruptions, together with momentary interruptions [27].

Availability is defined as the proportion of time a voltage source was uninterrupted. It is complement, unavailability, is the fraction of time a voltage source was interrupted. Since availability and unavailability deal strictly with interruptions, they are classified as a subsection of reliability [26,27].

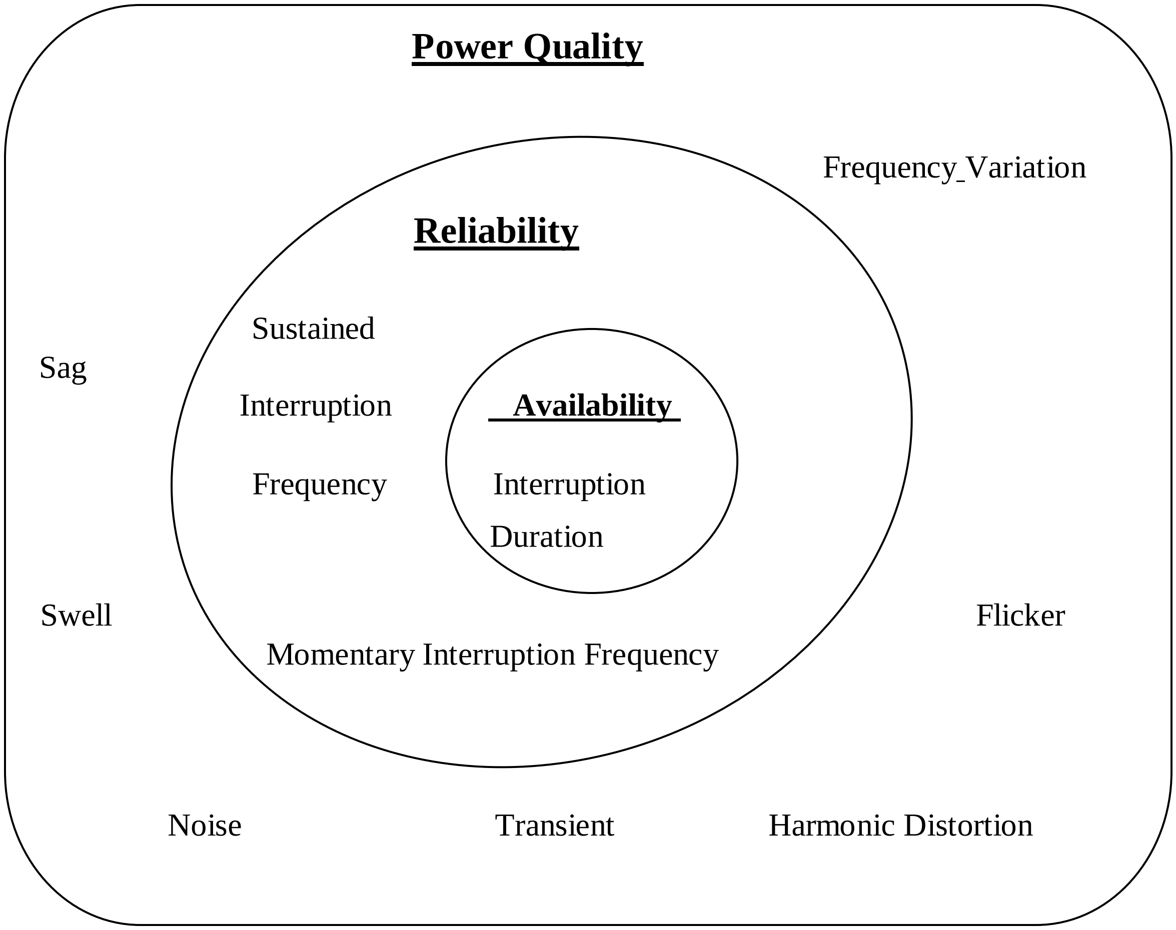


Figure 2.8: The grading of power quality, reliability, and availability [23]

2.9.1 Power Quality

Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as “the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment.” As appropriate as this description might seem, the limitation of power quality to “sensitive electronic equipment” might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, transformer, generator, computer, printer, communication equipment, or household appliance. All of these devices and others react adversely to power quality issues, depending on the severity of problems [28].

Power Quality is the measurement of how close to perfect an electrical voltage is at any given time or point. High quality electrical voltage is a sine wave that measures exactly what is expected in both voltage and frequency. The power flow should have a pure sinusoidal wave form and it should remain within specified voltage and frequency tolerances**.** In other word, powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment [27,28].

Perfect power quality is characterized by a perfect sinusoidal voltage source without waveform distortion, variation in amplitude or variation in frequency. To attain near perfect quality, a utility could spend vast amounts of money and accommodate equipment with higher power quality needs. On the other hand, a utility could spend little and require customers to compensate for the resulting power quality problems. Availability is defined as the percentage of time a voltage source was uninterrupted. Power quality deals with any deviation from a perfect sinusoidal voltage source. Reliability deals with interruptions. Availability deals with the probability of being in an interrupted state. Availability is the probability of something being energized and Unavailability is the probability of not being energized. It is most basic aspect of reliability and is typically measure in percent or per unit. Unavailability can be computed directly from interruption duration information [28].

.

2.9.1.1 The Problem Associated with Power Quality

Both electric utilizes and end users of electric power are becoming increasingly concerned about the quality of electric power. It is an umbrella concept for a multitude of individual types of power system disturbances. The issues that fall under this umbrella are not necessarily new. What is new was that engineers were now attempting to deal with these issues using a system approach rather than handling them as individual problem [27,28].

The power quality has been serious economic implications for customers, utilities and electrical equipment manufacturer. Large number industries involve increasing use of computers, microprocessors and power electronic system such as adjustable speed drives. The power electronic systems also contribute to power quality problems (generating harmonics). The impact of power quality problems is increasingly felt by customers – industrial, commercial and even residential [28].

a) **Transients**: -A transient is that a part of change in a system variable that disappears during transition from one steady state operation to another. Transient can be classified into two categories -impulsive transients and oscillatory transients [26,27,28].

i) **Impulsive transient: -** it is a sudden, non-power frequency change in voltage, current that it is unipolar in nature. The polarity of such a transient can be either positive or negative.

ii) **Oscillatory transient: -** it is a sudden, non-power frequency change in the steady-state condition of voltage, current, or both that includes both positive and negative polarity values.

b) **Long Duration Voltage Variations: -**When RMS (root mean square) deviations at power frequency last longer than one minute, then we say they are long duration voltage variations. They can be either over voltages which is greater than 1.1p. u or under a voltage which is less than 0.9p.u. Over voltage is due to switching off a load or energizing a capacitor bank. Also incorrect tap settings on transformers can result in over voltages. under voltage are the results of actions which are the reverse of events that cause over voltages i.e. switching in a load or switching off a capacitor bank [[26,27,28].

c) **Sustained Interruptions**: - If the supply voltage becomes zero for a period of time which is greater than one minute, then we say that it is a sustained interruption. Normally, voltage interruption lasting for more than one minute was often unending and requires human intervention to restore the supply [26,27].

d) **Short Duration Voltage Variations**: -The short duration voltage variations are generally caused by fault conditions like single line to ground and starting of large loads such as induction motors. The voltage variations can be temporary voltage dips i.e. sag or temporary voltage rise that means swells or an absolute loss of voltage which is known as interruptions [25,26].

i) **Voltage sags**: -Voltage sag is defined as the reduction of rms voltage to a value between 0.1 and 0.9p. u and lasting for duration between 0.5 cycle to 1 minute. Voltage sags are mostly caused by system faults and last for durations from 3 cycles to 30 cycles depending on the fault clearing time. It is to be noted that under-voltages (lasting over a minute) can be handled by voltage regulation equipment [26].

ii) **Voltage swells**: - A voltage swell is defined as an increase to between 1.1 and 1.8p. u in rms voltage or current at the power frequency for durations from 0.5cycle to 1 minute. As with sags, swells are usually associated with system fault conditions, but they are not as common as voltage sags [27].

ii) **Interruption**: - An interruption occurs when the supply voltage or current decreases to less than 0.1p. u for a period of time not exceeding 1 minute Interruptions can be the result of power system faults, equipment failures, and control malfunctions [26,27,28].

2.9.1.2 From Where power quality problems come from

Most originate inside the facility. They may be due to problems with: -

Installation: Improper grounding, improper routing, or undersized distribution.

Operation: Equipment operated outside of design parameters.

Mitigation**:** Improper shielding or lack of power factor correction.

Maintenance: deteriorated cable insulation or grounding connections.

2.9.2 Reliability of Power System

Power reliability can be defined as the degree to which the performance of the elements in a bulk system results in electricity being delivered to customers within accepted standards and in the amount desired. The degree of reliability may be measured by the frequency, duration, and magnitude of adverse effects on the electric supply [29].

The investigation of service reliability is an important part of distribution system operation and expansion planning. The reliability of distribution systems is usually measured using a set of standard reliability indices [29]. Every year distribution companies determine these reliability indices based on the historical outage data. Traditionally, these reliability indices are used to identify "weak" feeders so that design changes and maintenance activities could be performed in a targeted fashion. The distribution system reliability can be improved by incorporating additional protection and sectionalizing devices, or by adopting advanced maintenance strategies [26,28].

The additional protection and sectionalizing devices improve the system reliability by reducing the number of customers that experience an outage due to a fault. The system reliability could also be improved by automating the restoration processes. Maintenance activities improve the system reliability by reducing the failure rate of distribution line segments [29].

In order to evaluate effectiveness of various proposed service improvement schemes, predictive reliability assessment techniques are needed. Many algorithms have been proposed for predictive evaluation of system reliability. These algorithms broadly fall into two categories: the analytical and the simulation methods [28], In either method, firstly the mathematical models are obtained for faults on the distribution components (such as feeder segments, fuses and other protection equipment) along with the system response. The analytical methods then use the topological connectivity information of these components to evaluate the numerical values of the system reliability indices through a direct (non-iterative) calculation [28]. In the Monte Carlo simulation method, the stochastic nature of outages of the system components and their repairs is simulated for a large number of years. System reliability indices are calculated for each year of simulation and the average of these annual indices is used as the predicted value of the reliability indices [24,28].

In brief, reliability has been to do with total electric interruptions complete loss of voltage, not just deformations of the electric sine wave. Reliability does not cover sags, swells, impulses or harmonics. Reliability indices typically consider such aspects as; The number of customers, the connected load, the duration of the interruption measured in seconds, minutes, hours, or days, the amount of power (kVA) interrupted and the frequency of interruptions.

2.9.3 Power Availability

The concept of power availability is major issue in many activity sectors, with high possible economic impact in case of long interruption consecutive to a switchboard failure. The standards give the design and verification requirements so that no failure should be expected in case of fault, disturbance, or operation in severe environment conditions. Compliance to the standards shall ensure that the switchboard will operate correctly not only in normal conditions, but also in difficult conditions [10].

2.10 The Basic Distribution System Reliability Indices Calculation

The three primary customer point indices are fundamentally important parameters. They can be aggregated to provide an appreciation of the system performance using a series of system indices. The additional indices that are most commonly used [28] were defined in the following. The Institute of Electrical and Electronic Engineers (IEEE) defines the generally accepted reliability indices in it is standard number P1366, "Guide for Electric Distribution Reliability Indices". IEEE-P1366 lists several important definitions for reliability including what are momentary interruptions, momentary interruption events, and sustained interruptions [26] [29].

The reliability indexes are divided in to two; the first one is reliability customer indexes (SAIDI, SAIFI, CAIDI.CAIFI, ASAI, ASUI and etc.), the second is energy-indexes (ENS, AENS, etc.) [27,29,30].

The most common distribution indices include the System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), System Average Interruption Frequency Index (SAIFI), Momentary Average Interruption Frequency Index (MAIFI), Customer Average Interruption Frequency Index (CAIFI), Customers Interrupted per Interruption Index (CIII), and the Average Service Availability Index (ASAI). The distribution indices can be described in the following [27,28,29];

A) System Average Interruption Frequency Index (SAIFI)

The System Average Interruption Frequency Index (SAIFI) is the average number of times that a system customer experiences an outage during the year (or time period under study). The SAIFI is found by divided the total number of customers interrupted by the total number of customers served [29,30,31].

$$SAIFI = \frac{Nci * Ni}{N_T} \tag{2.1}$$

Where,

SAIFI = System Average Interruption Frequency Index.

Σ = Summation function.

Nci= Individual Feeder number of customer interrupted

N_i = Total number of customers interrupted.

N_T = Total number of customers served

B) **System Average Interruption Duration Index (SAIDI)**

The most often used performance measurement for a sustained interruption is the System Average Interruption Duration Index (SAIDI). This index measures the total duration of an interruption for the average customer during a given time period. SAIDI is normally calculated on either monthly or yearly basis; however, it can also be calculated daily, or for any other time period. To calculate SAIDI, each interruption during the time period is multiplied by the duration of the interruption to find the customer-minutes of interruption. The customer-minutes of all interruptions are then summed to determine the total customer-minutes. To find the SAIDI value, the customer-minutes are divided by the total customers [29,30,31]. The formula is,

$$\mathrm{SAIDI} = \frac{\mathrm{Nci*Ni}}{N_T} \tag{2.2}$$

Where,

SAIDI = System Average Interruption Duration Index, minutes

Σ = Summation function.

Nci= Individual Feeder number of customer interrupted

N_i = Total number of customers interrupted.

N_T = Total number of customers served.

C**) Customer Average Interruption Duration Index (CAIDI)**

Once an outage occurs the average time to restore service is found from the Customer Average Interruption Duration Index (CAIDI). CAIDI is calculated similar to SAIDI except that the denominator is the number of customers interrupted versus the total number of utility customers [29,30,31]. CAIDI, is;

$$\text{CAIDI} = \frac{\sum (\text{Nci}^* \text{ Ni})}{\sum (N_T)} = \text{SAIDI/SAIFI} \tag{2.3}$$

CAIDI = Customer Average Interruption Duration Index, minutes.

Σ = Summation function.

Nci= Individual feeders number of customer interrupted

N_T = Total number of customers interrupted.

D) **Customer Average Interruption Frequency Index (CAIFI)**

Similar to SAIFI is CAIFI, which is the Customer Average Interruption Frequency Index. The CAIFI measures the average number of interruptions per customer interrupted per year. It is simply the number of interruptions that occurred divided by the number of customers affected by the interruptions [29,30,32]. The CAIFI was,

$$\text{CAIFI} = \frac{\sum (\text{No})}{\sum (\text{Ni})} \tag{2.4}$$

Where,

CAIFI = Customer Average Interruption Frequency Index.

Σ = Summation function.

N_o = Number of interruptions.

N_i = Total number of customers interrupted.

E) **Customer Interrupted per Interruption Index (CIII)**

The Customer Interrupted per Interruption Index (CIII) gives the average number of customers interrupted during an outage [29,30]. It is the reciprocal of the CAIFI and was,

$$CIII = \frac{\sum (Ni)}{\sum (No)} \tag{2.5}$$

Where,

CIII = Customer Interruption per Interruption Index.

Σ = Summation function.

N_o = Number of interruptions.

N_i = Total number of customers interrupted.

F) **Average Service Availability Index (ASAI)**

The Average Service Availability Index (ASAI) is the ratio of the total number of customer hours that service is available during a given time period to the total customer hours demanded [30,31,32]. This is sometimes called the service reliability index. The ASAI is found as,

$$ASAI = \frac{[1 - (\sum (ri * Ni)]*100\%}{(N_T * T)} \tag{2.6}$$

Where,
ASAI = Average System Availability Index, percent.

Σ = Summation function.

T = Time period under study, hours. r_i=
Restoration time, hours.

N_i = Total number of customers interrupted.

N_T = Total number of customers served.

In this calculation, the restoration time, r_i, was in hours.

Note that there were 8760 hours in a regular year, 8784 in a leap year

G) **Energy Not-Supplied (ENS)**

$$\textit{Energy Not Supplied} = \text{Total Energy Not Supplied by the system} = \sum La(i)Ui \qquad (2.7)$$

where *La(i)* is the average load connected to load point *i* and

Ui is the annual outage time [31,32].

H) **Average Energy Not Supplied (AENS)**

It is the ratio of total energy not supplied to the total number of customer served in feeder of the system [31,32]. In mathematically;

$$\text{Average Energy Not Supplied} = \frac{\text{Energy Not Supplied}}{\text{Total Customer Served}} \qquad (2.8)$$

2.11 Practices of Reliability and Power Quality of Distribution Systems Network

2.11.1 The Practice Reliability of Power Distribution System

The function of an electrical distribution system is to distribute electrical energy to different load points for diverse applications. Distribution system should be planned in such a way that it must deliver energy to load points with high reliability. In past, considerably less importance is given to distribution system regarding reliability modeling and evaluation [33]

The distribution system is the core part of power system network which deliver power to the end user. Power systems are one of the most complex infrastructures found world wide and they are expected to operate with high quality and reliability. The fundamental purpose of power systems is to provide an economic and reliable channel for electrical energy to transfer from points of generation to customer locations. The economic and reliability constraints can be mutually competitive, making planning and operation of power systems a complex problem [31,32].

The distribution system reliability evaluation considers the ability of the distribution system to transfer energy from bulk supply points such as typical transmission system end stations, and from local generation points, to customer loads. In the early stages of extensive power system construction, relatively less attention is given to distribution networks because of their lower capital intensiveness when compared to generation and long distance transmission systems. Also, the outages in distribution networks were expected to have a localized effect [30,31]. However, analysis of practical utility failure registers and fault statistics reveals that distribution networks as a sub-section of the power systems contribute the most to customer interruptions and failure events [31].

2.11.2 The Practice of Power Quality of Distribution Systems Network

Perfect power quality is characterized by a perfect sinusoidal voltage source without waveform distortion, variation in amplitude or variation in frequency. To attain near perfect quality, a utility could spend vast amounts of money and accommodate equipment with higher power quality needs. On the other hand, a utility could spend less and require customers to compensate for the resulting power quality problems [30,31].

2.12 The Challenges of Reliability Distribution Network Town Line Feeder Interruption

The failure of distribution system is greatly affected by weather conditions, weather conditions like high winds, lighting and icing can considerably increase the probability of outages, due to radial nature of many distribution systems across the world outage of single component due to adverse weather conditions can cause multiple overlapping outages [33]. There is many problem appears in the Robe town challenged by interruption can be;

Transient Fault: A transient fault is a fault that disappears either by itself or by energization of the faulted circuit and it does not require any immediate repair work. The majority of the faults occurring on overhead feeders is transient faults. Common causes of transient faults are momentary tree contacts with conductor and flash overs initiated either by lightning or by conductors temporarily swinging together [31,32,33].

Permanent Forced Outage Duration: The permanent forced outage duration is defined as the average time it takes to restore the affected component to service without deliberate delays when the component outage occurrence has been automatically initiated due to a permanent fault on the component [29,30,31].

