



**ASSESSMENT OF RELIABILITY ASPECTS IN POWER
DISTRIBUTION SYSTEM AND DEVELOPMENT OF
REINFORCEMENT MECHANISMS
(CASE STUDY: SHASHEMENE CITY DISTRIBUTION SYSTEM)**

MSc THESIS

BY

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INSTITUTE OF TECHNOLOGY SCHOOL OF GRADUATE STUDIES,
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(SPECIALIZATION: POWER SYSTEM AND ENERGY ENGINEERING)

MAY, 2019

HAWASSA, ETHIOPIA



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A THESIS SUBMITTED TO THE
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING, INSTITUTE OF
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**SCHOOL OF GRADUATE STUDIES
HAWASSA UNIVERSITY
ADVISORS' APPROVAL SHEET**

This is to certify that the thesis entitled “ASSESSMENT OF RELIABILITY ASPECTS IN POWER DISTRIBUTION SYSTEMS AND DEVELOPMENT OF REINFORCEMENT MECHANISMS (CASE STUDY: SHASHEMENE CITY DISTRIBUTION SYSTEM) ”

submitted in partial fulfillment of the requirements for the degree of Master of Science in Power System and Energy Engineering, the Graduate Program of the Department of Electrical and Computer Engineering, Institute of Technology, and has been carried out by KABTAMU KETSELA ID.No. PGEgw/03/07, under our supervision. Therefore we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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ABSTRACT

A stable and reliable electric power supply system is an inevitable pre-requisite for the technological and economic growth of any nation. Due to this, Ethiopian electric utility (EEU) must strive and ensure that the customers' reliability requirements, which are met at the lowest possible cost. EEU should have their own reliability improvement strategy depending upon their needs and requirements of their customers. Although there are not complete methods in managing all reliability issues, utilities can maximize network performance and better serve customers by carefully addressing trouble prone areas. In order to achieve this objective, reliability factors based reliability analysis is performed under Electrical Power System Analysis (ETAP) software environment. In this thesis, it is observed that different reliability reinforcement mechanisms have been undertaken to evaluate predictive reliability analysis for the future system. Using line reconductoring for wendogent feeder the SAIFI, SAIDI and EIC reduced by 12%, 7.5% and 32% respectively. For shashemene city feeder using Autoreclosure SAIFI, SAIDI and EIC reduced by 45%, 35% and 35 % respectively. For Arsinegele feeder using separate CB the SAIFI, SAIDI and EIC reduced by 9.7%, 6.4% and 8.8% respectively and water pump feeder using covered conductor SAIFI, SAIDI and EIC reduced by 14.9%, 9% and 9.8% respectively. Reliability indices of shashemene substation show the substation is unreliable as compared to standard practices and Ethiopia's reliability requirement.

Key Words: Reliability indices, Auto reclosure, SAIFI, SAIDI, EIC

ACRONYMS AND SYMBOLS

AENS	Average Energy Not Supplied
ARCB	Auto Reclosing Circuit Breaker
ASAI	Average System Availability Index
ASIDI	Average System Interruption Duration Index
ASIFI	Average System Interruption Frequency Index
ASUI	Average System Unavailability Index
CAIDI	Customer Average Interruption Duration index
CB	Circuit Breaker
CBM	Condition Based Maintenance
CENS	Cost of Energy Not supplied
CSA	Central Statistical Agency
CUST.	Customer
Ed	Energy Demanded
EEU	Ethiopian Electric Utility
ETAP	Electrical Transient and Analysis Program
EIC	Expected Interruption Cost
ENS	Energy Not Supplied
EENS	Expected Energy not supplied
ETB	Ethiopian Birr
F	frequency (Hz)
Fig.	Figure
HL	Hierarchical Level
Hr	hour

Hz	Hertz
ICS	Interconnected System
Km	kilo meter
km ²	square kilometer
KV	Kilo Volt
KVA	kilo Volt Ampere
KW	kilo Watt
KWh	kilo Watt hour
La	Average Load
LP	Peak Load
LPEIC	Load Point Expected Interruption Cost
M	mean time to fail
M3	cubic meter
Mins	minutes
mm ²	Square millimeter
MTTM	Mean Time to Maintain
MTTR	Mean Time to Repair
MTTS	Mean Time to Switch
MV	Medium Voltage
MVA	Mega Volt Ampere
MW	Mega Watt
N	Number of customers
Ni	Average demand of customer i
P1	Probability of Being in State 1

Po	Probability of being in state 0
R	mean time to repair
RMS	Root Mean Square
ROW	Right of Way
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
SCS	Self Contained System
SIC	Standard Industrial Classification
T	time
MTBF	mean time between failures
TBM	Time Based Maintenance
Trafo	Transformer
Us	Average Annual Outage time
VCB	Vacuum Circuit Breaker
Yr	year
λ_s	Sustained failure rate
λ_t	Temporary Failure Rate
Ω	Ohm
μ	Repair frequency

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CERTIFICATE

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Date: May 2019

Place: Hawassa, Ethiopia

ADVISOR NAME Baseem Khan(Phd) Signature_____ Date_____

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CHAPTER ONE

1. INTRODUCTION

1.1. BACKGROUND

The basic function of the power system is to provide an adequate electrical supply to its customers as economically as possible with reasonable level of reliability. With growing demand and increasing dependence on electricity supplies, the necessity to achieve an acceptable level of reliability, quality and safety at an economic price, the utility have to evolve and improve the systems continuously depending upon the requirement of the customers.

Over the past, distribution systems have received considerably less attention devoted to reliability modeling and evaluation than the generating and the transmission systems [1]. The reasons for this are that the generating stations and the transmission systems are capital intensive and the generation and the transmission inadequacy can have widespread catastrophic consequences for both society and the environment. A distribution system, however, is relatively cheap as compared to the other two as its effects are localized.

Therefore, less effort has been devoted to quantitative assessment of adequacy of various alternatives and reinforcements in distribution systems. On the other hand, analysis of the customer failure statistics of most utilities around the world shows that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer [1]. The distribution systems account for up to 90% of all customer reliability problems, improving distribution reliability is the key to improve customer satisfaction [2]. Since the primary purpose of the system is to satisfy customer requirements and the proper functioning and longevity of the system are essential requisites for continued satisfaction, it is necessary that both demand and supply considerations are appropriately viewed and included in systems. Therefore, the distribution reliability is one of the most important in the electric power industry due to its high impact on the cost of electricity and its high correlation with customer satisfaction.