Underground Cable Internal Fault: Underground cable internal faults are shunt faults on underground cables, which occur due to insulation failures. Insulation failures develop over time. Moisture, temperature and electrical stresses were all factors that contribute to degrade the dielectric strength of insulation. Common causes of electrical stresses are lightning and switching surges. Thus, these faults occur in the absence of mechanical damage [30,31,33].

Permanent Forced Outage Duration: The permanent forced outage duration is defined as the average time it takes to restore the affected component to service without deliberate delays when the component outage occurrence has been automatically initiated due to a permanent fault on the component [30,31,32].

Transient Forced Outage Duration: The transient forced outage duration is defined as the average time it takes to restore the affected component to service without deliberate delays when the component outage occurrence has been automatically initiated due to a transient fault on the component [30,31].

Travel Time: By travel time is means the average time period from the moment of the outage occurrence until the repair crew arrives at the trouble area with appropriate equipment [34].

Causes of Interruptions: Interruptions are caused by either planned or unplanned opening operations of switching devices, disconnecting primary equipment from the network. Opening operations of switching devices are initiated either by the protection system or by humans. The protection system may operate incorrectly and opening operations initiated by humans may be in advertent. When the protection system functions as intended, it detects faults and initiates opening operations of circuit breakers to isolate faulted parts from the healthy parts of the power system in a selective manner. Faults are caused by external factors, such as road traffic accidents, digging into buried cable, vegetation, animals and severe weather, and by equipment failure [33,34].

Incorrect Protection Operations: Incorrect protection operations initiate disturbances and may extend the consequences of faults. Unwanted protection operations initiate disturbances, while unwanted protection operations and failure to operate of protection systems may extend the consequences of faults [33].

Non-Selective Fault Clearance Non-selective fault clearance means that a larger portion of the power system than necessary is disconnected in order to clear a fault. In case of a missing main protection operation, the corresponding backup protection will clear the fault. If the backup protection is remote, it operates non-selectively, which may result in an increased number of customers experiencing interruption. In addition, unwanted protection operations could result in non-selective fault clearance. Consequently, failure to operate of a protection system and unwanted protection operations may result in interruptions to customers who would not have been affected if the fault had been cleared selectively [32,33,34].

2.13 Interruption Factors

There are various factors that cause interruption in the electrical distribution systems. Equipment failures, animals, human errors, natural disasters are some of the frequently occurring factors leading to power interruption [35]. Distribution lines are vulnerable to these failure factors and their reliability is always a question. A brief discussion on each of these failure factors and their effects on reliability of the electrical distribution system are discussed below:

Equipment Failures: -Equipment failure is one of the top reasons for power interruption in the distribution system. Transformers, circuit breakers, overhead lines, switches and insulators are some examples of electrical equipment's installed in the distribution system. All of these equipment's have their own probability of failure. In order to decrease rate of failure, proper installation and timely maintenance of this equipment is highly recommended. Failure of transformers in a substation due to various faults can cause interruption of service to hundreds of customers. During this interruption, another healthy transformer is called upon to carry this load which risks this transformer being overloaded. This might lead to failures of transformers due to overloading leading to power interruption to thousands of customers. Proper decision should be made to determine whether to overload transformers or not. Overloading causes heating in transformers which decreases its thermal age [35,36].

Circuit breakers are other devices which cause frequent interruptions due to untimely coordination. Proper setting and maintenance is required for the healthy action of circuit breakers. Otherwise, there might be cases in which circuit breakers malfunction [34,35]. Usually circuit breakers are timely coordinated with other protective devices using relays. Untimely co-ordinations can be reduced by testing settings, relays, Current Transformer/Potential Transformer ratios and wiring [36].

Human Factors: -There are many ways in which a human can cause interruption in the distribution system. These interruptions can be categorized in to scheduled or unscheduled. Scheduled interruption occurs when part of the radial distribution system has to have maintenance or be upgraded. The utility company notifies it is customers in advance prior to maintenance. During maintenance, it might require equipment to be de-energized and all the customers downstream of that equipment will be interrupted. Even when fed by an alternative source, these customers experience momentary interruption due to switching after de-energizing the circuit [34,36].

Unscheduled interruption may occur due to human error, vehicle accident. One example is accidently operating wrong manual switch. Other errors include the falling of tree branches while trimming trees. Also, vehicle accidents can cause a significant impact on failure rates of distribution lines. Most road can cause damage to the poles bringing power lines to the ground. Using fences or crash resistant poles may reduce the impact of automotive interruptions [35,37].

Animals: -Animals are another large cause of interruption in the electric system [36]. Animals, like snakes, squirrels, birds and rats can cause problems and hence, impact the reliability of the electrical distribution system. Squirrels is the most common reliability concern for the utility company in wooden areas. Squirrels bring grounded equipment in contact with phase conductors causing faults. Special plastic guards are required to ensure protection of conductors. Birds are another cause of faults in the electrical distribution systems. They cause faults in systems by bridging the conductors with their wings. To prevent roosting, protective anti-roosting structures, like cones structures, should be placed on top of poles [37].

Snakes, being cold blooded animals, tend to squeeze through holes and stay in warm places like cabinets and substations. Snakes cause problems by bridging two conductors. Electrical cabinets should be sealed and food remains should be removed [37].

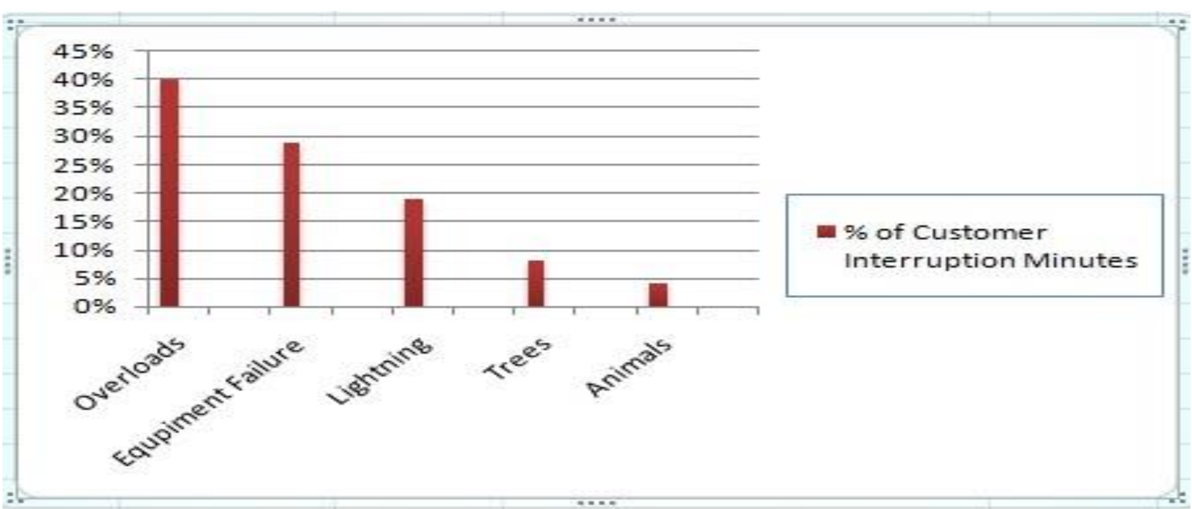
Large animals like cows, horses and bears can cause damage to poles by rubbing on guy wires. Guy wires provide stability to the poles against tension caused by power lines [37]. A lot of cattle lean on or rub on poles or guy wires making poles lean and this reduces the reliability as the chances of collapsing poles increase. Fences can be built around the poles in order to increase reliability [37].

Extreme Weather: -Extreme weather has been significant impact on reliability. It causes more outages in the electrical distribution system. Extreme wind with high velocities, like tornadoes and hurricanes, can blow off poles and distribution conductors causing damage to many devices in the meantime [37,38].

Trees: -Trees may cause interruption in the distribution system. Due to the falling of trees, overhead conductors may receive mechanical damage. Also, the growing of branches can push conductors together and need to be trimmed [38].

Therefore, in order to mitigate the effect of these failure factors on the reliability of the distribution system, proper protective devices such as relays, circuit breakers, and automatic switches must be installed.

When to summarize the causes of interruption versus percentage of interruption minutes.



. Fig.2. 9: The Major Causes of interruption [17]

CHAPTER THREE

METHODOLOGY

3.1 Research Methods of Collection Data

In this thesis, the methodology or techniques used to correct the reliability of distribution problem of distribution network approach are analyzed. The data collected is frequency interruption and duration interruption [17]. Depending on the collected data, this thesis assessed the reliability of Bale Robe town distribution substation and for improving the many power reliability gap, the use of reclosers and other protective devices as an integral part of the distribution system is proposed and it is possible impact on the reliability of the distribution system by using mathematical calculations and simulated using Etap software. This thesis technique uses to the an investigation of power system reliability problem of distribution system. Generally, in order to attain the above general and specific objectives of the thesis, the following methods and techniques are followed below.

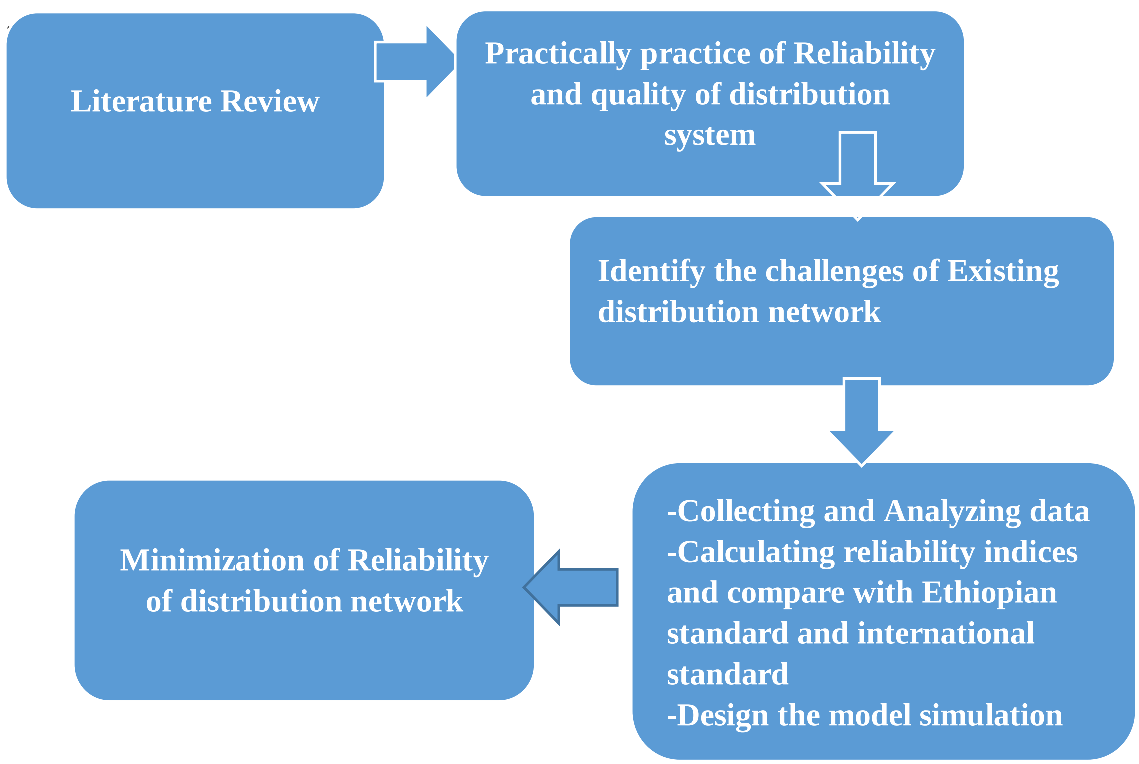


Fig.3. 1: The block diagram of thesis methodology

3.2 Data Source

Both primary and secondary sources of data were collected from south east region bale robe town substation.

3.2.1 Primary Sources of Data

Data were collected from directly from the secondary distribution of Bale Robe Town this data collected used for identification of which transformer overloaded, not balanced and needs upgrade with location of that transformer.

3.2.2 Secondary Sources of Data

Data were collected from a monthly power interruption report of Robe town distribution substations. Physical document, Reliability and quality of power distribution books, employee guide and internet is used. In addition, published and unpublished documents were used.

3.3 Research Design

Generally, in order to attain the general and specific objectives of the thesis, the cable capacity, medium voltage (Feeder capacity), low voltage and AAC capacity is designed in the following methods and techniques are followed as described here below.

The first step is to design the substation capacity to carry out the load connected with it which is the total rate of substation [17].

The rate of MVA customer requisition divided by the total rate of substation multiplying by 100% is must be less than 50% [17]. In mathematically;

$$\text{Total rate of substation}=\frac{\text{MVA customer requisition *100\% <50\%}}{\text{MVA total rate of substation}} \tag{3.1}$$

$$=\text{MVA customer requestion+Df*Load on substation=MVA} \tag{3.2}$$

The diversity factor (Df) of substation is 0.4

Then the calculated MVA in step 3.2 is divided by the total rate of MVA substation must be less than 80% [17]. In mathematically;

$$= \frac{\text{MVA calculated in step 3.2 *100\% <80\%}}{\text{MVA total rate of substation}} \tag{3.3}$$

$$=\text{Customer requisition capacity of rating power multiply by *Df} \tag{3.4}$$

$$\left.\begin{array}{l}\text{1MVA=38.5A for 33kv capacity of feeder line}\\ \text{1MVA=17.5A for 15kv capacity of feeder line}\end{array}\right\} \tag{3.5}$$

Then the feeder rate capacity in (A) in step (3.5) plus the feeder of substation capacity in current (A). (3.6)

The next step to calculate the following terms;

$$\text{\% CT=} \frac{\text{The total rate in step 3.6 *100\% <100\% must be}}{\text{CT capacity of the bus bar}} \tag{3.7}$$

$$\text{\% cable capacity=} \frac{\text{The total rate in step 3.6 *100\% <100\% must be}}{\text{Cable capacity of the bus bar}} \tag{3.8}$$

$$\text{\% AAC capacity=} \frac{\text{The total rate in step 3.6 *100\% <100\% must be}}{\text{AAC capacity of bus bar}} \tag{3.9}$$

Then finally it is possibility or impossibility of customer requisition is answered. If the above step 3.1 to step 3.9 is rule must be respected the customer requisition is accepted otherwise unaccepted.

3.4 Feasibility Study on Reliability Analysis

The feasible study on reliability analysis concentrates on the methods used for reliability evaluation. The existing system network will be bench mark and compare with the other country, so that the methods that need to be applied is suitable with the current systems. In order to achieve this thesis, bale robe town substation distribution system operation and design is used [17].

3.5 Design of Distribution Network

One of the main tasks in the design of distribution networks is to find such a network form and dimensioning, that the total costs incurred by the investments and by operation of the network will minimized. Also, distribution has been technically acceptable, safe and it is effects on nature and the environment must be limited [39].

The design of a network often involves finding several alternative solutions, and then comparing them with each other. These alternatives include different line routes, different transformer locations, different number of feeders or circuits, different number of transformer substations. To assure proper functioning of the protection system, the checking of short circuit currents has been carried out. To guarantee the fault current protection of conductors in all fault conditions, the rated current of protection should be considerably lower than the lowest fault current in the line. On the other hand, the protection should not operate under normal load currents. The minimum short-circuit current can be increased, for example, by strengthening the network starting from the feeding point. The aim of short-circuit and earth-fault calculations is to check whether the conductors can stand for maximum (3-phase) short-circuit current and whether the minimum fault current (1-phase short-circuit) is high enough for the protective relays or fuses to operate properly [39,40].

3.6 The Design Procedures in Electric Distribution

Distribution system analysis and design is experienced a gradual development. The increasing power of computers now allows for managing the large volumes of data and other obstacles inherent to distribution systems. A variety of sophisticated optimization methods, which were impossible to conduct in the past, have been developed and successfully applied to distribution systems [40].

3.6.1 Design of Medium Voltage Network System

Medium voltage networks have the highest impact on reliability in electricity distribution because more than 90 % of the customer experienced outages occur on MV networks. A challenge with the MV network is that it usually very large, and the line length of a single feeder may be even more than 100 km. MV distribution networks constitute the backbone of power distribution systems and for this reason utilities justifiably strive to improve their performance. Distribution Automation provides a means of enhancing feeder performance in the event of a fault by automatically restoring supply, after the fault has been cleared by a circuit breaker, to as many customers as possible, while isolating the faulted section of the line or cable [41].

The primary distribution system is that portion of the power network between the distribution substation and the utilization transformers. The primary distribution system consists of circuits, referred to as primary or distribution feeders, that originate at the secondary bus of the distribution substation. The distribution substation is usually the delivery point of electric power in large industrial or commercial applications [41]. The LV-network, different alternatives for line routes must be checked for the Network. The location of MV/LV transformer substations must also be re-considered in view of accessibility by the MV -line. The main MV -line shall be constructed with AAAC 95 mm^2 and the T-offs with AAAC 50 mm^2[42,43].

3.6.2 Design of Conductors and Cables

The overhead line conductors must have an adequate current carrying capacity. Besides the loading current, also the short-circuit and earth-fault currents and their duration shall be taken into account. Short-time exceptional operation and switching situations are not necessary to take into account, when defining the short-circuit and earth-fault current [41,44].

The overhead conductors must be mechanically strong and conform to the up-to-date standards for overhead lines. Each conductor size has it is own economic range of use. The economic dimensioning means that it is worth choosing a conductor with greater cross-section, if saving in the loss cost is greater during the expected operating time than the difference between the investment costs of the two conductors [41].

3.7 Design of Low-Voltage Network

The secondary distribution system is that portion of the network between the primary feeders and utilization equipment. The secondary system consists of step-down transformers and secondary circuits at utilization voltage levels. Residential secondary systems are predominantly single-phase, but commercial and industrial systems generally use three-phase power [39].

The aim is to find the most economical development scheme which will fulfill the technical criteria and whose practical implementation is reasonable. The design should be started by estimation of the loads for the economic life-time of the network [39,40].

The design then continues with the determination of line routes and applied cross-sections. Alternative line routes and transformer locations can be considered and the most economical line routes and transformer locations, as well as the optimum amount of transformers needed, can be defined [41].

After the voltage drop constraint is met, the design continues with checking of the functioning of the protection. The network obtained in this way is the economical optimum based on the given criteria and cost parameters. However, it may not be practically acceptable. After the economic and technical criteria have been fulfilled, the network shall be checked from practical point of view (available space, right-of-ways) [41].

The dimensioning of LV and MV networks shall be calculated according to the defined / set criteria, to determine the optimum cross-sections and transformer sizes. The practical aspects of network construction must be kept in mind when designing distribution networks. The schemes must be reasonably easy to implement [41,42].

3.7.1 Design Low-Voltage Network Required Information

A) **A Map Including**

Houses, shops, schools, hospitals, other special consumers, load data, average load of consumers, street lighting data, estimate of load growth, increase in consumer amount, and increase in load of "average consumer"[41].

B) Estimation of the Loads

As all the loads are not 100% at the same time, the peak load of the network is smaller than the sum of individual peak loads. This coincidence effect is taken into account by a diversity factor, which shows the relation of the real maximum network load to the sum of the maximum consumer loads connected to the network [40,41].

The coincidence effect must be considered when defining the loads of the lines and transformers, in order not to get too big cross-sections and transformer sizes. The diversity factor varies depending on the number and type of consumers, being normally 0.7 ... 0.85 [43,44]

3.7.2 Location of the Transformers

The transformer density should be defined so that the line distance from the MV/LV transformer to the furthest consumer should not be longer than 600m, to avoid problems in protection and voltage level. In special cases upon 900m distance may be approved after detailed analyses of the voltage drops, short-circuit currents and functionality of fuse protection [39,40].

3.7.3 Determination of Line Routes

The MV-line routes should approximately follow roads, in order to make the line construction and maintenance works easier. However, angles should be avoided when reasonably possible [39]. The LV-line routes should be defined so that all consumers requiring electricity are considered. The straightest routes are preferred in order to save cable and facilitate the installation work [40,45].

3.8 Loads and Measurements

Two of the most important parameters in distribution network design is the average consumer load and the annual load growth percentage in each consumer category. The Correct load information is essential for accurate and reliable network analysis [42]. The best way to achieve consumer load information is to carry out load measurements. The Homogenous consumers like households are measured in large groups, by measuring the load of a single feeder at transformer. Bigger consumers must be analyzed individually [42].

In case of electrification of new areas, consumer load information of similar consumers in other areas should be used when estimating the future loads in the new network [41]45].

3.9 Line Route Selection

The restricting factors affecting the process are engineering and technology, system planning (size & character of load, reliability of power sources, Positions of substations, future expansion possibilities, etc.), institutional, Economics (lowest operational and construction cost [43].

The Final choice is usually governed by cost having regard to future requirements and safety. In connection also final route selection is a matter of judgement and requires sound evaluation of divergent requirements including costs of easts, cost of clearing, costs of maintenance as well as what effect the line may have on the environment. The final route should be; economical, qualified for construction and easy to manage [43,46].

3.10 Description of the Study Area

Robe, more commonly known as Bale Robe (in order to differentiate it from other towns in Ethiopia which is also called Robe), is a town and separate woreda in south central Ethiopia. Located in the Bale Zone of the Oromia Region, this town has a latitude and longitude of 7°7′N 40°0′E with an elevation of 2,492 meters (8,176 ft) above sea level. It is located about 430 kilometers by road from Ethiopia's capital Addis Ababa[47].

Robe shares Robe Airport with neighboring Goba. Ethiopian Airlines has been scheduled flight two times a week connecting it to the capital Addis Ababa and to the southern city Arba Minch. The main market day is Thursday, with a smaller market working on Tuesdays and Sundays at another place in the town. Notable tourist attractions include the Sof Omar Caves, which lie to the east[47].

The national census reported a total population for Robe of 44,382, of whom 22,543 are men and 21,839 are women. The plurality of in habitants said they are Muslim, with 48.08% of the population reporting they observed this belief, while 45.02% of the population practiced Ethiopian Orthodox Christianity and 6.13% are Protestant. Records at the Nordic Africa Institute website provide details of a primary school in Robe in 1968.As of 2013, there are schools for secondary education in Bale Robe. There is also a teachers-training college, and university here called Mada Walabu University.The main mode of transport within the town is called "Auto rickshaw"(Bajaj) [47].

CHAPTER FOUR

DATA COLLECTION ANALYSIS AND INTERPRETATION

4.1 Background of Data Collection

In order to the investigation of power system reliability problem in distribution network of the Bale Robe town distribution system, the data collected are five years monthly historical statistical data of power interruption duration and frequency is used for the years from January 2015 up to December 2019. These historical data are collected from EEU South Eastern Region Distribution Substation. The distribution substation has been four 15kv feeder lines those are Goba feeder line, Agarfa feeder line, Madda Walabu University feeder line and Sinana feeder line and also two 33kv feeder line those are Maliyu and Gasera feeder line in the town, the evaluation is done for five feeder line that is city line feeder except Madda Walabu Feeder line [17].

4.2 Monthly Interruption Frequency and Duration of Interruption

Based on the collected data, five-year monthly power interruption frequency and interruption duration are plotted as drawn below [17].

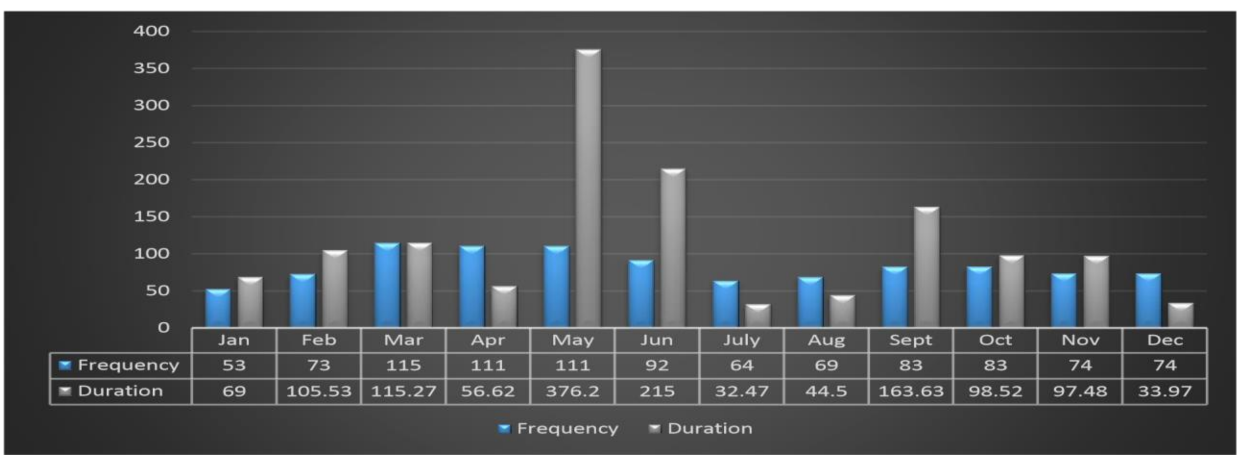


Fig.4. 1: Monthly interruption frequency and duration of interruption for the year 2007 E.C /2015 G.C

Depending on the data collected as it is observed from figure 4.1 more frequent interruptions has been happened in April, March and May, but the more duration interruption has been happened in May, Jun and September. Therefore, all types of this faults contribute for this much outage, the most frequently and duration happened fault in this months is transient short circuit [17].

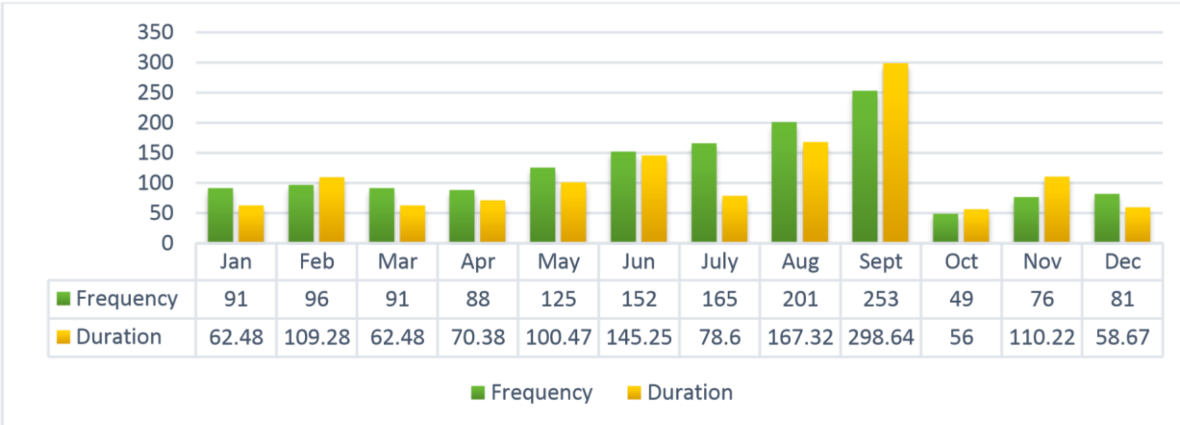


Fig.4. 2: Monthly interruption frequency and duration of interruption for the year 2008 E.C/2016 G.C

The Figure 4.2 shows that the majority of frequency interruption falls in the months of September, August and July are Permanent short circuit faults contribute the major fault for this months. On the other hand, from figure 4.2 the majority of duration interruption power outage existed in September, August and June and the main contributors for this outage are operational and permanent short circuit faults [17].

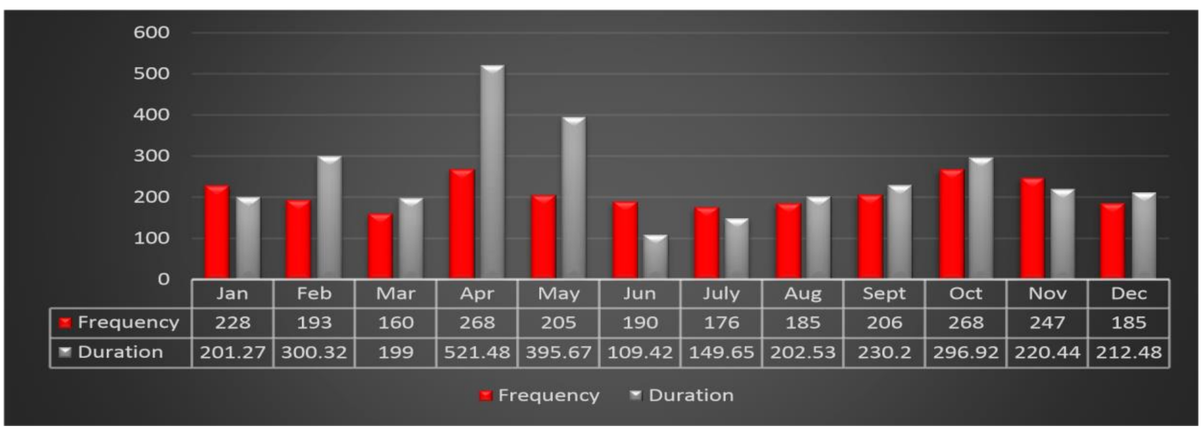


Fig.4. 3: Monthly interruption frequency and duration of interruption for the year 2009 E.C/2017 G.C

Based on the data as it is seen from figure 4.3, in April, October and January are more frequent power interruption and also April, May and February are more duration of power interruption are happened. The most contributor for this much power interruption is a frequently happened permanent short circuit fault [17].

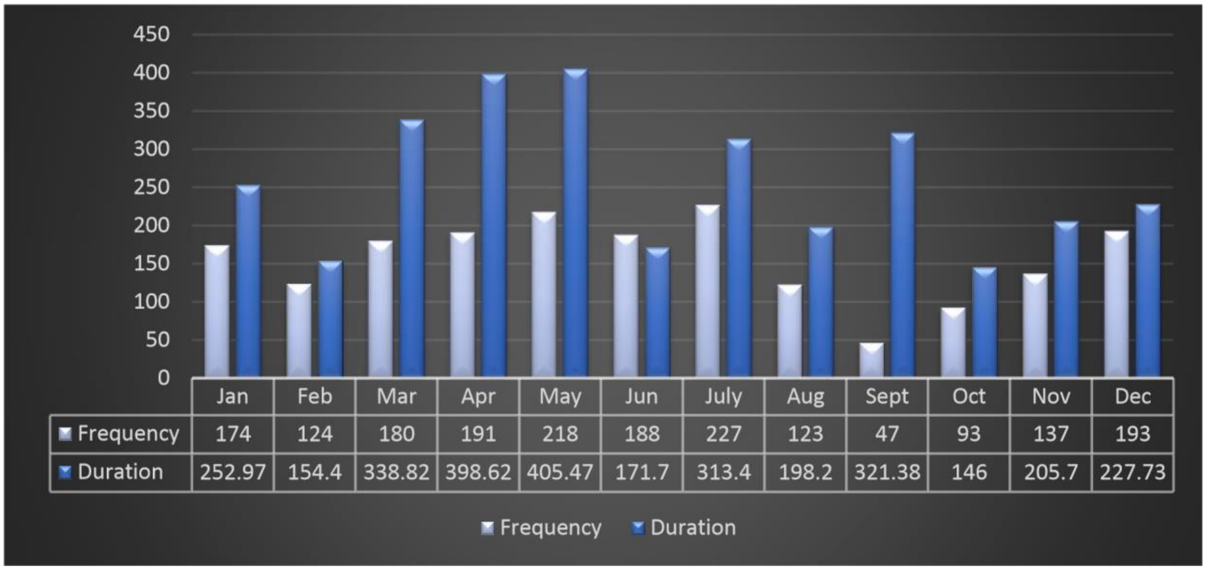


Fig.4. 4: Monthly interruption frequency and duration of interruption for the year 2010 E.C/2018 G.C

It can be seen from figure 4.4 that in July and May the most power outage frequency and May and April are the duration of power outage has been happened. This is predominantly due to a frequently happened operational and permanent short circuit faults [17].

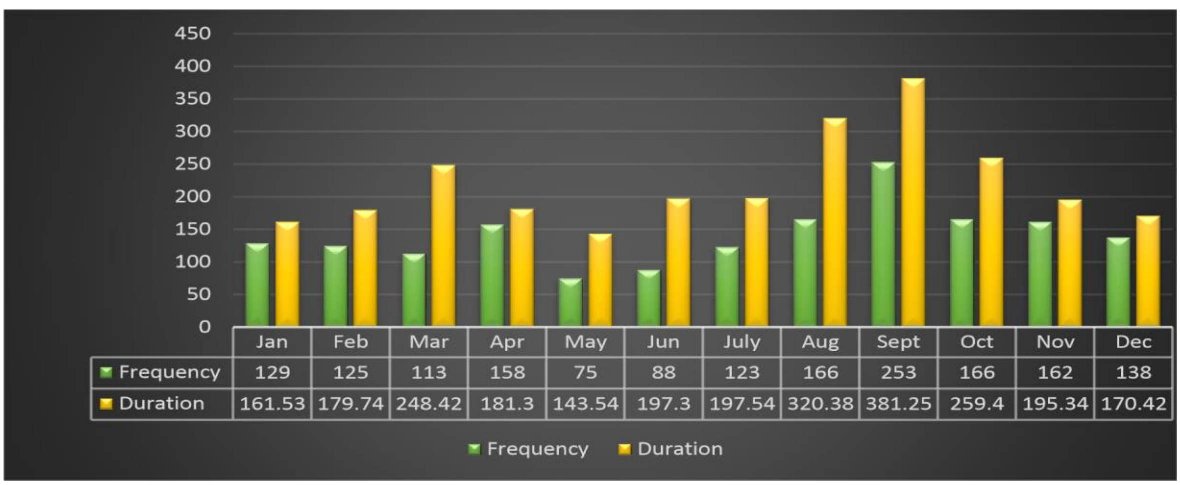


Fig.4. 5: Monthly interruption frequency and duration of interruption for the year 2011 E.C/2019 G.C

The Figure 4.5 shows that the majority of frequency interruption falls in the months of September, August and November are Permanent short circuit faults contribute the major fault for this months. On the other hand, from figure 4.5 the majority of duration interruption power outage existed in September, August and March and the main contributors for this outage are operational and permanent short circuit faults [17].

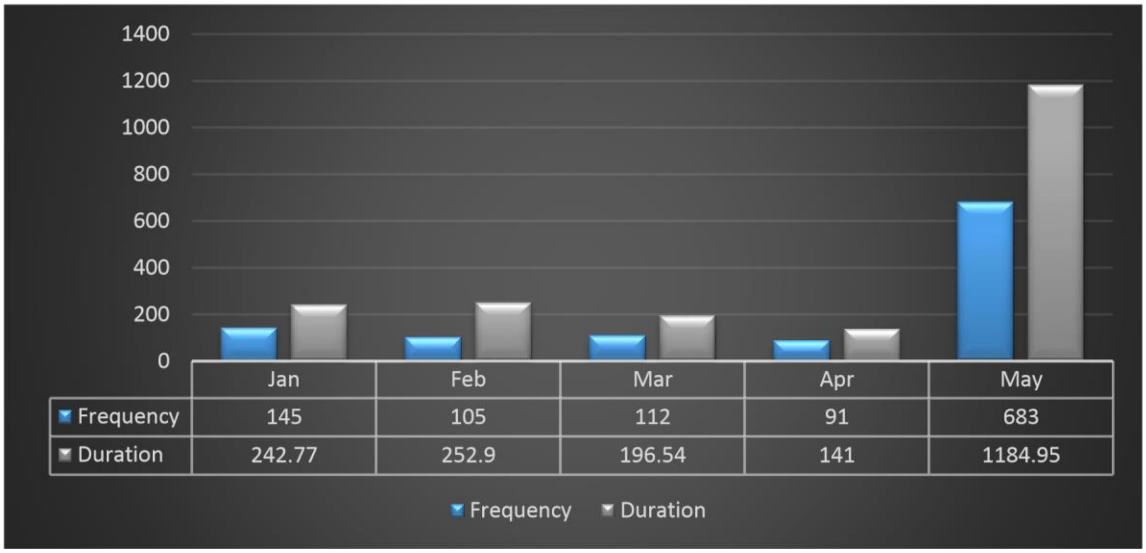


Fig.4. 6: Monthly interruption frequency and duration of interruption for the year 2012 E.C/2020 G.C

The Figure 4.6 above shows that the May month majority of frequency interruption and duration of interruption falls is Permanent short circuit faults (Line to Line contact such as due to fall down of tree) contribute the major fault for this month's respectively. So the main contributors for this outage is operational and permanent short circuit faults happened [17].

When generalize, the figure above 4.1 up to 4.6 monthly interruption frequency and interruption duration are plotted depending on data gained from Bale Robe distribution substation. The months' interruption duration and interruption frequency, there are six main fault types those are temporary short circuit, temporary earth fault, operational, permanent short circuit, permanent earth fault and load shading as mentioned are happened in Bale Robe town distribution substation [17].

4.3 Depending on Data Collected the Analytical Method of Reliability Indices Evaluation and Analysis

From the point of view after the data are collected, using mathematical analysis that means customer-oriented and energy-oriented indices are calculated. Based on the customer oriented and energy-oriented indices all system indices are calculated using equation 2.1 up to 2.8. The following figures explain the five-year system indices which are done using analytical evaluation [50,51,52].