Power interruption becomes a serious problem in the case study area of this thesis work. The outage frequency is as high as **607.65** and service restoration duration is as long as **920.27** hours per year per the selected feeder for the year 2009 E.C (appendix C). The data clearly indicates that power interruption per day is a common phenomenon in the area and due to this problem day to day activities of the society are highly affected. Therefore the indices shows that the

reliability in Ethiopia is poor and needs immediate attention. With the mission of electricity to all in near future, the distribution system is expanding rapidly with in very short duration, this may lead to haphazard distribution system and the system may not be as reliable as expected.

Reliability improvement strategy has to be developed for the utility depending upon their requirements. Also with strategies, outage mitigation techniques in distribution systems are to be used and these can be classified in two categories namely; Electric and Non-electric. Electric mitigation techniques have a direct impact on the distribution system and affect the distribution system analysis and these techniques include addition of protective devices (reclosers and fuses) and switching devices (manual and automated switches), system reconfiguration, feeder reconductoring and integration of distributed generation.

On the other hand, non electric mitigation techniques do not have any impact on other engineering analysis tools and can be evaluated solely with reliability studies and these techniques include vegetation management, installation of lightning arresters, animal guards, and proper crew management. The impact and the efficiency of the mitigation techniques could be evaluated through quantitative reliability assessment of the distribution system such as; measuring the past performance and predicting the future performance.

The level of reliability is closely related to its cost function; achieving good level of reliability necessitates huge financial investment on system reinforcement and poor reliability entails more downtime cost to customer. Therefore in this thesis, approaches such as; electric and non-electric mitigation techniques shall be evaluated to find the mechanisms to improve reliability of shashemene Power Distribution System.

Therefore in this thesis, mitigation techniques shall be evaluated to find the mechanisms to improve reliability of Shashemene Power Distribution System.

1.2. Power System Reliability and Functional Zones

1.2.1 Power System Reliability

Power system reliability is the ability of the power system to supply adequate electrical energy. System adequacy and system security is the main aspects of power system reliability as shown in Fig.1.1.

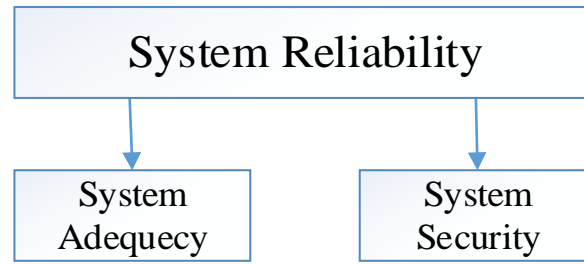


Figure1.1Aspects of system reliability [1]

System adequacy relates to the existence of necessary generation, transmission and distribution facilities within the system to satisfy the customer demand. System security relates to the ability of the system respondto disturbances arising within the system. [1].

1.2.2 Power System Functional Zones and Hierarchical Levels

For the purposes of planning, operation and analysis a power system can be categorized into three functional zones (generation, transmission and distribution). Power systemreliability can be conducted in these functional zones that give rise to hierarchical levels (HL) as shown in Fig. 1.2.

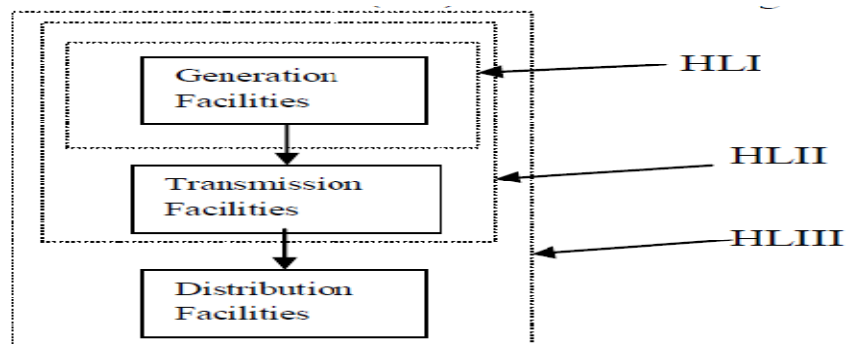


Figure1. 2 hierarchical levels in power system [1]

Reliability assessment at hierarchical level I (HLI) is concerned only with the generation facilities and their ability to satisfy the system demand. In this functional zone, the system generation is analyzed to determine its ability to meet the total system load requirement considering corrective and protective measures taken of the generating units. [1]

Hierarchical level II (HLII) refers to the combined assessment includes generation and transmission facilities and the ability to deliver energy to the bulk power points. [1].

Hierarchical level III (HLIII) refers to the entire system assessment includes all three functional zones and starts at the generating point and ends at the satisfaction of the individual customers in the distribution systems. Reliability evaluation of the distribution functional zone is thus performed separately using the HLII load point indices as input values [1]. The bulk power system is assumed that 100 % reliable, When evaluating distribution system reliability,

1.3 Distribution System Reliability

Distribution system reliability modeling and evaluation has in the past received less consideration than that of generation or transmission systems. Failures in the distribution system costs relatively less compared to the failures in the generation system that can have widespread economic consequences for the utilities and the society [2].

But analysis of the customer failure statistics indicates that the failures at the distribution systems resulting in the greatest contribution to the unavailability of supply of power to the customers [1]. Thus, if the distribution system is not reliable, a customer connected to a highly reliable transmission and generation system could receive a poor power supply. This shows the significance of performing distribution system reliability evaluation.

Reliability evaluation of a distribution system is associated with the continuity of supply of energy from the bulk supply points to the individual customer load points. The basic parameters used to evaluate the reliability of a distribution system can be categorized as load point indices and system indices [1]. The load point failure rate, the average outage time and the average annual outage time are the basic load point indices. The system indices can be obtained from these three load point indices and information on the number of customers and load connected at each load point in the system. The set of system reliability indices can be further classified into customer-oriented indices and load-oriented indices [1]. Customer-oriented indices include the System

Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), and Customer Average Interruption Frequency Index (CAIFI). Load-oriented indices include Average System Interruption Frequency Index (ASIFI) and Average System Interruption Duration Index (ASIDI).

1.4 Problem Formulation

Ethiopian Government is currently making all rounded effort to change the country's economic Status from the current least developed level to a medium income level. Expanding and strengthening of the electric power supply sector is one among the most emphasized economic dimensions.