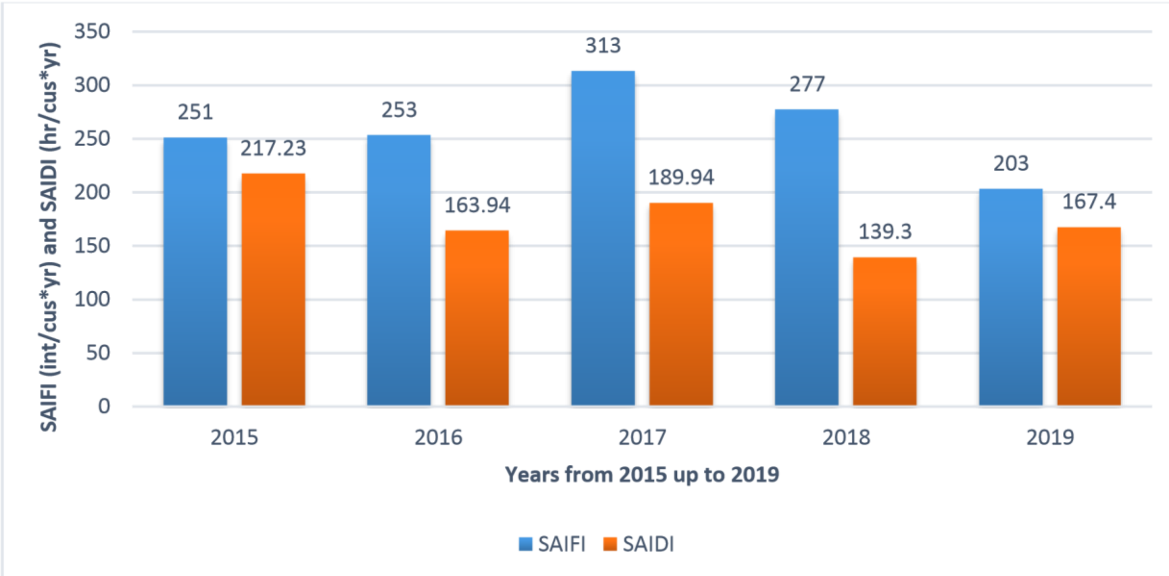


Fig.4. 7: Five years SAIFI (int/cust/yrs) and SAIDI (hr/cust/yrs) value of Goba Feeder Line [Appendix G**]**.

Depending on the point of view as it is seen from figure 4.7, the system interruption frequency index is increased from 251 Int/customers/year in 2015 to 313 Int/customers/year in 2017 and decreased from 313 Int/customers/year in 2017 to 203 Int/customers/year in 2019.

The system interruption duration index decreased from 217.23 hr/customers/year in 2015 to 163.94 hr/customers/year in 2016 and 189.94 hr/customers/year in 2017 to 139.3 hr/customers/year in 2018.It is increased from 163.94 hr/customers/year in 2016 to 189.94 hr/customers/year in 2017 and also increased from 139.3 hr/customers/year in 2018 to 167.4 hr/customers/year in 2019 .Generally the Goba feeders of the line are not close to Ethiopian standards of reliability indexes and international standards.

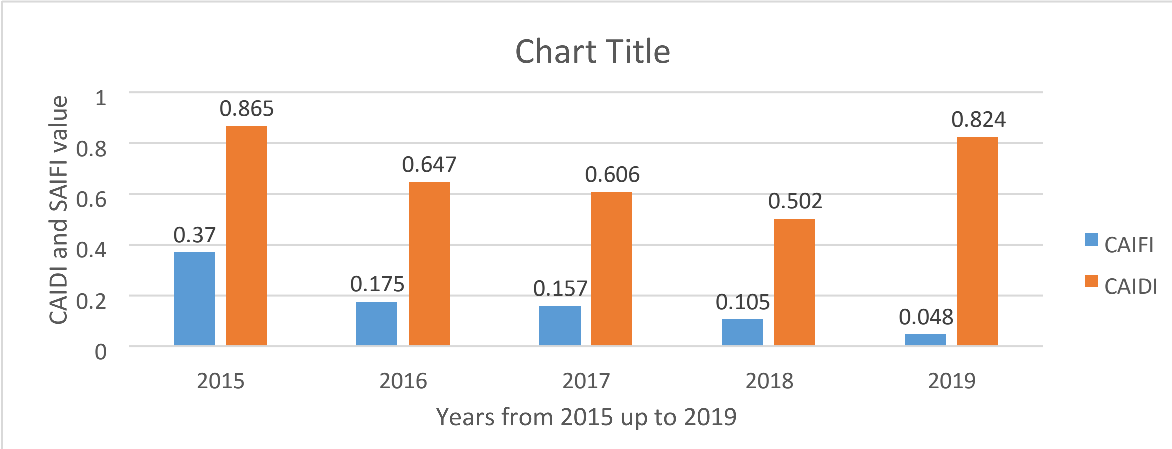


Fig.4. 8: Five years CAIFI (int/cust) and CAIDI (hr/int) value of Goba Feeder Line [Appendix G]

As it is seen above figure 4.8: the customers average interruption interruption frequency index is decreased from 0.37 Int/customers in the year 2015 to 0.048 Int/customers in year 2019. The customer average interruption duration indexes decreased from 0.865 hr/int 2015 to 0.502hr/int in 2018 and also increased from the 0.502 hr/int year 2018 to 0.824 hr/int 2019.

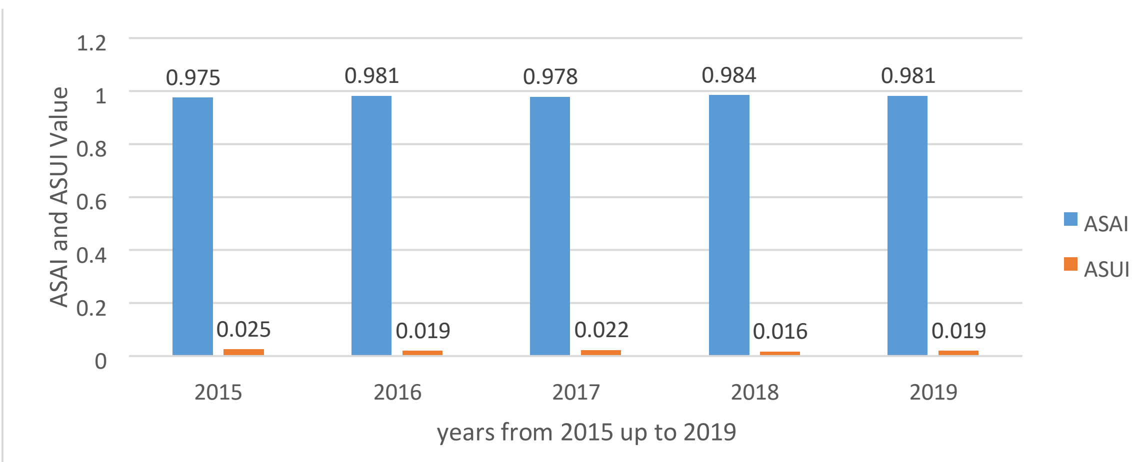


Fig.4. 9: Five years ASAI and ASUI value of Goba Feeder Line [Appendix G]

Depending on the point of view as it is seen from figure 4.9, the average system availability index is increased from 97.50% in 2015 to 98.10% in 2016, and decreased 2016 to 2017 again increased from the year 2017 to 2018, and also decreased from 2018 to 2019. The average system unavailability index decreased from 2015 to 2016, increased from 2016 to 2017 and decreased from 2017 to 2018 again also increased from the year of 2018 up to 2019.

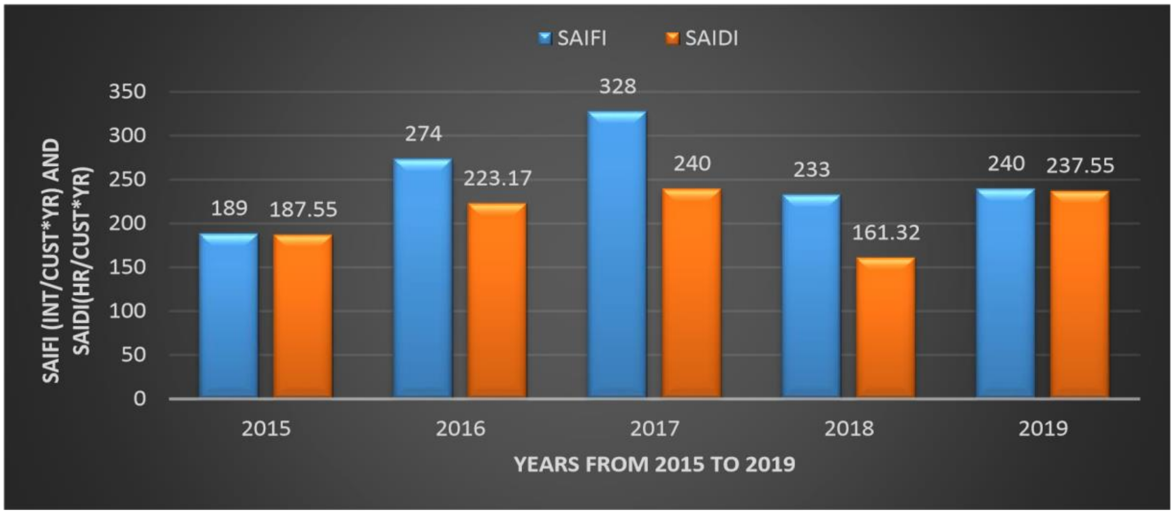


Fig.4. 10: Five years SAIFI (int/cust/yr.) and SAIDI (hr/cust/yr.) value of Agerfa Feeder Line [Appendix G]

Depending on the point of view as it is seen from figure 4.10, the system interruption frequency index is increased from 189 Int/customers/year in 2015 to 328 Int/customers/year in 2017, decreased from 328int/customers/yr. to 233 int/customers/yr. and also increased from the year of 2018 up to 2019.The system interruption duration index increased from the years 2016 to 2017 and 2018 to 2019. In this five consecutive is decreased from 187.55 hr/customer/yr. 2015 to 240 hr/customer/yr. 2017 and decreased from 2017 to 2018 and also increased from the year of 2018 to 2019.Generally the Agerfa feeders of the line are not close to Ethiopian standards of reliability indexes and international standards.

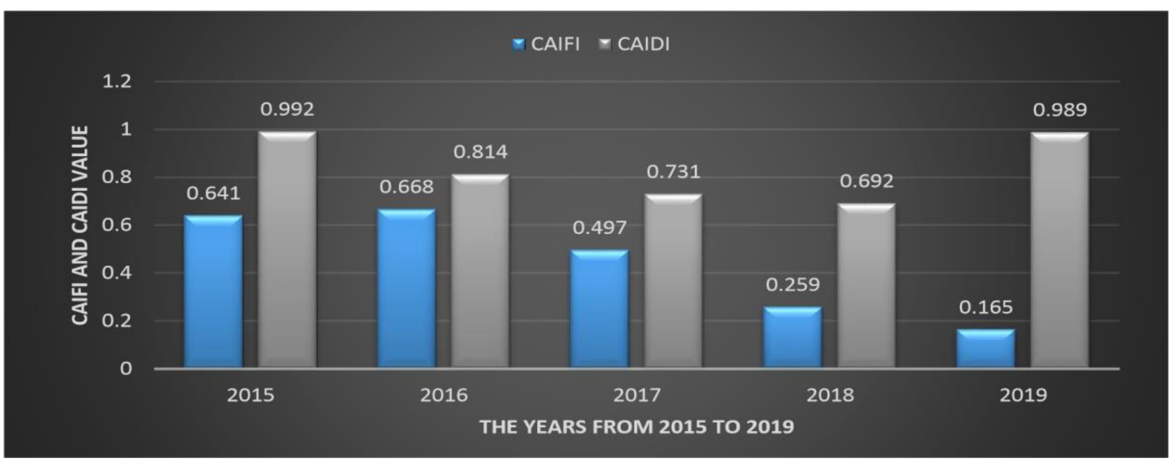


Fig.4. 11: Five years CAIFI (int/customer) and CAIDI (hr/int) value of Agerfa Feeder Line [Appendix G]

As it is seen above figure 4.11: the customers average interruption frequency index is increased from 0.641 Int/customers in the year 2015 to 0.668 Int/customers in year 2016 and decreased from 2016 0.668 Int/customers to 0.165int/cust in the years of 2019.The customer average interruption duration indexes decreased from 0.992 hr/int 2015 to 0.692hr/int in 2018 and also increased from the 0.692 hr/int year 2018 to 0.989 hr/int 2019.

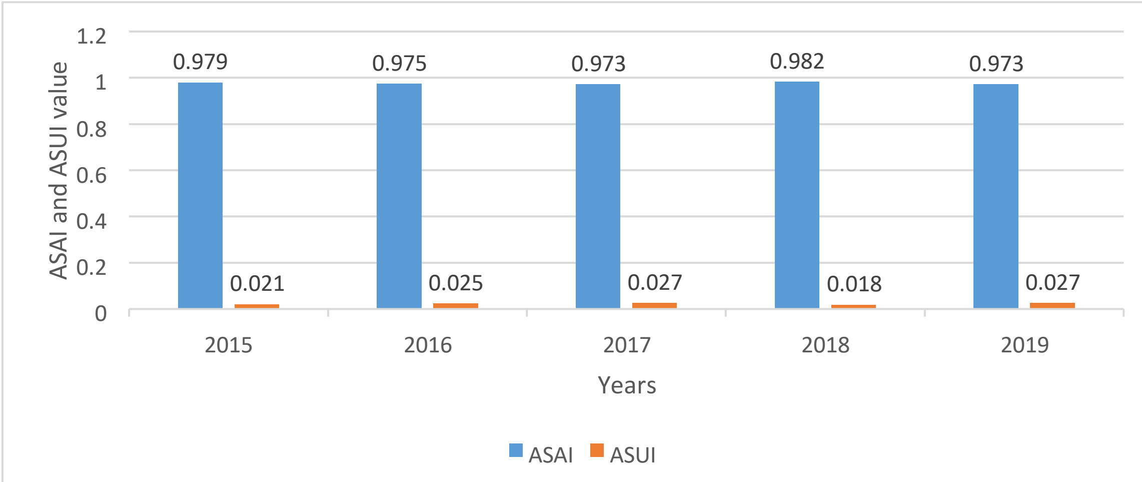
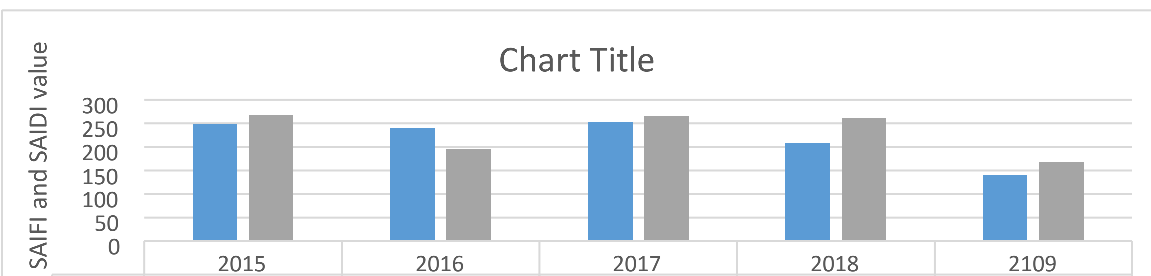


Fig.4. 12: Five years ASAI and ASUI value of Agerfa Feeder Line [Appendix G]

Depending on the point of view as it is seen from figure 4.12, the average system availability index is decreased from 97.9% in 2015 to 97.3% in 2017, and increased from 2018 to 2019. The average system unavailability index decreased from 2015 to 2017and increased from 2018 to 2019.



	2015	2016	2017	2018	2109
SAIFI	248	239	252	207	139
SAIDI	267	194.35	265.34	260.25	167.55

Fig.4. 13: Five years SAIFI (int/cust/yr.) and SAIDI (hr/cust/yr.) value of Sinana Feeder Line [Appendix G]

Depending on the point of view as it is seen from figure 4.13, the system interruption frequency index is decreased from 248 Int/customers/year in 2015 to 239 Int/customers/year in 2016, decreased from 252 int/customers/yr. in 2017 to 139 int/customers/yr. in 2019.The system interruption duration index decreased from the years 2015 to 2016 and 2017 to 2018.And also increased 2016 to 2017 and decreased again 2018 to 2019. Generally, the sinana feeders of the line are not close to Ethiopian standards of reliability indexes and international standards.

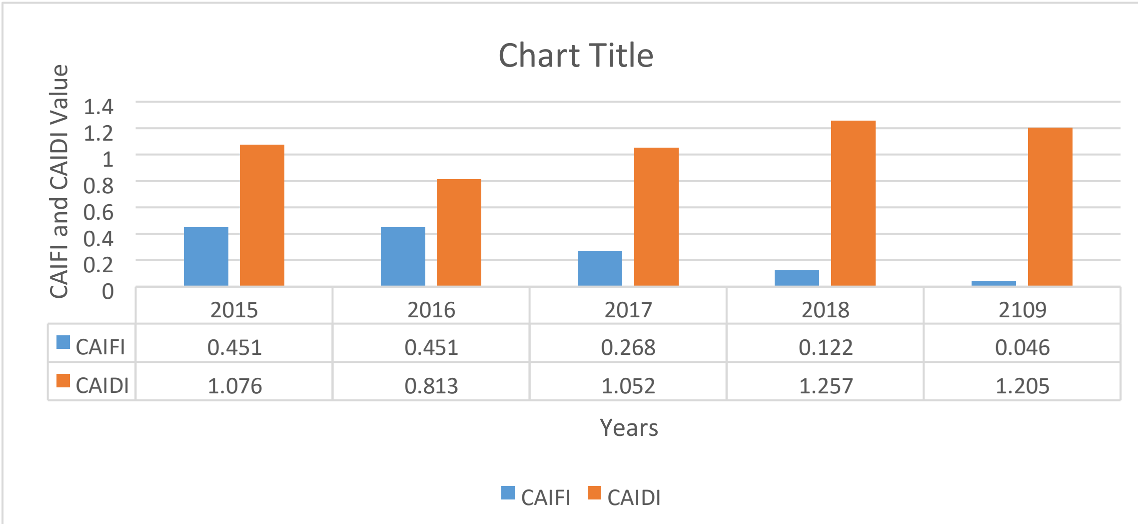


Fig.4. 14: Five years CAIFI (int/customer) and CAIDI (hr/int) value of Sinana Feeder Line [Appendix G]

As it is seen above figure 4.14: the customers average interruption frequency index is decreased from 0.451 Int/customers in the year 2015 to 0.046 Int/customers in year 2019.The customer average interruption duration indexes decreased from 1.076 hr/int 2015 to 0.813hr/int in 2016 and from the 1.052 hr/int year 2017 to 1.205 hr/int 2018 and also decreased from 2018 to 2019, otherwise increased case.