Since shashemene is west arsi zone commercial center, small and large scale industries but, electric power interruption is becoming a day to day phenomenon. 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.

The analysis of the customer failure statistics reveals that the distribution system makes highest individual contribution to the unavailability of supply to the customer. With the existing system, the customer interruption in Ethiopia (shashemene) is as high as **920.3hrs** /customer/year. Out of this, **88%** of interruption duration is due to failure in the distribution system (Appendix C, Table 6.1). With the vision of electricity to all within the near future, the interruptions per customer may further deteriorate due to rapid expansion of the distribution systems. The value of SAIDI mentioned above seems just a number; but the reality is that interruptions have major direct and indirect consequences on economic growth and security of supply.

Hence, considering this fact in this thesis work, a comprehensive reliability assessment of shashemene's power distribution problems has been conducted. Based on the result of the investigation performance improvement measures has been identified and considered which can be implemented for the area.

General Objective

The main objective of this thesis is to assess and study power distribution system reliability in shashemene town. And develop a frame work for reliability reinforcement methods, to come with proper mitigation techniques for betterment of the system.

Specific Objectives

The specific objectives of the thesis are;

- To identify the potential causes of power outages in distribution systems;
- To assess and work out reliability indices of the existing distribution system of case study city
- Assess system reliability and work out its indices based on selected base years interruption data of the city feeder using available reliability analysis tool inside ETAP12.6.0
- To identify different reliability reinforcement mechanisms and evaluate the benefit of each method over the cost of investment;
- To Compare different reliability improvement methods and propose the most economical reliability reinforcement mechanisms to be implemented in the distribution system of the study area.

1.6 Significance of the study

This thesis deals with the assessment of reliability of existing power distribution and development of mitigation techniques for current interruption problem by using different engineering techniques. It is known fact that electric power is a commodity that can be produced, processed, sold and utilized. There are two parties in this regard; the producer and the customer. Therefore when there is a power failure, both the producer and the customer will be affected; but the customers are always the one who are affected more. Some customers are sensitive to the frequency of power failure (i.e. how many times power failure occurs), but others are sensitive to the duration of power failure (i.e. for how long power failure sustains).

In the study area there exist two types of customers: customers sensitive to the frequency of power failure and customers sensitive to duration of interruption. Therefore in reliability analysis

both frequency and duration of interruption are important and have to be given attention during the planning and operation stages of power system.

Considering all the above problems, this thesis work can be applied in solving the existing problem of frequent and long duration interruptions in the area. Therefore, it can significantly benefit both the utility holder (EEU) and customers.

1.7 Overview of the Study Area

This thesis is focused on assessment of reliability of the power distribution system in West ArsiZone, especiallyshashemene town. Shashemene is located at the geographical coordinates of $7^{\circ} 12'.1''$ N and $38^{\circ} 36'.9''$ E and is 240 km away from Addis Ababa. It covers an area of about 759.53 sq. km with an elevation of 2300 meters above sea level. Based on the figures from the central statistical agency in 2012 national census reported this town had a total population of 122,046[3].

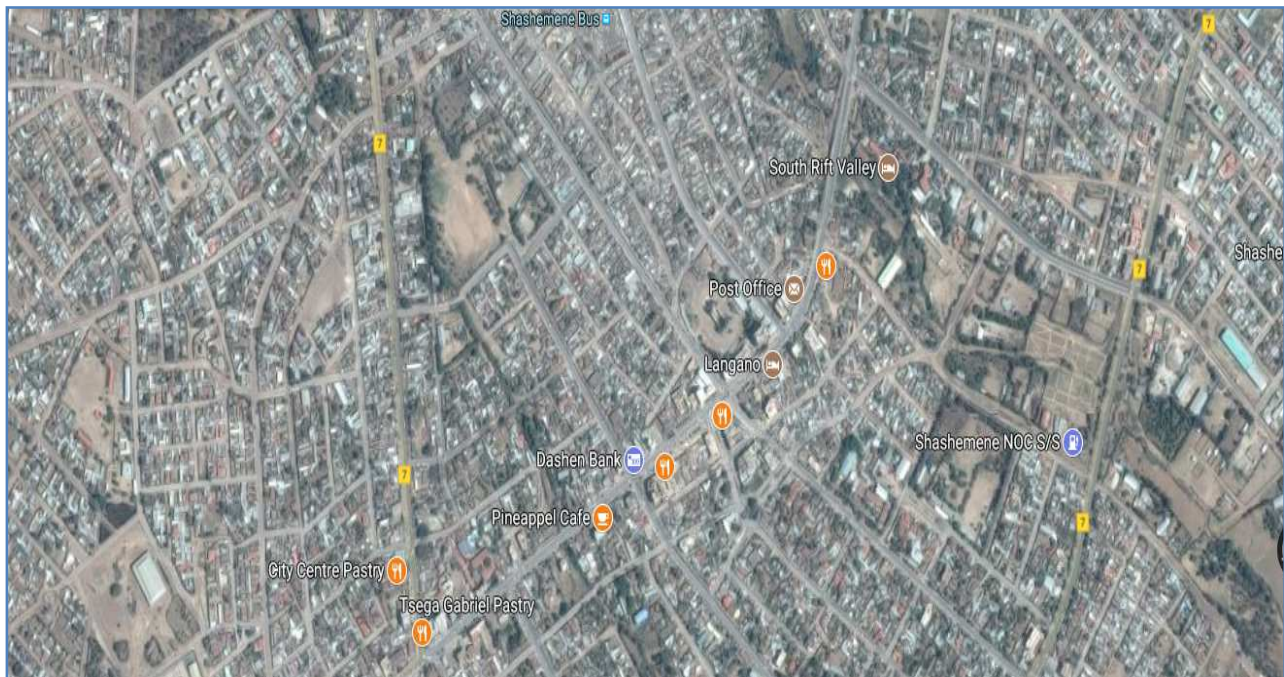


Figure1. 3 Geographical map of shashemene town[3]

1.7.1 Power Supply Source

The Power Distribution Substation which supplies power to the study area is located in the administrative center of west Arsi zone, shashemenetown. The substation is supplied from 132 kV sub transmission line from Alaba and Melkawakena's side.

The basic distribution network model is shown in the figure 1.4 below. Shashemenetown, Arsinegele, wend genet, Alaba, etc are feed from a single source i.e. Shashemene Substation.