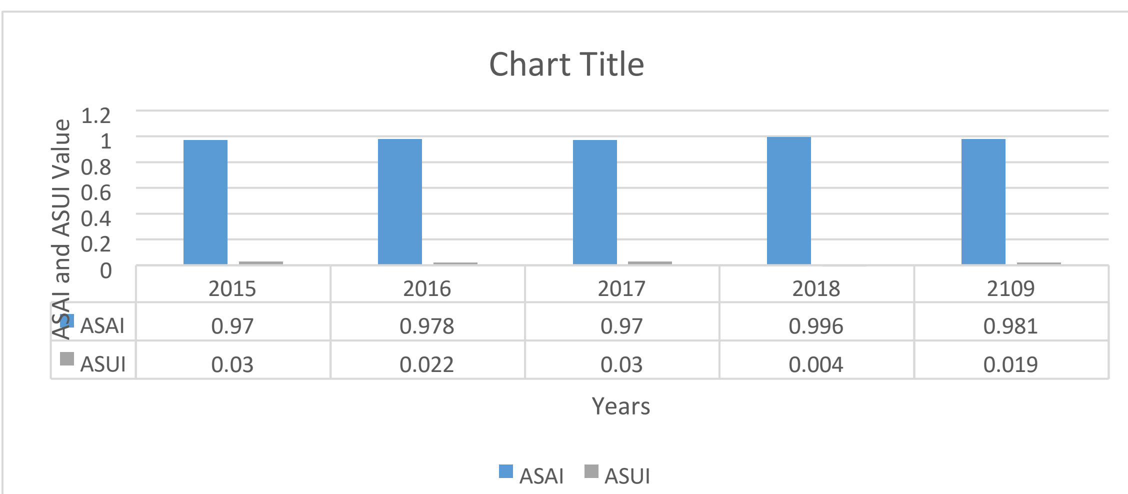


Fig.4. 15: Five years ASAI and ASUI value of Sinana Feeder Line [Appendix G]

Depending on the point of view as it is seen from figure 4.15, the average system availability index is increased from 97. % in 2015 to 97.8% in 2016, and 2017 to 2018 increased and from the year 2016 to 2017 decreased again decreased from the year 2018 to 2019. The average system unavailability index decreased from 2015 to 2016 and decreased from 2017 to 2018.

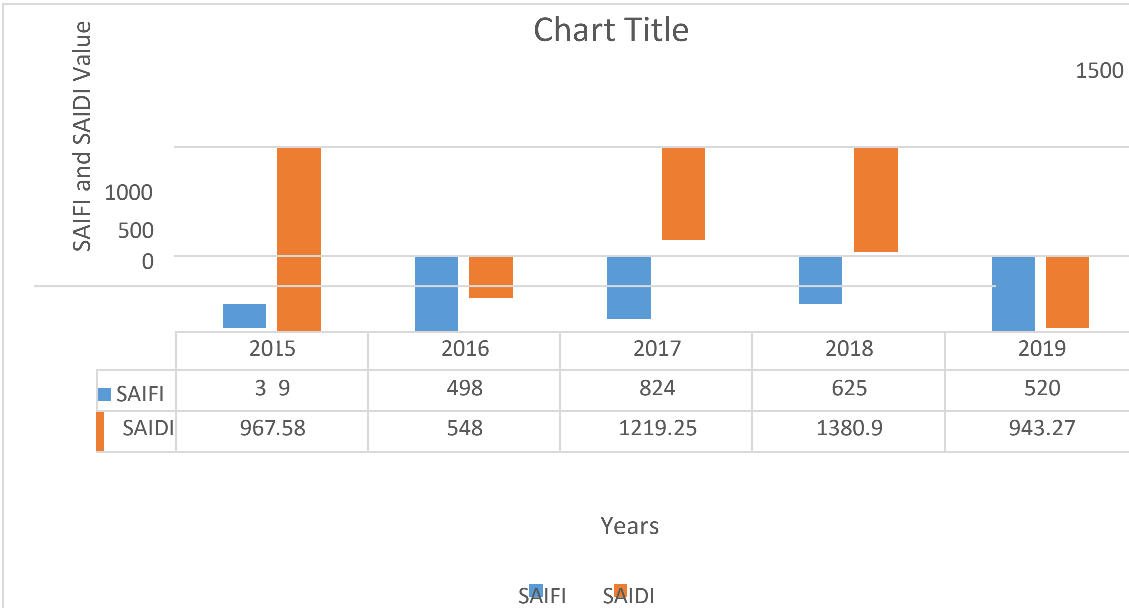


Fig.4. 16: Five years SAIFI (int/cust/yr.) and SAIDI (hr/cust/yr.) value of Gasera Feeder Line [Appendix G]

Depending on the point of view as it is seen from figure 4.16, the system interruption frequency index is increased from 319 Int/customers/year in 2015 to 824 Int/customers/year in 2017, decreased from 824 int/customers/yr. in 2017 to 520 int/customers/yr. in 2019.The system interruption duration index decreased from the years 2015 to 2016 and 2018 to 2019.And also increased 2016 to 2018. When generalize the Gasera feeders of the line is very far from Ethiopian standards of reliability indexes and international standards.

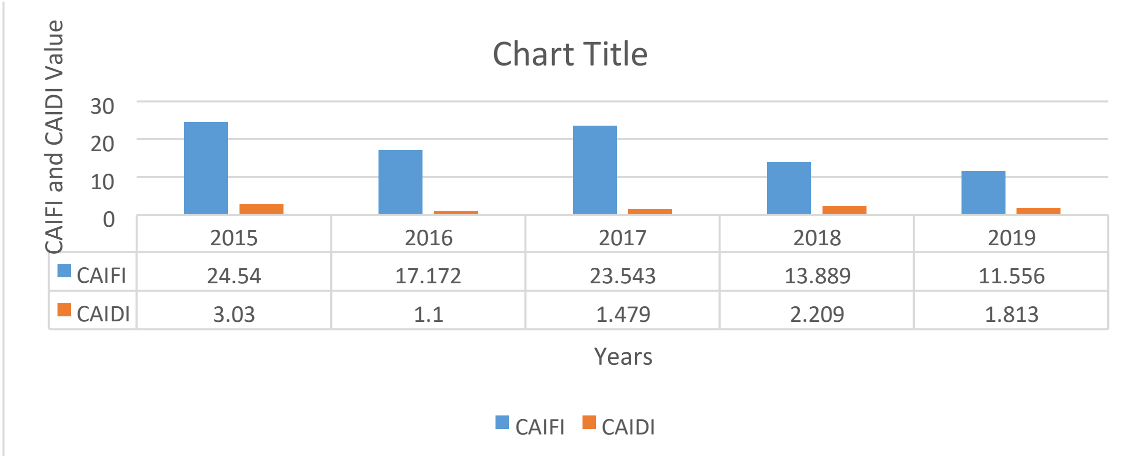


Fig.4. 17: Five years CAIFI (int/customer) and CAIDI (hr/int) value of Gasera Feeder Line [Appendix G]

As it is seen above figure 4.17: the customers average interruption frequency index is decreased from 24.54 Int/customers in the year 2015 to 17.172 Int/customers in year 2016 and from the year of 2017 to 2019.The customer average interruption duration indexes decreased from 3.03 hr/int 2015 to 1.1 hr/int in 2016 and from 1.479 hr/int year 2017 to 1.813 hr/int 2019 and also increased from 2016 to 2017.

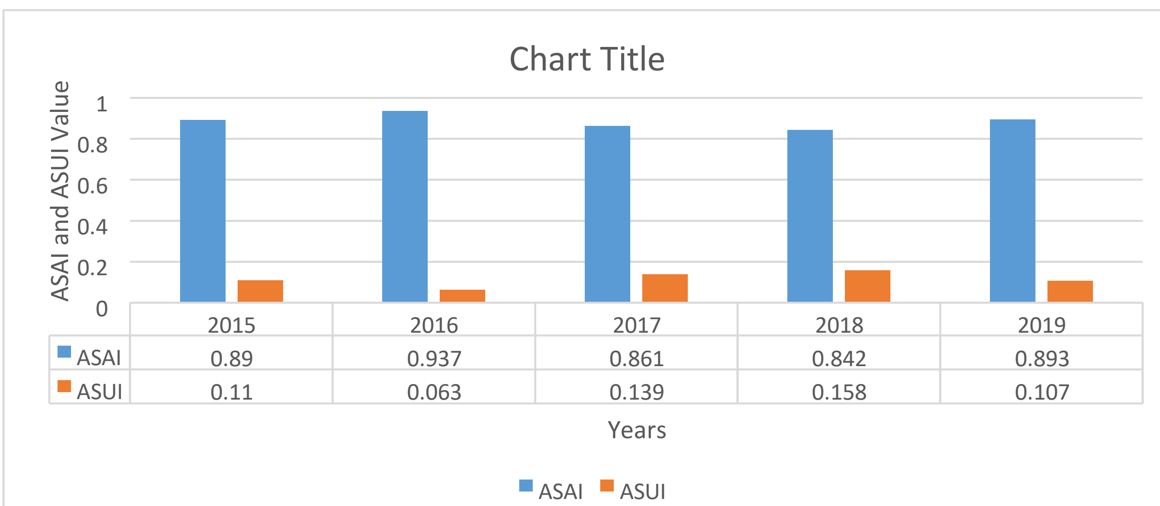


Fig.4. 18: Five years ASAI and ASUI value of Gasera Feeder Line [Appendix G]

Depending on the point of view as it is seen from figure 4.18, the average system availability index is decreased from 93.7% in 2016 to 84.2% in 2018. The average system unavailability index increased from 2015 to 2016 and increased from 2018 to 2019.

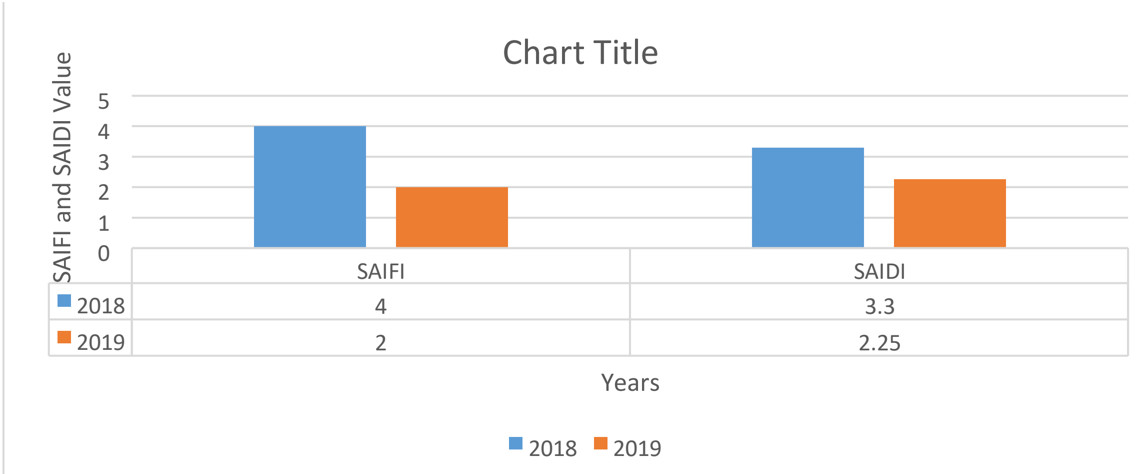


Fig.4. 19: Two years SAIFI (int/cust/yr.) and SAIDI (hr/cust/yr.) value of Madda Walabu University Feeder Line [Appendix G]

Depending on the point of view as it is seen from figure 4.19, the system interruption frequency index is decreased from 4 Int/customers/year in 2018 to 2 Int/customers/year in 2019.The system interruption duration index decreased from the years 2018 to 2019.

When generalize the Madda Walabu University is the best feeders from all five feeders of the line is very closest from Ethiopian standards of reliability indexes and approach to international standard index. The feeder line of Madda Walabu University is the best feeders of all because of the distance of the feeder is 3km from the substation and the probability of medium voltage failure is less.

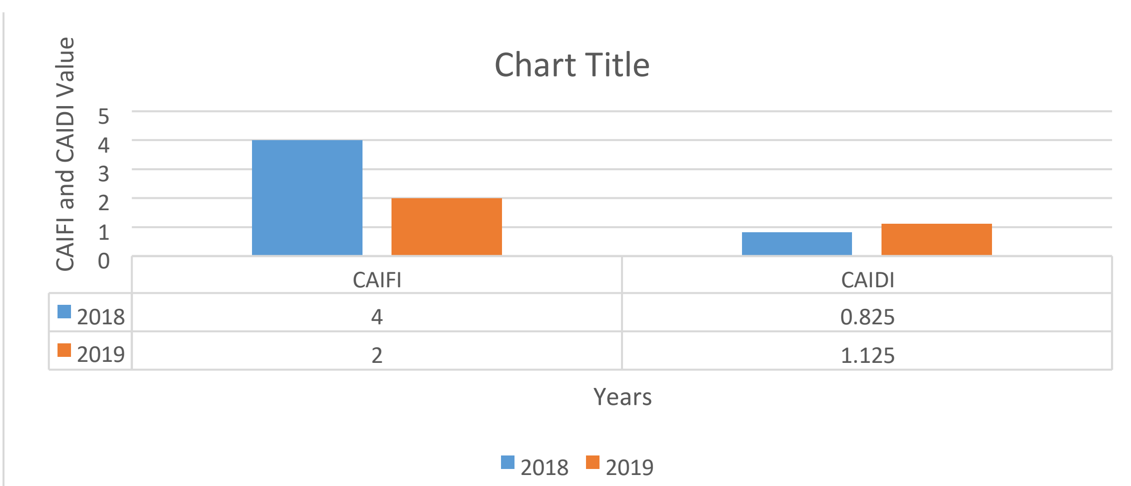


Fig.4. 20: Two years CAIFI (int/customer) and CAIDI (hr/int) value of Madda Walabu University Feeder Line [Appendix G]

As it is seen above figure 4.20: the customers average interruption frequency index is decreased from 4 Int/customers in the year 2018 to 2Int/customers in year 2019.The customer average interruption duration indexes increased from 0.825 hr/int 2018 to 1.125 hr/int in 2019.

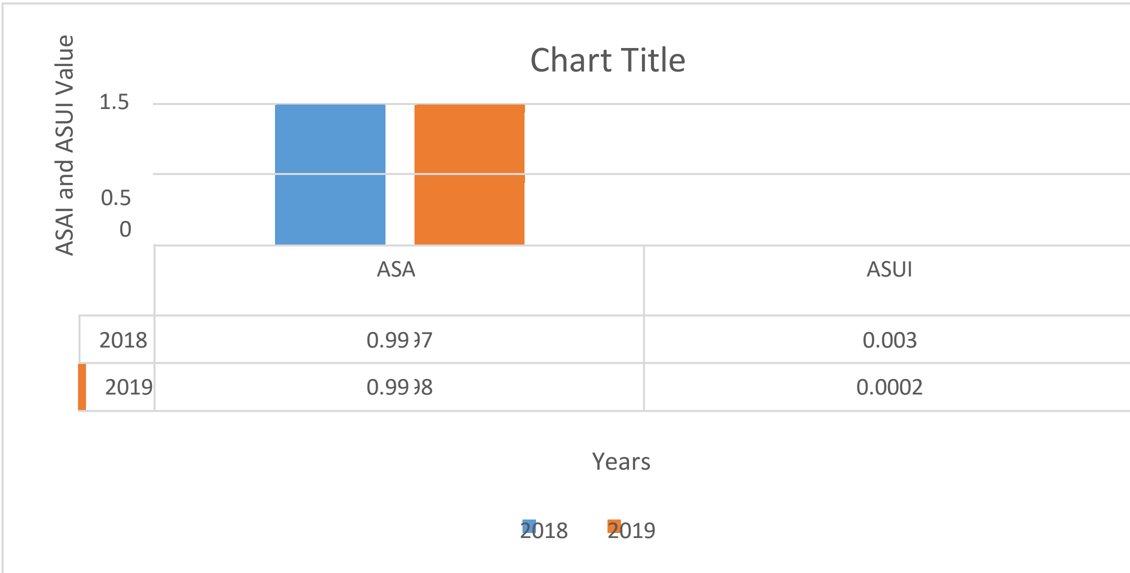


Fig.4. 21: Two years ASAI and ASUI value of Madda Walabu University Feeder Line [Appendix G]

Depending on the point of view as it is seen from figure 4.21, the average system availability index is increased from 99.97% in 2018 to 99.98% in 2019. The average system unavailability index decreased from 2018 to 2019. Generally, the Madda Walabu University is the best feeders from all five feeders of the line is very closest to both Ethiopian standards of reliability indexes and international standard index.

Table 4.1 below shows that the average reliability indices of bale Robe town feeder and the overall system which is calculated using the average frequency and duration of interruptions of the years from 2015 to 2019 by using equations 2.1, 2.2,2.3,2.4 ,2.5,2.6,2.7 and 2.8.

Table.4. 1: The average reliability indexes of south east (Robe town) substation without Recloser and other protective device.

Feeder Name	SAIFI	SAIDI	CAIDI	ASAI	ENS(MwHr) (2015-2019)
Goba Feeder	259	175.56	0.69	0.9798	295.1025
Agerfa Feeder	253	209.92	0.85	0.9764	315.1576
Sinana Feeder	217	230.90	1.08	0.9790	151.0736
MWU Feeder	3	1.11	0.39	0.9997	120.960
Gasera Feeder	557	1011.8	1.93	0.8846	426.462
Average Overall System	258	325.86	0.998	0.9634	261.75

Table.4. 2: The average reliability indices of south east (Robe town) substation with Recloser and other protective device

Feeder Name	SAIFI	SAIDI	ENS(MwHr)(2015-2019)
Goba Feeder	1.2505	65.345	144.923
Agerfa Feeder	1.1588	56.3908	187.127
Sinana Feeder	1.205	53.360	68.360
Overall System	1.21	58.37	133.47

Table 4.3: shows the reliability indices (SAIFI and SAIDI) of best experienced countries including that of the Ethiopian Power Energy Authority (EEA) and compare with South East (Robe town) substation. This reliability index shows that the reliability of the network is very far from international standards as shown in table 4.3 below.

Table.4. 3: Reliability indices standards of different countries [19].

Country		SAIDI (Hours/year)	SAIFI (Interruptions/years)
United States		4	1.5
UK		1.5	0.8
Italy		0.967	2.2
Spain		1.73	2.2
Austria		1.2	0.9
Netherlands		0.55	0.3
Denmark		0.4	0.5
France		1.03	1
Ethiopia		25	20
South East Region (Robe Town) Substation	Goba F	175.56	259
	Agerfa F	209.92	253
	Sinana F	230.90	217
	MWU F	1.11	3
	Gasera F	1011.8	258
Overall System		325.86	198

When generalize the South Eastern Substation (Robe town substation) based on the data collected and analysis there is a problem of reliability because of the following major point are drawn below:

1. The reliability of the power supply in Robe town not meet to the requirements set by the regulatory body that was Ethiopian Electric Agency (EEA) except Madda Walabu Feeder Line.
2. In comparison to reliability standards set by Ethiopian Electric Power Authority, Bale Robe distribution system has reliability indices values far away from the Ethiopian standard and international standards (bench marks) of many countries such as United State, United Kingdom, Italy, Spain, Austria, Netherlands, Denmark and France.
3. There was very low availability of electric power in the network (Especially Gasera Line Feeder 33kv).

4. There was also much loss of energy not supplied (ENS) due to sustained interruptions of Robe Town Substation.

4.4 The Loss of Revenue Before and After Improvement in Bale Robe Town Distribution Substation due to Power Interruption

Depending on the data gained and simulation result after the reliability of the existing power distribution system is improved using two (2) normally closed recloses and other protective device, the total five feeder of average unsold energy not supplied is 261.75 MWh per year before recloser is used and after recloser the simulation of average unsold energy not supplied is 133.47MWh per year. In this thesis my contribution must as possible reduce the SAIFI, SAIDI and ENS compared with the existing system.

The improvement can be estimated as follows;

Case1: The revenue loss before improvement due to the interruption of power in distribution substation energy is the first three feeder lines were Goba, Agerfa and Sinana can be calculated below;

[0.273 to 0.6943 Birr/kWh] * 761333.7 KWHr = 207,844.1 to 528,593.98 Birr/year.

Therefore, the average revenue loss is 368,219.04 Birr per year which was $11,506.845 per year.

Case2: The next two feeders are The revenue loss before improvement due to the interruption of power in distribution substation energy was:

[0.273 to 0.6943 Birr/kWh] * 547442 KWHr = 14,9451.67 to 380,088.98 Birr/year.

Therefore, the average revenue loss is 264,770.325 Birr per year which is $8,274.073 per year.

Generally, the case1 and case2 average revenue loss is 632,989.365 Birr per year which is $19,780.92 per year

The revenue loss after improvement due to the power interruption of distribution substation energy is:

[0.273 to 0.6943 Birr/kWh] * 400410KWHr = 109,311.93 to 278,004.663 Birr/year.

Therefore, the average revenue loss is 193,658.30 Birr per year which was $6,051.82 per year.

Generally, the average saved revenue because of reliability improvement is 174,560.11 Birr per year.

In order to calculate the investment cost of one reclosers used to design the system. Average cost of one Smart Recloser is $12,000*32 Birr/dollar=384,000 Birr [27], for total three feeders of line needs two recloser each. Therefore, we need totally six recloser, the total cost of six recloser was become=384,000 Birr*6=2,304,000 Birr.

The payback period or after recloser inserted practically the years of recover the recloser and other other accessories life time can be calculated as follow [3]:

$$PaybackPeriod = \frac{InvestementCost(Birr)}{AnnualSaving(Birr / Year)} \tag{4.1}$$

Payback period=2,304,000/174560.11=13.2 Years

4.5 The Technique of Reliability Improvement of the Distribution system

Generally, there is a problem of Reliability of distribution system of the network in Bale Robe town.so in order to minimization of this problem listed below;

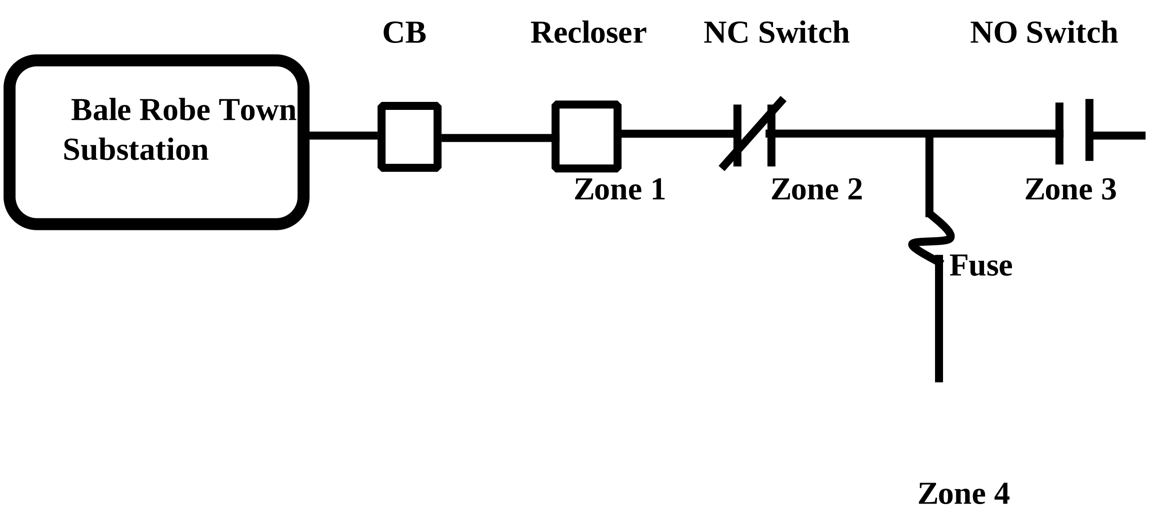


Fig.4. 22: The block diagram Design of system reliability improvement

Recloses: Similar to the Relay and Fuse objects, it controls the terminal switches of the switched element according to the current flowing through the monitored element. The Reclose object also has been the capability to perform reclosing actions; furthermore, two different time-current curves can be defined (one fast and one slow/delayed) [43].

They are switching devices that have the capability to return to their original closed position after a waiting time (referred to as dead time) has passed since they opened [44]. A recloser can perform several opening operations (usually between 2 and 4) before it locks out in an open position. Reclosers are defined by two time-curves (one fast and one slow), the number of opening operations (according to the fast and slow time-curves), and dead time between the opening and reclosing operation [45].

Circuit breakers: A circuit breaker is a switching device designed to open and close a circuit by non-automatic means and to open the circuit automatically upon a signal sent by an external controller [45]. Closed switching devices can be modeled as a small impedance or by internally fusing the buses connected by the switch [46].

Relays: It is a protective device that is connected to one terminal of a circuit element; it can monitor currents and voltages at the terminal to which it is connected. It uses the current and voltage values to operate the terminal switches of the switched circuit element; it also has the capability to perform reclosing actions. The monitored and switched circuit element must be explicitly defined. They are external controllers used to automatically operate circuit breakers and are characterized by their time-curve [46]. Time-curves reflect the switch opening time as a function of the monitored electrical variable; opening times are defined to prevent any damage to the system elements or the general public.
Time-curves can be device-specific (developed by the device's manufacturer) or calculated according to a set of equations [47]. Relays can be used to monitor voltages, currents, or any other internal element variable that is relevant to the system protection scheme [53,54].

Fuses: It is a protective device that controls the terminal switches according to the current flowing through the monitored element. As in the Relay object, the monitored and switched element must be defined explicitly. Although real fuse operation is determined by two different time-curves (minimum melting time and maximum clearing time), their representation follows the same principle as relays; that is, it is a switching device whose operation is defined by a single time-curve [48].

Sectionalizes: Line sectionalizes is switching devices that do not possess the capability to interrupt fault currents; therefore, they must be coordinated with an upstream recloser [48]. A sectionalizes counts the number of times the monitored current surpasses a threshold value and locks out in an open position after a predefined number of operations have occurred (usually 2 or 3). The opening operation is performed during the upstream recloser's dead time.

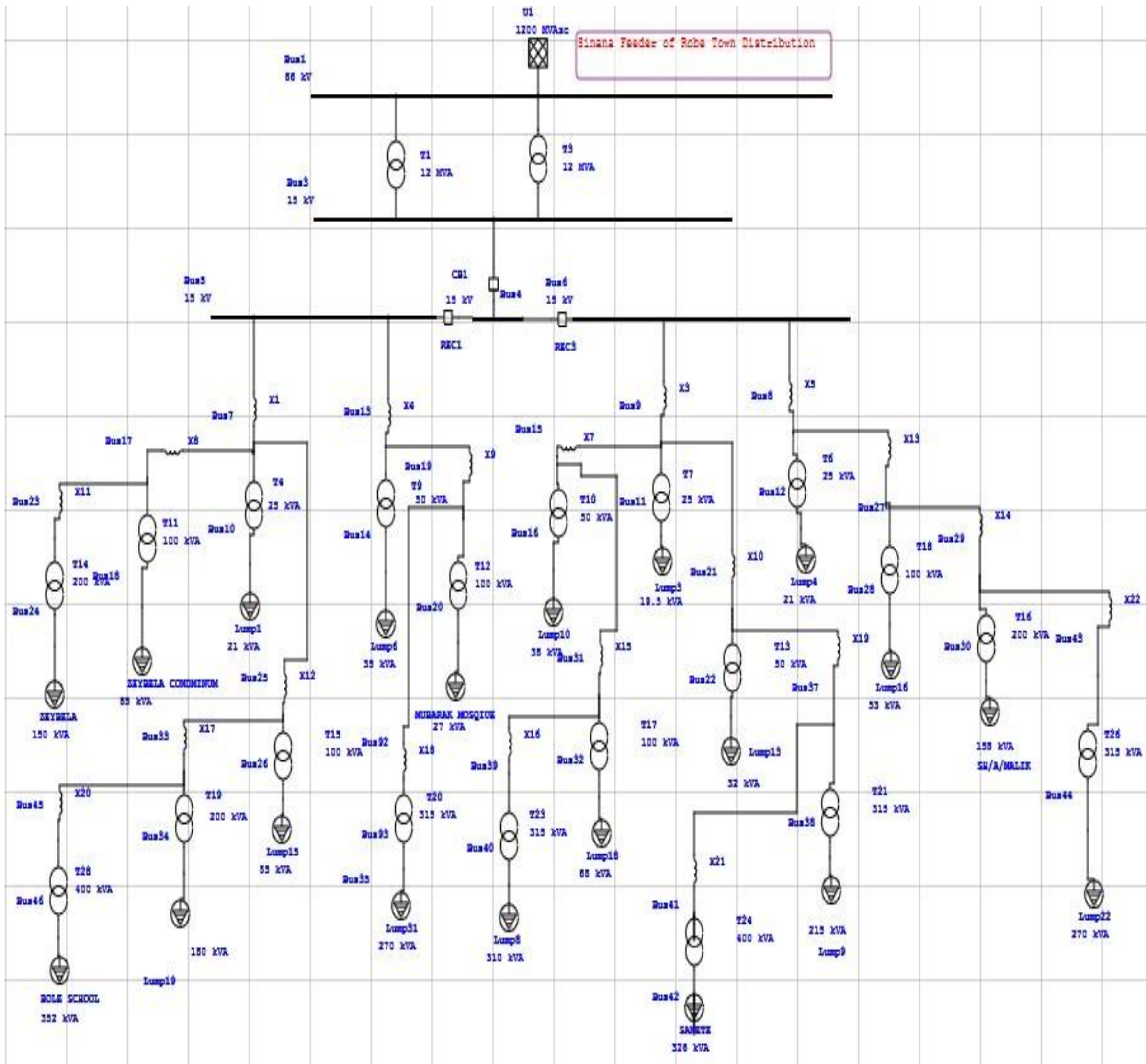


Fig.4. 23: Robe Town Distribution of Sinan feeder on ETAP software with Reclosers

Project:		ETAP	Page:	1
Location:		16.0.0C	Date:	14-07-2020
Contract:			SN:	4359168
Engineer:		Study Case: RA	Revision:	Base
Filename:	Sinana Feeder		Config.:	Normal

SUMMARY

System Indexes

ACCI	kVA/ customer
AENS	6.2145 MW hr/ customer-yr
ALII	kVA pu
ASAI	0.9939 pu
ASUI	0.00608 pu
CAIDI	47.097 hr / customer interruption
CTAIDI	hr / customer
ECOST	190,698.70 $ / yr
EENS	68.360 MW hr / yr
IEAR	2.790 $ / kW hr
SAIDI	53.2430 hr / customer-yr
SAIFI	1.1305 f / customer.yr

ACCI	System Average Customer Curtailment Index
AENS	Average Energy Not Supplied
ALII	System Average Connected kVA Interrupted per kVA of Connected Load Served
ASAI	Average service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CTAIDI	System Customer Total Average Interruption Duration Index
ECOST	Expected Interruption Cost
EENS	Expected Energy Not Supplied
IEAR	Interruption Energy Assessment Rate
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index

Fig.4. 24: Simulation result of Sinana feeder on ETAP software with Reclosers

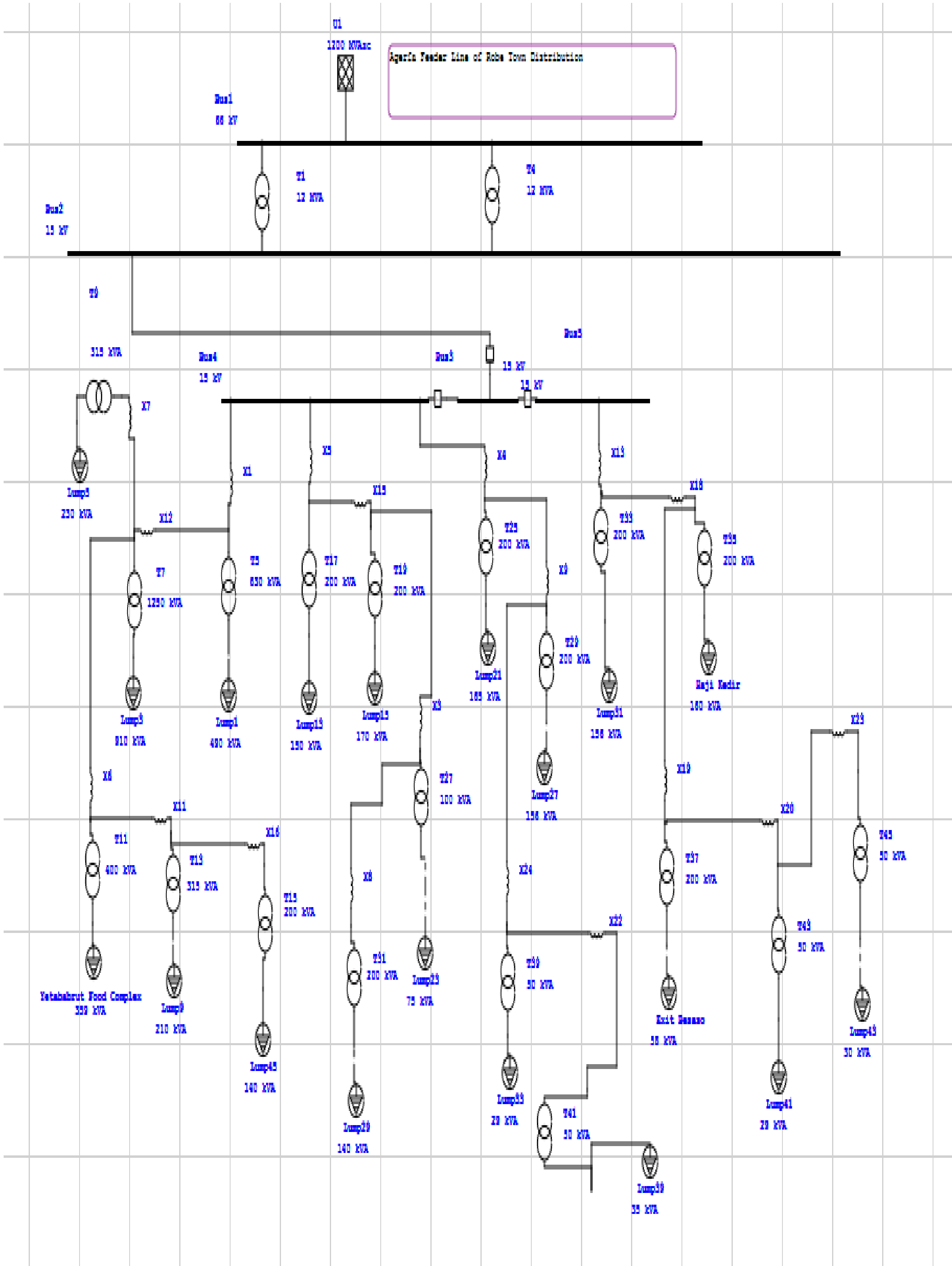


Fig.4. 25: Robe Town Distribution of Agarfa feeder on ETAP software with Recloses

Project:		ETAP	Page:	1
Location:		16.0.0C	Date:	20-07-2020
Contract:			SN:	4359168
Engineer:		Study Case: RA	Revision:	Base
Filename:	Agerfa Feeder Analysis		Config.:	Normal

SUMMARY

System Indexes

ACCI	kVA/ customer
AENS	9.8514 MW hr / customer.yr
ALII	kVA pu
ASAI	0.9936 pu
ASUI	0.00644 pu
CAIDI	48.665 hr / customer interruption
CTAIDI	hr / customer
ECOST	1,412,814.00 $ / yr
EENS	187.176 MW hr / yr
IEAR	7.548 $ / kW hr
SAIDI	56.3908 hr / customer.yr
SAIFI	1.1588 f / customer.yr

ACCI	System Average Customer Curtailment Index
AENS	Average Energy Not Supplied
ALII	System Average Connected kVA Interrupted per kVA of Connected Load Served
ASAI	Average service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CTAIDI	System Customer Total Average Interruption Duration Index
ECOST	Expected Interruption Cost
EENS	Expected Energy Not Supplied
IEAR	Interruption Energy Assessment Rate
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index