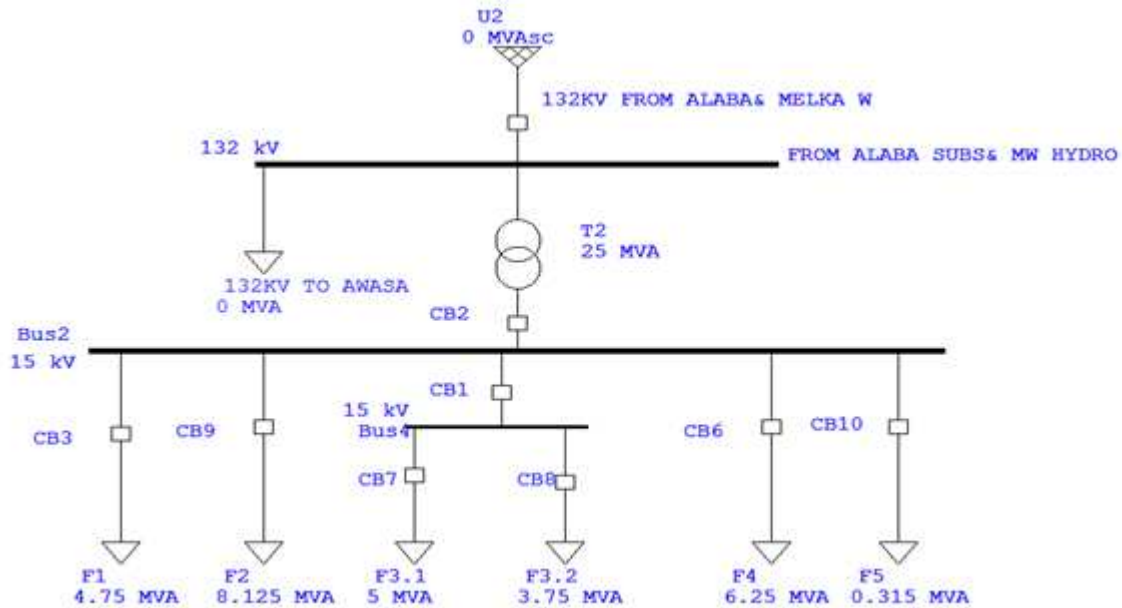


Figure1. 4shashemene substation single line diagram

Shashemene Substation has six 15 kV outgoing feeders (F1, F2, F3.1, F3.2, and F4&F5): These feeders supplying Arsinegele, shashemene, kofele, wendogenetwereda surrounding rural villages.

The total average load demand in the system does not vary significantly from month to month in a year. The average load connected in the study area is **6.096 MVA**. And the peak load recorded was **10.42 MVA**

1.7.2 Shashemene distribution lines

The existing distribution lines both low voltage and MV networks are operated radially. The medium system voltage provides a convenient voltage for connecting substantial loads or the larger blocks or the office buildings. So, the requirements of medium voltage systems are as close as possible to each individual load points.