Fig.4. 26: Simulation result of Agerfa feeder on ETAP software with Reclosers

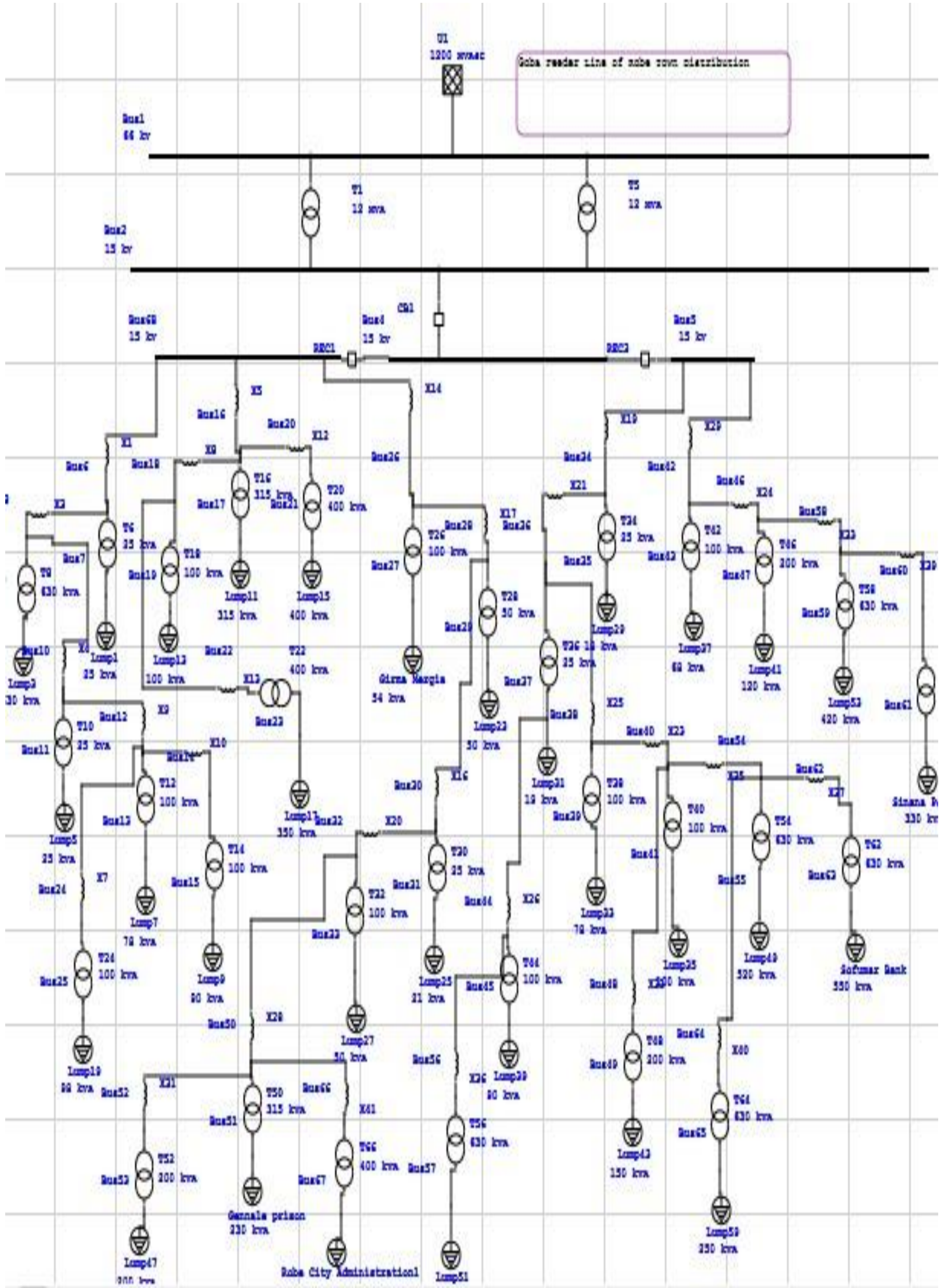


Fig.4. 27: Robe Town Distribution of Goba feeder on ETAP software with Reclose

Project:	ETAP	Page: 1
Location:	16.0.0C	Date: 14-07-2020
Contract:		SN: 4359168
Engineer:	Study Case: RA	Revision: Base
Filename: Goba Feeder		Config.: Normal

SUMMARY

System Indexes

ACCI	kVA / customer
AENS	10.3517 MW hr / customer.yr
ALII	kVA pu
ASAI	0.9925 pu
ASUI	0.00746 pu
CAIDI	52.255 hr / customer interruption
CTAIDI	hr / customer
ECOST	874,261.70 $ / yr
EENS	144.923 MW hr / yr
IEAR	6.033 $ / kW hr
SAIDI	65.3450 hr / customer.yr
SAIFI	1.2505 f / customer.yr

ACCI	System Average Customer Curtailment Index
AENS	Average Energy Not Supplied
ALII	System Average Connected kVA Interrupted per kVA of Connected Load Served
ASAI	Average service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CTAIDI	System Customer Total Average Interruption Duration Index
ECOST	Expected Interruption Cost
EENS	Expected Energy Not Supplied
IEAR	Interruption Energy Assessment Rate
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index

Fig.4. 28: Simulation result of Goba feeder on ETAP software with Reclosers

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this thesis, the complete Investigation of reliability problem as power quality of distribution network is analyzed.

Based on the results of this thesis, the reliability of the Bale Robe town power distribution system does not meet the requirements set by Ethiopian Electric Agency (EEA). The average frequency of interruptions of Bale Robe town present feeder were 259 int/cust/yr., 253 int/cust/yr., 217 int/cust/yr., 3 int/cust/yr. and 557 int/cust/yr. of Goba, Agerfa, Sinana, MWU and Gasera feeders respectively and the average duration of interruptions are 175.56hr/cust/yr., 209.92hr/cust/yr., 230.90hr/cust/yr., 1.1hr/cust/yr. and 1011.8 hr/cust/yr. of Goba, Agerfa, Sinana, MWU and Gasera feeders respectively. Similarly, Bale Robe town distribution system reliability violates the requirement set by EEA which has set for SAIFI as equal to 20 int/cust/yr. and SAIDI is 25 hr/cust/yr.

In this thesis the different distribution system network is modeled and analyzed. By implementing this model, the overall reliability of the first three feeders of power distribution is improved by 99.5%, 71.75% and 47.4% for SAIFI, SAIDI and ENS that has been reduced from as compared with the existing system respectively.

Specially in the case of 33kv medium voltage line construction or rehabilitation use Aerial Burned Conductor more safe because of in the condition of rain and wind the probability of failure medium voltage is less.

5.2 Recommendations

The following recommendations are forwarded.

- The Ethiopian Electric power and Ethiopian electric utility should work a lot on the whole power system, from generation to distribution to reduce the problem of reliability and power quality and especial attention should be given to power interruption problem which has been a day to day problem for the end users.
- During any work in the field to protect materials from damage and for the safety of humans, care has to be taken.
- Giving attention for preventive maintenance and operation to improve random power interruptions, sustainability of equipment's and deliver reliable power to the end users' needs additional attention.
- The performance of the existing Bale Robe town distribution network is not good. Therefore, the Ethiopian electric utility should work to improve the reliability and power quality of distribution system close to Ethiopian reliability standards.
- The Bale Robe town distribution substation must introduce the SCADA system for the improvement of reliability of distribution network.

References

[1] Arash Bashardoust, Meisam Farrokhifar, Amin Yousefzadeh Fard, Amin Safari, Ehsan Mokhtarpour, -Optimum Network Reconfiguration to Improve Power Quality and Reliability in Distribution System‖, Vol. 9, No. 4 (2016), pp.101-110.

[2] Abeba B., Getachew Biru (Dr.-Ing.), Study of Distributed Generation in Improving Power System Reliability ‖, AddisAbaba University Ethiopia, master's thesis, June 2016.

[3] Ahmed Abdel-Aleem, Mahmoud A. El-Sharief, Mohsen A. Hassan, and Mohamed G. El-Sebaie1‖ implementation of fuzzy and adaptive neuro-fuzzyinference systems in optimization of production inventory problem‖, Appl. Math. Inf. Sci. 11, No. 1, 289-298 (2017).

[4] Ahmad Shokrollahi, Hossein Sangrody, Mahdi Motalleb, Mandana Rezaeiahari, Elham Foruzan, Fattah Hassanzadeh, -Reliability Assessment of Distribution System Using Fuzzy Logic for Modelling of Transformer and Line Uncertainties‖, USA and Iran, IEEE.

[5] Amache J., Dr. Getachew B. -Reliability assesment of radial distribution system with distributed generation: (A case study of cottebe substations) ‖, Addis Ababa institute of technology, Addis Ababa University, June 2016.

[6] A. Ahmed (Aug. 13, 2017). DC Power Supplies—Protection of Systems from SurgesandTransients.[Online].Availablehttp://www.industrialelectronics.com/DC_pwr_9.html A Akhikpemelo, N. Eyibo, A. Adeyi, "Reliability Analysis of Power Distribution Network". Continental J. Engineering Sciences, 2016

[7] Azami, R. and Fard, A.F., "Impact of demand response programs on system and nodal reliability of a deregulated power system," Sustainable Energy Technologies, IEEE International Conference on, November 2015.

[8] Balijapelli N., Venkata S. S., Christie R. D., "Predicting Distribution System Performance Against Regulatory Reliability Standards," to appear in lEEE Transactions on Power Delivery.

[9] Bill Glennon, Christina Kusch, and Elijah Nelson, -Improve Reliability and Power Quality on Any System‖, Schweitzer Engineering Laboratories, Inc, Buenos Aires, Argentina, September 24–26, 2018.

[10] Billinton, Roy, and Satish Jonnavithula. "A test system for teaching overall power system reliability assessment." IEEE Transactions on Power Systems.

[11] Bloomberg New Energy Finance, "Sustainable Energy in America Factbook," www.bcse.org/sustainableenergyfactbook/, 2017.

[12] *Dan Zhu*," Power System Reliability Analysis with Distributed Generators" Thesis Submitted to The Faculty of Virginia Polytechnic Institute and State University, May, 2016

[13] D. Haughton and G. T. Heydt," Smart Distribution System Design: Automatic Reconfiguration for Improved Reliability", IEEE

[14] Elmakias, New computational methods in power system reliability, volume 111, Springer-Verlag Berlin Heidelberg, 2017.

[15] S. T. Chavhan, C. Bhattar, P. V. Koli, and V. S. Rathod, ''Application of STATCOM for power quality improvement of grid integrated wind mill,'' in Proc. IEEE 9th Int. Conf. Intell. Syst. Control (ISCO), Jan. 2015, pp. 1–7.

[16] Ulas Eminoglu, Ridvan Uyan, Reliability Analyses of Electrical Distribution System, International Refereed Journal of Engineering and Science (IRJES), Volume 5, Issue 12 (December 2016), PP.94-102.

[17] Ethiopian Electric Utility 2019

[18] Ezeolisah, C. (July- December 2015). TCN Transmission News. In-House Journal of Transmission Company of Nigeria, Vol. 4, 1-76.

[19] Greg Rouse and John Kelly, Electricity Reliability: Problems, Progress and Policy Solutions, Galvin Electricity Initiative, 2011.

[20] Guerra G, Martinez-Velasco JA (2016) Optimum allocation of distributed generation in multi-feeder systems using long term evaluation and assuming voltage-dependent loads. SustEnergy Grids Netw5: 13–26.

[21] Guerra G, Martinez-Velasco JA (2017) A virtual power plant model for time-driven power

flow calculations. AIMS Energy 5: 887–911.

[22] Guerra G, Martinez-Velasco JA (2018) Optimal sizing and operation of energy storage systems considering long term assessment. AIMS Energy 6: 70–96.

[23] IEEE Std. 1127, “IEEE Guide for the Design, Construction, and Operation of Safe and Reliable Substations for Community Acceptance and Environmental Compatibility.”

[24] IEEE Power and Energy Society, “IEEE guide for electric power distribution reliability indices,” IEEE Standard 1366 (2016)

[25] IEEE, IEEE Guide for Electric Power Distribution Reliability Indices, New York: IEEE Power & Energy Society, 2015

[26] International Energy Agency. World Energy Outlook 2016 Executive Summary; International Energy Agency: Paris, France, 2016.

[27] L. Wright, Lee. A. -Mitigation of Undesired Operation of Recloser Controls Due to Distribution Line Inrush‖, IEEE Rural Electric Power Conference, Asheville, North Carolina, April 19-21, 2015.

[28] Martinez-Velasco JA, Guerra G (2015) Analysis of large distribution networks with distributed energy resources. *Ingeniare*23: 594–608

[29] Martinez-Velasco JA, Guerra GA (2016) Allocation of distributed generation for maximum reduction of energy losses in distribution systems, In: *Energy Management of Distributed Generation Systems* (L. Mihet-Popa, ed.), ch. 05. InTech.

[30] Martinez-Velasco JA, Guerra G (2016) Reliability analysis of distribution systems with photovoltaic generation using a power flow simulator and a parallel Monte Carlo approach. *Energies*9: 537.

[31] *Michael J. Bio,* ‘’Bus/Switching Configurations’’ E.P. Breaux Electrical, Inc. Birmingham, Alabama Electric Power Engineering Handbook, Grigsby, L.L., Ed., CRC Press, Boca Raton, FL, 2015

[32] M. Mann, E. Melaas, and A. Malik, “Using VIIRS Day/Night Band to Measure Electricity Supply Reliability: Preliminary Results from Maharashtra, India,” Remote Sensing, vol. 8, p. 711, 2016

[33] M.T.L. Gayatri, A.M. Parimi, and A.V.P. Kumar ‘‘Utilization of unified power quality

conditioner for voltage sag/swell mitigation in microgrid,'' in Proc. Biennial Int. Conf. Power Energy Syst., Towards Sustain. Energy (PESTSE), Jan. 2016, pp.1–6.

[34] Okorie, P. U. and A. I. Abdu, (2015). Reliability Evaluation of Power Distribution Network System in Kano Metropolis of Nigeria. International Journal of Electrical and Electronic Science, Vol.2, No. 1 , 1-5.

[35] Okorie, P. U. (2016). Reliability Assessment of Power Distribution of Abakpa Network Sub-Station of Kaduna Disco. International Journal of Innovative Research in Education, Technology and Social Strategies. *Vol.2, No.1,* 78-84.

[36] Oz emir, A., Bagriyanik, M., Kaypmaz, A., Gul, O., & Ilisu, I. (2015, February). Impact of adverse weather conditions on outage statistics of 154 kV Power Transmission system. In Electronics, Communications and Computers (CONIELECOMP), 2015 International Conference on (pp. 29-34). IEEE.

[37] P.U. Okorie1, a, U. O Aliyu, b, B. Jimoh, c and S.MSani4,d‖ Reliability Indices of Electric Distribution Network System Assessment‖ Journal of Electronics and Communication Engineering Research Volume 3 ~ Issue 1 (2015) pp: 01-06

[38] P. Chandra Sekhar, R. A Deshpande, V. Sankar, Evaluation and Improvement of Reliability Indices of Electrical Power Distribution System‖, IEEE, 2016.

[39] Rashid Niaz Azari, Mohammad Amin Chitsazan, Iman Niazazari. Optimal Recloser Setting, Considering Reliability and Power Quality in Distribution Networks. American Journal of Electrical Power and Energy Systems. Vol. 6, No. 1, 2017, pp. 1-6.

[40] Raju, K, Narsaiah Srinivas G, ―Distribution System Reliability with Distributed Generation Based on Customer Scattering‖, VOLUME: 13, NUMBER: 2, June 2015.

[41] Rey R G and Muneta MR. Power quality harmonics analysis and real measurements data. Croatia. InTech; 2015

[42] Richard E. Brown, Electric Power Distribution Reliability, Second Edition. Roystone Anthony, (2015). "Reliability Analysis of Distribution Network", UniversitiTunHussein Onn Malaysia.

[43] R. Banerjee ''Importance of power quality, 'Int.J.Eng.Res.Appl., vol.5, Jul. 2015.

[44] R. Mathew, Ashok S. and Kuma ravel S., "Analyzing the effect of DG on reliability of distribution systems," Electrical, Computer and Communication Technologies (ICECCT), 2015 IEEE International Conference on, Coimbatore, 2015, pp. 1-4.

[45] R. Billinton and R. N. Allan, *Reliability evaluation of power systems,* Second ed. Springer Science & Business Media, 2016.

[46] Robe city Administration 2019.

[47] Tefera Mekonnen, Teshome Tolesa, Dr K Ramesh Babu, Reliability Improvement of Power Distribution System using Auto recloser Case Study: Bedele Power Distribution System‖, An ISO 3297: 2007 Certified Organization, Website: www.ijircce.com, Vol. 5, Issue 3, March 2017.

[48] Thompson, Stan. -Auto-Recloser - Safety and Minimizing Downtime‖. Transmission &Distribution Issue 1, 2018. Retrieved- 2018-07-02.

[49] Sanaullah, Ahmad, et al. "Analyzing Distributed Generation Impact on the Reliability of Electric Distribution Network.", IJACSA 2016.

[50] Salman Mohagheghi, Fang Yang, BamdadFalahati, "Impact of Demand Response on Distribution System Reliability," Power and Energy Society General Meeting, 2014. [52] Sandia National Laboratories and NRECA (2015) *DOE/EPRI Electricity Storage Handbook.*

[51] Son wane, P. M. and B.E. Kushare, (June 2015). Distribution System Reliability: An Overview. International Journal of Innovations in Engineering and Technology (IJIET)Volume 5, Issue 3., 148-153.

[52] S. L. Braide "Improved Reliability Analysis of Electricity Power Supply to Port Harcourt Distribution Network "International Journal of Engineering Science Invention (IJESI), vol.07, no. 07, 2018, pp 23-36.

[53] Y. He and E. Eriksson, "Simple Distribution Networks, Reliable Power Electricity ",

Energiforsk rapport 2015:105, February 2015.