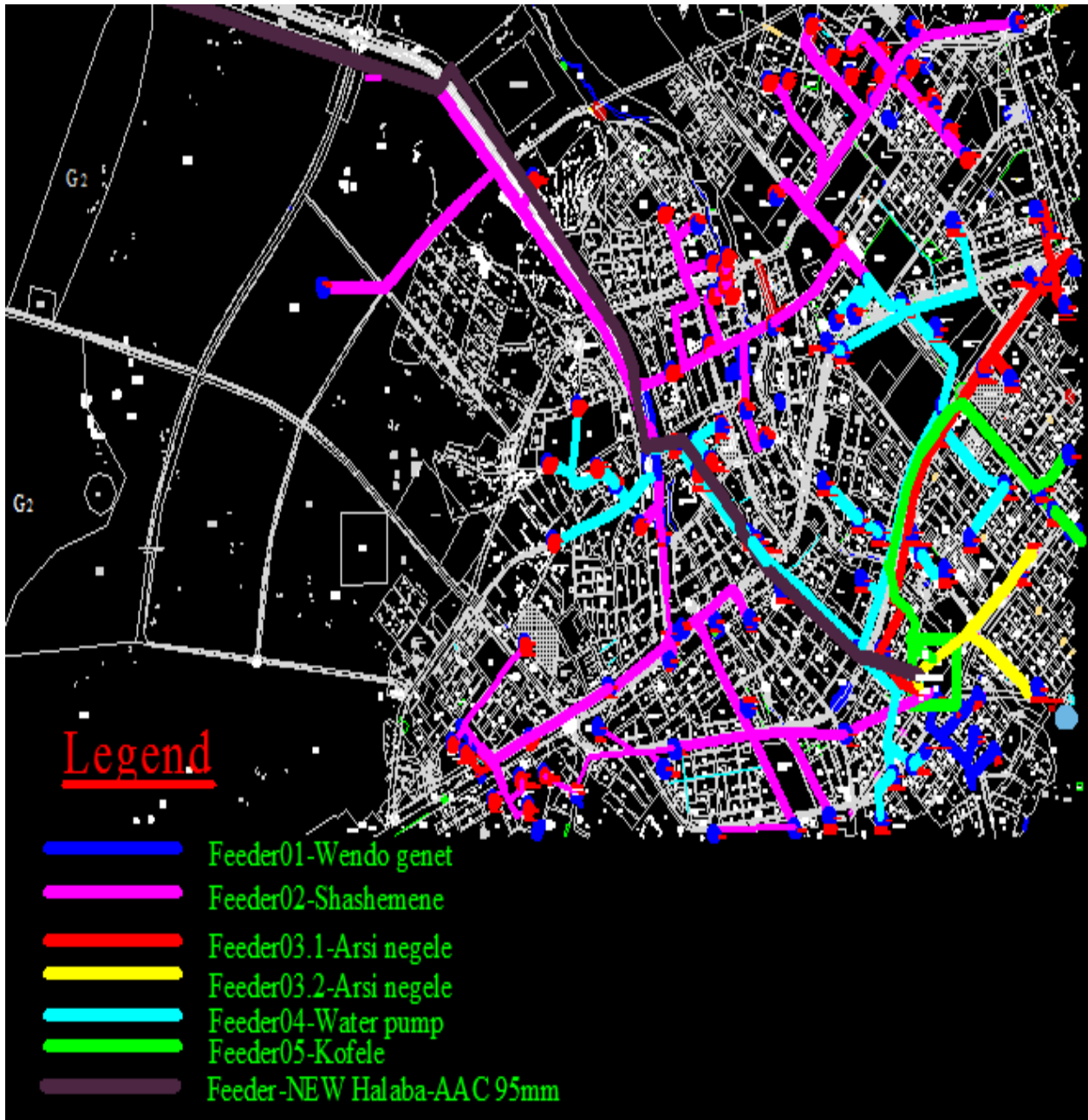


Figure1. 5shashemene town distribution system

The various sizes (from 25kVA to 630kVA) of distribution transformers are used. The transformers from 25kVA-315kVA are usually pole mounted for both urban and rural areas.. Beyond 315kVA transformer are mounted on the ground and are provided with fencing. Almost all the transformers are equipped with individual fuse and disconnectors on MV side. Lightning arresters are used for individual transformers for protection from lightning.

Table 1.1 shows the exposure of primary distribution feeders (including laterals), the number of customers and the average load connected to each feeder. All 15 kV feeders and laterals are 50mm² All Aluminum Conductors (AAC).

Table1. 1detail of MV lines

Feeder name	Voltage level (kV)	Exposure (circuit- km)	Resistance at 20oc (Ω/km)	Average load connected(KVA)	Number of customers connected
F1(wend genet)	15	24.9	0.5419	1425	1811
F2(shashemene)	15	46.525	0.5419	14060	10480
F3.1(arsinegele)	15	30.70	0.5419	5636	2107
F3.2(arsinegele)	15	27.50	0.5419	609	3521
F4(water pump)	15	24.175	0.5419	762	5473
F5(kofele)	15	30.85	0.5419	2525	3454
Total		184.65		25017	26846

The load distribution among the feeders can also be represented using pie chart as follows;

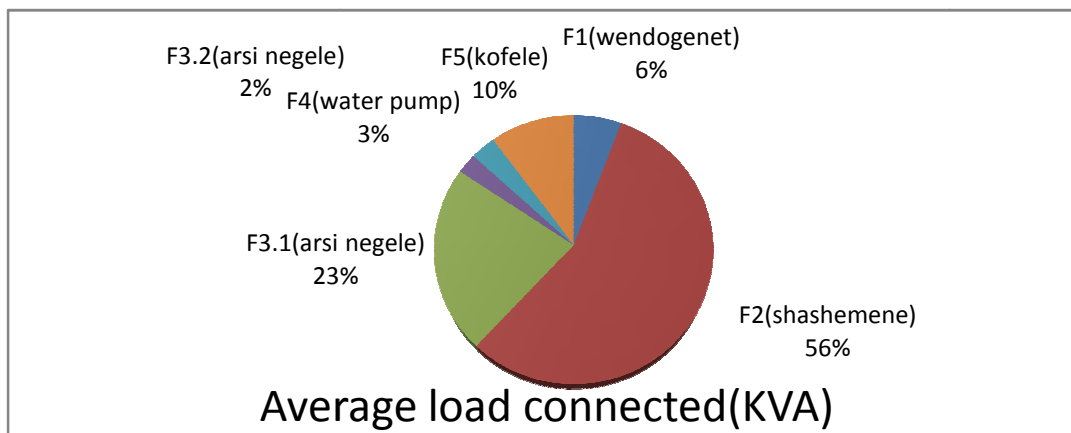


Figure1. 6 load distribution

Feeder F2 is the most loaded feeder followed by F3.1, but F3.2 is the least loaded feeder.

1.7.3 Reliability Aspects

In Ethiopia the reliability standard for electricity supply is not practiced as of now. Since due attention is not given, the statistical data for reliability aspects are not available and the available data are not updated.

However, working out of the distribution reliability indices is challenging due to the geographical locations, data gathering practices, index definitions and planned and unplanned interruptions and of major events.

It is calculated from the recorded 3years power outage data of each feeder, the failure frequency and repair duration of the main feeders and laterals in the system is presented in table 1.2 below.

Table1. 2 **calculated average failure frequency and repair duration of**

Feeder name	Failure frequency (1/km/year)	Repair duration (hours)
F1(wendogenet)	4.757	1.332
F2(shashemene)	5.725	0.916
F3.1(arsinegele)	5.399	1.060
F3.2(arsinegele)	4.254	1.613
F4(water pump)	5.101	1.577
F5(kofele)	7.685	1.565

For comparison purposes, the above tabulated values of failure frequency and repair duration among feeders can also be presented by using bar graph as shown in Fig.1.9 below.

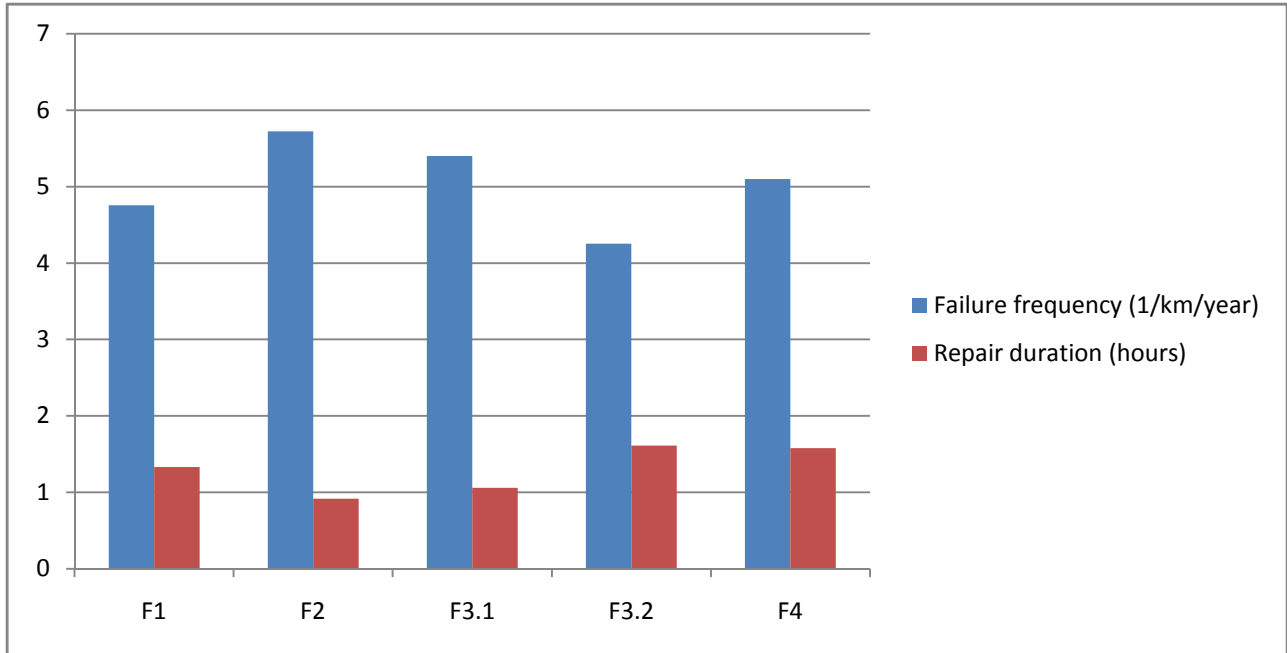


Figure1. 7 Failure frequency and repair duration of feeders

The failure data of distribution 15/0.4 kV transformers has not been recorded yet. In addition, recording the cause of the fault or equipment (transformer, line, etc) failure has not been practiced yet. But the substation and distribution workers said that tree contact is the number one cause of line failure followed by human error.

The reliability indices calculated for the year 2009 E.C for Shashemene Distribution System is presented in table 1.3 below.

Table1. 3 calculated reliability indices of study area

Reliability Indices	Units	Values
SAIFI	Inter/customary	607.658
SAIDI	Hrs/customer.yr	920.269
ASAI	%	98.249

This just gives the overall picture of the whole system in the area and not the localized problem. The indices help us to identify the weak areas and the need of reinforcement. This data will also help us to make predictive analysis for the future system.

1.8 Literature Review

To get better insight about different reliability evaluation techniques, reliability indices, causes of interruption, evaluation of cost of customer interruption, reliability reinforcement mechanisms, and detailed literature study was essential. Under the literature study the general introduction about the thesis on distribution reliability assessment is explained in chapter 1. Chapter three to chapter six are descriptions made as a literature study. Several researchers have been working on the area of reliability analysis, interruption cost evaluation and application of reliability reinforcement mechanisms in distribution power systems has been published. In the following paragraphs, some of the papers and other research works reviewed are presented.

In [4], the author presented analysis of power system in terms of power system reliability techniques, Power quality evaluation, protection analysis and evaluating against maintenance intervention, man power availability and weather conditions contributing to component outages.

In [5], the author proposed a methodology which utilizes basic network reliability concepts to evaluate the performance of the existing network and future options. To quantify network performance through contingency enumeration process the load point EENS is used. In this work the reliability improvement alternative is selected in such a way that the alternative results in the lowest present worth.

In [6], the authors have conducted a study aimed at assessing the characteristics needed to estimate the customer interruption costs in different customer sectors of Estonia due to electric service interruptions. To estimate the costs the authors used indirect analytical methods on base of GNP and annual household income as well as on base of analysis of corresponding characteristics of other countries. The final estimates for different customer sectors as well as for the whole country were found averaging estimated found by different methods.

In [7], using analytical and simulation techniques evaluate the expected customer costs at the system and load level of a radial distribution system is presented. In this work a time sequential Monte Carlo simulation has been developed. But in this thesis work, assessment of reliability aspects in power distribution systems, customers cost of interruption and finally development of cost effective reliability reinforcement mechanisms for the existing shashemene power distribution system is presented.

In [22], a Monte Carlo simulation approach to reliability evaluation of one Distribution system is presented. Stochastic model of distribution system components with Weibull Distribution and Markov model of components are used. A set of system related reliability indices were calculated using sequential Monte Carlo simulation. Monte-Carlo simulation was performed with full use of power restoration switches and full network load flow analysis. Load transfer was also considered to alleviate the overloading of distribution lines and transformers.

In [23], reliability evaluation techniques, which are applied in distribution system planning studies and operation, are presented. Reliability of distribution systems is an important issue in power engineering for both utilities and customers. Reliability is a key issue in the design and operation of electric power distribution systems and load. Reliability evaluation of distribution systems has been the subject of many recent papers and the modeling and evaluation techniques have improved considerably.

In [24], current distribution system is presented. The most of existing electrical infrastructure is becoming aged due to the delayed replacement of assets caused by distribution company's budget constraints. Bearing in mind these aspects, the authors have developed a technique for the evaluation of the distribution system reliability based on a Sequential Monte Carlo (SMC) which takes into account the role of equipment ageing. Real-world examples are provided to illustrate the effect of including ageing system failures into system and individual reliability indexes.

In [25], the use of reclosers is one of the advanced techniques for increasing power supply reliability in electric distribution systems. Optimal location determination for their efficient use is needed, which is an NP-complete problem in general. SAIFI (system average interruption frequency index) is an integral indicator, which measures the average accumulated duration and frequency of sustained interruptions per customer. It was chosen to estimate power supply reliability.

In [26], Paper deals with the analyses of electrical power network reliability parameters connected to maintenance. Knowledge of the component reliability parameters in power networks is necessary for the reliability computation and also for reliability-centered maintenance system. Component reliability parameters are possible to retrieve only with accurate databases of distribution companies. Such a database includes records of outages and interruptions in power networks. Maintenance influences the indicators evaluating interruptions -

maintenance time in fact means unavailability. There are analyses of interruption indicators improvement, modern techniques like Live Working and Reliability Centered Maintenance in this paper.

In [27], provides a framework for a predictive, condition-based, and cost effective maintenance optimization program for transmission and distribution systems. As system equipment continue to age and gradually deteriorate the probability of service interruption due to component failure increases. An effective maintenance strategy is essential in delivering safe and reliable electric power to customers economically.

In [28], this paper presents a fast approach for the reliability assessment of complex radial distribution systems. In this technique, using the shortest path from any node to the system energy source, the type and location of protection/isolating device of each load point and each component are identified. Then, based on the type and respective location of the devices to each other, reliability evaluation is performed. Following a fault on the system the affected loads are restored by identifying a loop created by closing a normally open tie switch (NOTS) and the nearest disconnecting/sectionalising switch to the opened protection/isolating device. The proposed algorithm has been tested on a number of the reliability test systems and the results presented show the effectiveness and applicability, as well as reduced running-time of the new approach.