[54] Y. Zhao. (Nov. 11, 2016). Electrical Power Systems Quality. [Online]. Available: http://best.eng.buffalo.edu/Research/Lecture%20Serie %202013/Power%20Quality%20Intro.pdf

Appendixes

Appendix A: Agerfa 15 kV Feeder Line

AGERFA 15KV FEEDER									
SELECTED TRANSFORMERS BY % OF LOADING									
No.	***Location Name***	***Trafo Capacity (KVA)***	***Service Type***	***Phase Current(A)***	***Line Current(A)***	***Out put Voltage***	***Power on Trafo(kw)***	***Actual Power of Trafo (kw)***	***% of Loading***
1	***Yet Food Complex***	***630***	***Dedicated***	***450.00***	***779.40***	***386.87***	***417.79***	***504***	***82.90***
		315		***270.25***	***468.07***	***382.07***	***247.79***	***252***	***98.33***
		200		***156.45***	***270.97***	***387.00***	***145.30***	***160***	***90.81***
		1250		***560.86***	***971.41***	***388.67***	***523.14***	***1000***	***52.31***
2	***Haji Kedir***	***50***	***Dedicated***	***34.36***	***59.51***	***383.79***	***31.69***	***40***	***79.24***
		100		***85.10***	***147.39***	***384.37***	***78.64***	***80***	***98.30***
3	***Health Office***	***200***	***Public***	***134.68***	***233.27***	***385.05***	***123.62***	***160***	***77.26***
4	***Kera***	***315***	***Public***	***250.14***	***433.24***	***387.07***	***229.87***	***252***	***91.22***
5	***Workina***	***315***	***Dedicated***	***244.24***	***423.02***	***382.92***	***225.56***	***252***	***89.51***
6	***Yadot***	***200***	***Dedicated***	***124.68***	***215.95***	***384.82***	***114.62***	***160***	***71.64***
7	***Around TAF Oil***	***50***	***Dedicated***	***38.45***	***66.60***	***383.07***	***35.03***	***40***	***87.58***
7	***TAF Oil***	***50***	***Dedicated***	***19.37***	***33.52***	***379.67***	***17.63***	***40***	***44.08***
8	***Gabrel church***	***100***	***Public***	***75.20***	***130.25***	***379.67***	***71.41***	***80***	***89.26***
9	***Edible Oil Process***	***100***	***Dedicated***	***58.47***	***101.27***	***395.67***	***53.97***	***80***	***67.46***
10	***Walta'i***	***200***	***Dedicated***	***163.57***	***283.30***	***384.60***	***152.49***	***160***	***95.31***
		200	***Dedicated***	***168.50***	***291.84***	***388.47***	***156.95***	***160***	***98.09***
11	***Imamu Mosquie***	***200***	***Public***	***139.84***	***242.20***	***388.13***	***128.29***	***160***	***80.18***
12	***Substation Area***	***50***	***Public***	***35.88***	***62.14***	***382.28***	***33.12***	***40***	***82.81***
13	***Exit Besaso***	***100***	***Dedicated***	***80.90***	***140.12***	***384.67***	***74.68***	***80***	***93.35***

Appendix A-I: Agerfa 15 kV Feeder Line

AGERFA 15KV FEEDER
SELECTED TRANSFORMERS PHASE BALANCE BY NEUTRAL CURRENT

Transformer Capacity	Location Name	R	S	T	N	Output Voltage	Power on Trafo (KW)	Actual Power of Trafo(kw)	Remark
50	Haji Kedir	38.45	29.35	35.3	17	385.53	31.69	40	in order to remark at the end of this work,The Transformers Must Be L Balanced
100		93.4	82.4	79.5	50	380.73	78.64	80	
200	Health Office	129.58	134.1	140.32	93.9	214.70	123.62	160	
100	Gabrel church	69.89	83.4	72.3	17.6	382.47	71.40	80	
50	Around Substation Area	39.54	26.5	41.6	19.25	382.92	33.12	40	
100	Exit Besaso	84.59	80.2	77.89	58	384.82	74.68	80	

Note: Line current= √3*phase current
**Power on Transformer = √3*V*I*cos*α
% age of Loading = power on trafo /Actual power*100%

Appendix B: Gasera 33kV Feeder Line

GASERA 33KV FEEDER
SELECTED TRANSFORMERS
BY % OF LOADING

No.	Location Name	Trafo Capacity (KVA)	Service Type	Phase Current(A)	Line Current(A)	Output Voltage	Power on Trafo(kw)	Actual Power of Trafo (kw)	% of Loading
1	Umer Abda	100	Dedicated	78.00	135.10	382.73	71.64	80	89.55
2	Hussien Kedir	315	Dedicated	123.56	214.01	382.92	113.54	252	45.06
3	Gerante	50	Public	39.00	67.55	384.82	36.02	40	90.04
4	Tele Kebtit School	25	Public	21.33	36.94	383.40	19.63	20	98.13

Appendix B-I: Gasera 33kV Feeder Line

GASERA 33KV FEEDER

SELECTED TRANSFORMERS PHASE BALANCE BY NEUTRAL CURRENT

No.	Transformer Capacity (KVA)	Location Name	R	S	T	N	Output Voltage	Power on Trafo (KW)	Actual Power of Trafo(kw)	Remark
1	50	Gerante	58	38	21	17	385.87	36.02	40	So it needs phase balance and upgrade transformer
2	25	Tele Kebtit School	25	26	13	10	380.73	19.63	20	
	Note: Line current= √3*phase current Power on Transformer = √3*V*I*cosα % age of Loading = power on trafo /Actual power*100%									

Appendix C: Goba 15kV Feeder Line

GOBA 15KV FEEDER

SELECTED TRANSFORMERS BY % OF LOADING

No.	Location Name	Trafo Capacity (KVA	Service Type	Phase Current(A)	Line Current(A)	Out put Voltage	Power on Trafo(kw)	Actual Power of Trafo (kw)	% of Loading
1	Rift valley University	25	Dedicat	6.46	11.18	385.87	5.98	20	29.89
2	Sofumer Comerial bank	315	Public	501.90	869.32	380.73	458.60	252	181.99
3	Blae Robe Main Tele	100	Dedicat	21.30	36.90	386.33	19.75	80	24.69
4	Green Cafteria	100	Public	41.57	72.00	214.70	21.42	80	26.77
5	Bale Robe Tafach Dabo	25	Dedicat	12.87	22.30	384.37	11.88	20	59.38
6	Robe City Admin 1	315	Public	342.23	592.76	383.05	314.61	252	124.85
7	Robe City Admin 2	315	Public	138.47	239.84	382.47	127.10	252	50.44
8	Girma Mergia	50	Dedicat	45.27	78.41	387.07	42.05	40	105.13
9	Bilisuma	315	Public	225.43	390.46	382.92	207.17	252	82.21
10	Sinana Police station	315	Public	292.97	507.44	384.82	270.57	252	107.37
11	Bale Robe Adababay	50	Dedicat	31.90	55.25	383.40	29.35	40	73.38
12	Bale Robe Civil Market	25	Dedicat	19.37	33.55	379.67	17.65	20	88.25
13	Meda Welabu Stadium	315	Public	213.97	370.61	395.00	202.84	252	80.49
14	Bale Robe CSC	315	Public	163.73	283.59	377.93	148.51	252	58.93
15	Robe teachers College 1	315	Public	94.60	163.85	388.47	88.19	252	35.00
16	Robe teachers College 2	200	Public	119.10	206.29	382.28	109.27	160	68.29
17	Oromia Seed Enterprise	100	Dedicat	7.00	12.12	384.67	6.46	80	8.07
18	ODP Tele	50	Dedicat	9.90	17.15	381.23	9.06	40	22.65
19	Bale Robe Hospital	630	Dedicat	27.90	48.32	382.43	25.61	504	5.08
20	Gennale Prison	200	Public	212.00	367.20	378.53	192.59	160	120.37
21	Donsa	315	Public	160.10	277.30	382.18	146.85	252	58.27
22	Abdurhman Flour Mill	100	Dedicat	14.53	25.17	380.17	13.26	80	16.57
23	Karkaha Sefer	200	Public	136.03	235.62	380.30	124.16	160	77.60
24	Kebit Tera	315	Public	255.70	442.89	375.08	230.17	252	91.34
25	Muhamed Abda	100	Dedicat	27.97	48.44	378.13	25.38	80	31.72
26	Aba dema Hotel	315	Public	236.50	409.63	379.03	215.13	252	85.37
27	Mebon Cafteria	315	Public	392.97	680.64	369.47	348.44	252	138.27
28	Water Resource	100	Dedicat	40.07	69.40	382.23	36.75	80	45.94
29	Haji Ibro	50	Dedicat	0.47	0.81	382.37	0.43	40	1.07
30	Bale Robe Poly Technic	315	Public	142.53	246.87	377.07	128.98	252	51.18
31	Sington Academy	100	Public	44.03	76.27	382.37	40.41	80	50.51
32	Tele Donsa	25	Dedicat	4.13	7.16	380.50	3.77	20	18.87
33	Water Pump 1	100	Dedicat	42.97	74.42	376.87	38.86	80	48.58
34	Gasoil Station	25	Dedicat	0.13	0.23	376.77	0.12	20	0.01
35	Water Pump 2	100	Dedicat	0.20	0.35	375.37	0.18	80	0.23
36	OBN	630	Dedicat	42.30	73.27	376.70	38.24	504	7.59
37	Bale Robe Int' University	200	Dedicat	2.53	4.39	374.10	2.27	160	1.42

Appendix C-I: Goba 15kV Feeder Line

Transformer Capacity	Location Name	R	S	T	N	Out put Voltage	Power on Trafo (KW)	Actual Power of Trafo(kw)	Remark
25	Rift valley University	16	0.3	3.1	17	385.87	5.98	20	Transformer must be balanced
315	Sofumer Comercial	596.1	467	443	198	380.73	458.60	252	
100	Green Cafteria	7.3	109	8.8	94	214.70	21.42	80	
315	Robe City Admin 1	373.2	326	328	169	383.05	314.61	252	
315	Robe City Admin 2	134.8	145	136	18	382.47	127.10	252	
315	Bilisuma	121.9	330	225	238	382.92	207.17	252	
315	Sinana Police station	301.9	317	260	149	384.82	270.57	252	
315	Meda Welabu Stadium	224.6	292	125	119	395.00	202.84	252	
315	Bale Robe CSC	157.7	122	218	140	377.93	148.51	252	
315	Robe teachers College 1	78.4	120	86	45	388.47	88.19	252	
200	Robe teachers College 2	174.1	91.5	92	69	382.28	109.27	160	
200	Gennale Prison	272.7	246	117	164	378.53	192.59	160	
315	Donsa	244.2	104	132	145	382.18	146.85	252	
200	Karkaha Sefer	118.3	100	190	89	380.30	124.16	160	
315	Kebit Tera	297.7	314	156	156	375.08	230.17	252	
315	Abadama Hotel	290.9	284	134	165	379.03	215.14	252	
315	Mebon Cafteria	423.8	478	277	327	369.47	348.44	252	
315	Bale Robe Poly Technic	243.8	73.9	110	110	377.07	128.98	252	

Note: Line current= √3*phase current

Power on Transformer = √3*V*I*cosα

% age of Loading = power on trafo /Actual power*100%

Appendix D: Sinana 15kV Feeder Line

SINANA 15KV FEEDER

SELECTED TRANSFORMERS BY % OF LOADING

No.	Transformer Capacity (KVA)	Location Name	Service Type	Phase Current (A)	Line Current (A)	Output	Power on Trafo	Actual Power of Trafo	% of Loading
1	315	Aman Disaso	Public	136.97	237.2	394.3	129.62	252	51.437
2	100	Zeybela	Public	202.87	351.4	387.6	188.72	80	235.9
3	50	Zeybela Tele	Dedicated	4.23	7.34	390.8	3.97	40	9.925
4	50	Zeybela Condominiur	Public	77.67	134.5	388	72.33	40	180.83
5	200	Radio Staion	Public	222.47	385.3	390.1	208.27	160	130.17
6	25	Radio Staion Tele	Dedicated	5.27	9.13	392.4	4.96	20	24.8
7	315	Bole School	Public	296.17	513	389.8	277.07	252	109.95
8	315	Sanete	Public	317.73	550.3	387.6	295.54	252	117.28
9	25	Fiker Dabo	Dedicated	11.23	19.45	390.3	10.52	20	52.6
10	315	Goro Mazoria	Public	131.3	227.4	390	122.89	252	48.766
11	100	Hamza Mosque	Public	195.3	338.3	385.4	180.64	80	225.8
12	100	Sh/Abdulmalik	Public	115.63	200.3	388.4	107.79	80	134.74
13	25	Sh/Abdulmalik Tele	Dedicated	2.63	4.56	388.1	2.45	20	12.25
14	100	Galema School	Public	17.87	30.95	2.43	0.104	80	0.13
15	50	Jafer Mosque	Dedicated	10.7	18.53	387.9	9.96	40	24.9
16	50	Ahmed Flour Mill	Dedicated	18.87	32.68	387.4	17.54	40	43.85
17	50	Mubarek Mosque	Public	51.87	89.84	387.4	48.22	40	120.55
18	100	Meterology	Public	33.4	57.85	390.5	31.3	80	39.125
19	200	Newman Flour Factor	Dedicated	139.7	242	379.4	127.22	160	79.513

Appendix D-I: Sinana 15kV Feeder Line

SINANA 15KV FEEDER

SELECTED TRANSFORMERS FOR REHABILITATION

No.	Transfor mer Capacity	Location Nan	Line Curre nt (A)	Out put Voltage	Power on Trafo (KW)	Actual Power of Trafo	Extra Power	Remark
1	100	Zeybela	351.4	387.6	188.72	80	108.72	Upgraded to 200 KVA
2	50	Zeybela Condo	134.5	388.03	72.33	40	32.33	Upgraded to 100 KVA
3	200	Radio Staion	385.3	390.07	208.27	160	48.27	Upgraded to 315 KVA
4	315	Bole School	513	389.8	277.07	252	25.07	Additional Transformer
5	315	Sanete	550.3	387.57	295.54	252	43.54	Additional Transformer
6	100	Hamza Mosqu	338.3	385.4	180.64	80	100.64	Upgraded to 100 KVA
7	100	Sh/Abdulmalik	200.3	388.4	107.79	80	27.79	Upgradedto 100 KVA
8	50	Mubarek Mosq	89.84	387.37	48.22	40	8.22	Upgraded to 100 KVA

Appendix E: Madda Walabu University 15kV Feeder Line

No.	Location Name	Trafo Capacity (KVA)	Service Type	Phase Current (A)	Line Current (A)	Out put Voltage	Power on Trafo(kw)	Actual Power of Trafo (kw)	% of Loading
1	Madda Walabu University	630	Dedicated	510.54	884.26	386.87	474.00	504	94.05
2		630	Dedicated	523.58	906.84	383.79	482.96	504	95.83
		630	Dedicated	535.85	928.09	384.37	495.16	504	98.25
3		315	Dedicated	275.45	477.08	385.05	252.83	252	100.33
4		315	Dedicated	250.14	433.24	387.07	229.87	252	91.22
5		200	Dedicated	154.85	268.20	382.92	143.00	160	89.38
6		200	Dedicated	174.58	302.37	384.82	160.49	160	100.31
7		100	Dedicated	89.79	155.52	383.07	82.54	80	103.18
9		100	Dedicated	72.46	125.50	395.67	68.80	80	86.00

Appendix E-I: Madda Walabu University 15kV Feeder Line

No.	Transformer Capacit	Location Name	R	S	T	N	Out put Voltage	Power on Trafo (KW)	Actual Power of	Remark
1	200	Madda Walabu University	129.58	134.1	140.3	93.9	214.70	123.62	160	Load must be balanced
2	100		69.89	83.4	72.3	17.6	382.47	71.40	80	
3	315		39.54	26.5	41.6	19.25	382.92	33.12	40	
	Note: Line current= √3*phase current Power on Transformer = √3*V*I*cosα % of Loading = power on trafo /Actual power*100%									

Appendix F: South Eastern Substation Load Data

SOUTH EASTERN SUBSTASTION MONTHLY SUBSTASTION **LOAD DATA**

REGION:- **SOUTH EAST**

SUBSTASTION **BALE ROBE** — **Month Agust/Nehasse**

EXTSTINNG CAPACITANCE **24MVA** — **Date 19/12/10**

SERVICE CONDITION **FULL ATENDED**

		PEAK LOAD						MINIMUM LOAD					
		Power	Current(A)				Hours	Power	Current(A)				Hours
N.o	Bay /Line	(MW)	R	S	T	Date	Time	(MW)	R	S	T	Date	Time
1	Goba Line	4	180	180	180	12/4/2010	12:00	1.73	78	78	78	12/17/2010	7:00
2	Agarfa Line	2.71	122	122	122	12/10/2010	12:00	1.07	48	48	48	12/16/2010	7:00
3	Sinana Line	1.64	74	74	74	12/11/2010	20:00	0.53	24	24	24	11/28/2010	7:00
4	Melyu Line	2.45	54	54	54	12/10/2010	20:00	0.1	2	2	2	11/26/2010	18:00
5	Gassera Line	1.36	30	30	30	12/11/2010	20:00	0.14	3	3	3	12/2/2010	11:00

	Traffo.Maximum Load				Traffo. Minimum Load				Energy Meter	
	KV	MW			KV	MW				Not Function
6	15	7.96			15	1.42				"
7	33	3.77			33	0.1				"

		Permanent Fault				Transirnt Fault								
		Earth Fault		Short Circuit		Earth Fault		Short Circuit		Operational		Peak Load	Over Load	
N.o	Bay/Line	Rate	Duration	Rate	Duration	Rate	Duration	Rate	Duration	Rate	Duration	(MW)	Rate	Duration
1	Goba Line			5	5:54			5	0:32	12	5:23	4	3	1:52
2	Agarfa Line			8	8:32					10	2:36	2.71		
3	Sinana Line			7	6:18			1	0:08	7	13:02	1.64		
4	Melyu Line	14	38:22:00	20	42:30:00			1	0:08	7	4:37	2.45		
5	Gassera Line	36	118:59:00	21	67:41:00					11	7:41	1.36		

		Permanent Fault				**Transirnt Fault**							**Shading**	
		Earth Fault		**Short Circuit**		**Earth Fault**		**Short Circuit**		**Operational**		**Peak Load**		Duration
N.o	Bay/Line	Rate	Duration	Rate	Duration	Rate	Duration	Rate	Duration	Rate	Duration	(MW)	Rate	
1	Goba Line			7	32:45:00							5.6	28	223:52:00
2	University			4	36:41:00					1	0.15	0.78		
3	Agarfa Line			7	11:45:00					2	0.33	3.47	24	192:25:00
4	Sinana Line			1	0.22					1	0.5	1.62	28	216:45:00
5	Melyu Line	17	47:28:00	29	32:34:00			1	0.08	2	14:52	2.27	10	7:58
6	Gassera Line			16	21:10							1.27	12	87:45:00

Bale Robe Town Substation Data Feeder

Name of Feeder	**Load On the Feeder**	**Current Ratio Capacity**	**Cable Capacity in put**	**Cable Capacity Out put**
Goba Feeder	252A	250/5A	70MM^2	70MM^2
Agerfa Feeder	168A	500/5A	70MM^2	70MM^2
Sinana Feeder	94A	150/5A	70MM^2	70MM^2
Madda Walabu University	10A	75/5A	70MM^2	70MM^2
Gasera Feeder	42A	100/1A	120MM^2	120MM^3

Appendix G: The total number of customer connected in each feeder with incremental years

		No Cust Connected	Indices of each years	
Years	Substation Feeders Line		SAIFI (int/cus/yr)	SAIFI (int/cus/yr)
2015	Goba Feeder Line	680	238.61	235.68
2015	Agerfa Feeder Line	295		
2015	Sinana Feeder Line	550		
2015	Gasera Feeder Line	13		
	Total	**1538**		
2016	Goba Feeder Line	1450	256.5	185.25
2016	Agerfa Feeder Line	410		
2016	Sinana Feeder Line	530		
2016	Gasera Feeder Line	29		
	Total	**2419**		
2017	Goba Feeder Line	2000	304.87	228.44
2017	Agerfa Feeder Line	660		
2017	Sinana Feeder Line	940		
2017	Gasera Feeder Line	35		
	Total	**3635**		
2018	Goba Feeder Line	2650	249.96	192.4
2018	Agerfa Feeder Line	900		
2018	Sinana Feeder Line	1700		
2018	MW University Feeder Line	1		
2018	Gasera Feeder Line	45		
	Total	**5296**		
2019	Goba Feeder Line	4200	188.71	183.2
2019	Agerfa Feeder Line	1450		
2019	Sinana Feeder Line	3000		
2019	MW University Feeder Line	1		
2019	Gasera Feeder Line	45		
	Total	**8696**		