In [29], authors provide a framework for a predictive, condition-based, and cost effective maintenance optimization program for transmission and distribution systems. As system equipment continue to age and gradually deteriorate the probability of service interruption due to component failure increases. An effective maintenance strategy is essential in delivering safe and reliable electric power to customers economically.

In [30], Author attempts to thoroughly identify causes for power interruptions and customer Dissatisfaction and discusses the design, reliability and operation and maintenance of Addis Ababa distribution system.

1.9 Organization of the Thesis

This thesis has seven chapters. The first chapter introduces background of power system reliability analysis, problem formulation, objectives of the study, significance of the study, and overview of the study area and literature review.

Chapter two of this thesis describes the overall methodology used in achieving the objectives of the thesis using flow chart and description of all modules in the flow chart.

Basics of reliability analysis techniques, reliability indices and the potential problems within reliability indices are presented in chapter three. Additionally in this chapter factors affecting the reliability indices are presented.

Chapter four describes the cause of power outage and cost of power interruption respectively. Different reliability reinforcement techniques that can be used to improve distribution systems reliability are presented in chapter six of this thesis.

In sixth chapter Results, analysis and discussion on the system under study is presented. Both historical reliability assessment and predictive reliability assessment in selecting different reliability reinforcement techniques are presented in detail.

Finally, in chapter seven findings from the study, conclusions, recommendations and suggestions for future work are presented.

CHAPTER TWO

METHODOLOGY

2.1 INTRODUCTION

The prime aim of this study is to see how reliability could be improved in the distribution system by applying different mitigation techniques so that “Optimum Reliability” is achieved, meaning that the total societal cost is minimum. The reliability indices of the existing system shall be evaluated and see how risk of power failure could be mitigated. The fault rates and reliability indices for the year 2009 E.C, is being considered as base year for the study under consideration.

In order to achieve all the objectives presented in section 1.5 the general flow chart (shown in Fig.2.1) is developed for reliability assessment and development of reliability reinforcement methods of the distribution system in the study area. The following subsections are descriptions of all the modules in the flow chart.

2.2 Literature Review

Different literatures which concern about reliability analysis methods, reliability mitigation/improvement mechanisms, and cost benefit analysis of those mitigation techniques are reviewed to have the idea of implementing reliability engineering in existing electric power distribution system.

2.3 Data collection

Data is the core part of any research for the proposed solutions to be actual solutions of the existing problem. Therefore the researcher of this thesis collected much data about the overall nature of the existing Shashemene Electric Power Distribution System as much as possible. Due to the nature of the study, it is started by reviewing literatures related to the investigation of quality and reliability problems of power distribution systems. Recent and unpublished important information and data have been collected from Ethiopian Electric Power Utility (EEU).

Recorded data have been gathered for detail assessment and investigation to come up with a clear solution of the problem at hand. The collected data from the field work have been then analyzed.

The data includes the following;

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

- Site visit
- Technical data collection from the shashemenedistrict distribution system
- To gather data for the distribution system which helps to carryout reliabilityAnalysis

- ❖ For the purpose of analysis the following data from hawasa wire business office collected
 - The single line diagram of MV (medium Voltage) network in the distribution system of the case study area.
 - All the line parameters such as resistance/km cross sectional area and length of each and every MV line segment in the system.
 - The loading data of each outgoing feeder in the system.
 - Fault/failure data which is recorded 2009 E.C year from south region transmission and operation office.
 - Number and class of customers in the study area.
 - Billing data for each class of customers (residential, Industrial, commercial, agricultural, govt.& public).
 - The collected data has been used to clearly analyze the problems of the feeder under study.
 - Customers' cost of interruption through interview and questionnaire.

- ❖ Investigation of power distribution design problems and reliability problems for power distribution systems in the city

- ❖ Analysis of the technical and economic performance of the distribution system

The thesis work considers primary distribution system and particularly the 15kV outgoingfeeders.Due to the fact that distribution system is the major contributor of the reliability problems in the study area.

2.4 Data Analysis and Organization

All data collected has to be analyzed and organized in order to make it suitable for the analysis software (ETAP) used for reliability analysis. The following paragraphs will describe how each data is analyzed systematically.[20]

- Components' failure rate and restoration time are calculated from the data collected.
- The average load data of each outgoing feeder in the distribution system is calculated from one year recorded load data.
- The number of customers for each load point is estimated.

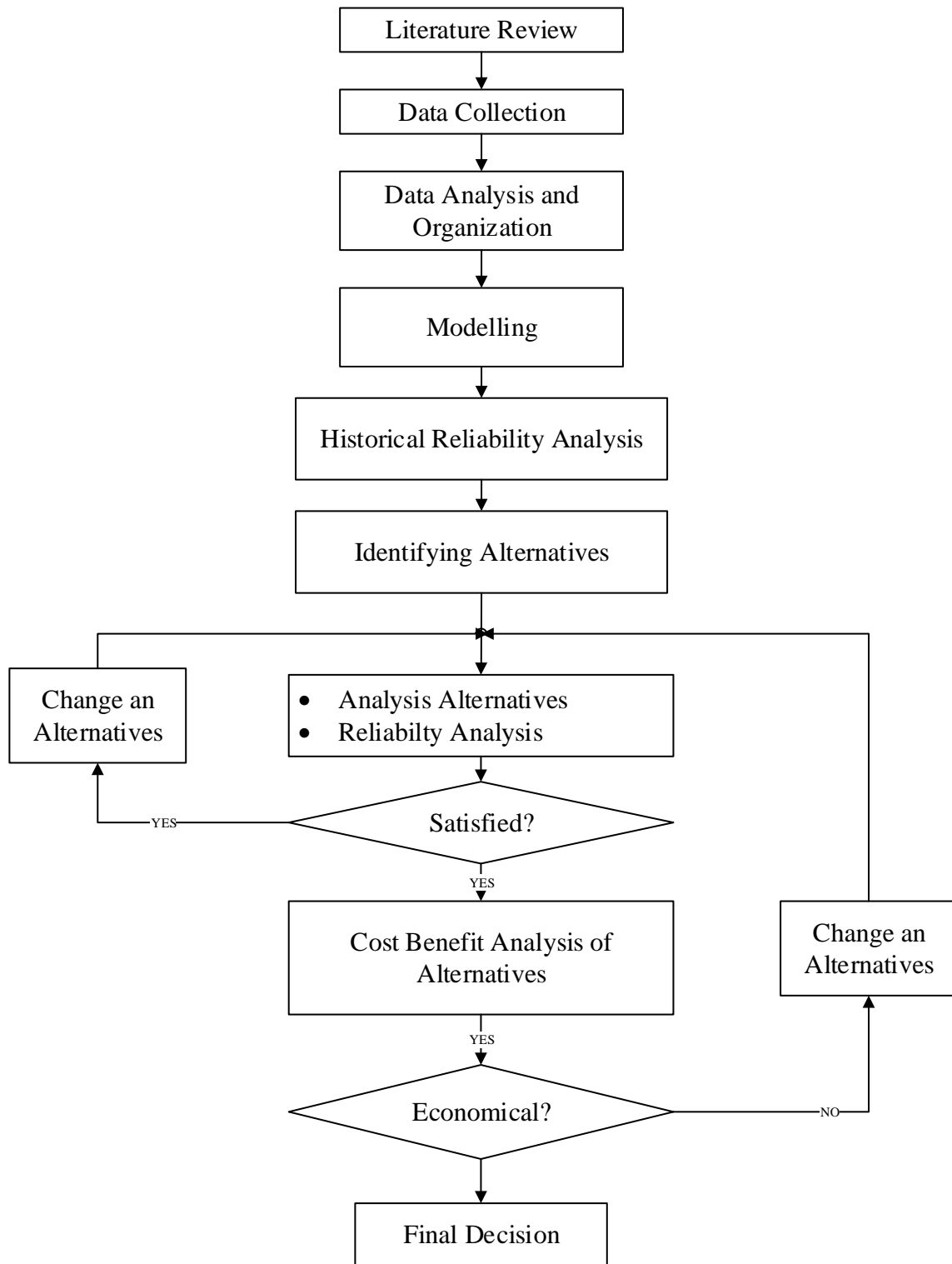


Figure2. 1 General process flow of reliability analysis [1]

2.5 Modeling

Component models are critical to distribution system reliability. From a reliability viewpoint, all of the information required to create a distribution system model is contained in distribution component information [5].

Simple reliability models are based on component failure rates and component repair times, but sophisticated models make use of many other reliability parameters. Some of the most common component reliability parameters are the following.

- I. **Sustained failure rate (λ_s)** - is the number of times per year that a component can expect to experience a permanent failure.
- II. **Mean Time To Repair (MTTR)** – is the expected time it will take for a failure to be repaired (measured from the time that the failure occurs).
- III. **Mean Time To Switch (MTTS)** - is the expected time it will take for a sectionalizing switch to operate after a fault occurs on the system.
- IV. **Mean Time To Maintain (MTTM)** –is the average amount of time that it takes to perform scheduled maintenance on a piece of equipment
- V. **Temporary Failure Rate (λ_t)** – it describes the number of times per year that a component can expect to experience a temporary short circuit.

The distinction between permanent and temporary failure is made by the time it takes for failure to be repaired or the component to be reenergized. If the repair duration for the failed component is longer than five minutes, the failure is sustained; and below five minutes, the failure is temporary [2].

For reliability analysis, in addition to component modeling, the load should be modeled in such a way that it can give full information for the analysis software. The load model consists of three parameters;

- a) **Average load** – it represents the average operating load demand of the load point.
- b) **Number of customers**- represents the number of customers connected to that load point.
- c) **The cost model**- it represents the average cost incurred by the customer(s) connected to the load point due to interruption. The cost can be in ETB/kW, ETB/kWh or ETB.

The single line diagram of Shashemene Power Distribution System is constructed by ETAP 12.6.0 software.

- Each 15/0.4 kV transformer is taken as load point with estimated value of average load, number of customers,
- Each small town (i.e. outside Shashemene) and every rural kebele in the system is taken as a load point with estimated value of load demand, known number of customers , and estimated customer damage function.
- Every primary feeder and lateral is modeled by its failure rate and repair duration.
- Bus bars such as 132kV and 15 kV are modeled by their failure rate and repair duration.
- 132/15 kV transformers are also modeled by their corresponding failure rate and repair duration.
- Each switching device in the system can also be modeled by the mean time to switch on or off.

2.6 Historical Reliability Assessment

To know the present or past performance of the distribution system, historical reliability assessment must be done. It is used to identify the possible causes of power interruption in power distribution and weak areas of the system in terms of reliability.

2.7 Identifying Alternatives

The reliability of present distribution system can be improved through introduction of variety of reliability reinforcement mechanisms in the system. Among the alternatives are;

1. Use of disconnecter switches (manual or motor operated) at some selected points of F1 (alaba), F2 (water pump), F3.1 (arsinegele old), F5 (kofele), etc feeders.
2. Use of sectionalizing switches on feeders listed in 1.
3. Use of auto reclosing devices
4. Feeder reconfiguration
5. Replacing some of overhead lines with covered overhead lines /cable
6. Placement of distributed generation at selected load points
7. Applying periodical tree trimming, line(pole) inspection practices
8. Use of animal guards.

9. Training line-men for quick line restoration/crew management

2.8 Analysis of Alternatives

Each mechanism that is to be applied in the distribution system must be analyzed in terms of load flow, short circuit and reliability by using ETAP simulation software. If the alternative does not satisfy those conditions it will be rejected; but if it satisfies the set criteria it will go for economic analysis. If the alternative is found to be economically justifiable it will be accepted; otherwise it will be discarded.

2.9 Cost to Benefit Analysis

After identifying the alternatives which are technically feasible, it is important to evaluate the cost of all the alternatives. The cost of implementation of alternatives will be compared with the social benefit gained by the alternative when it is implemented. If the benefit gained is greater than the cost the alternative will be accepted to implement; otherwise rejected and another alternative will be selected again. This will be done for all technically feasible alternatives.[12]

CHAPTER THREE

DISTRIBUTION SYSTEM RELIABILITY ASSESSMENT AND METRICS

3.1 INTRODUCTION

Distribution reliability is the ability of the distribution system to perform its function under stated conditions for a stated period of time without failure [13]. The distribution system assessment is to determine the system reliability and customer satisfaction. Many utilities across the world today use reliability indices to track the performance of the utility.

3.2. Reliability Analysis

The two main approaches applied for reliability evaluation of distribution system are Simulation method based on drawings from statistical distributions (Monte Carlo) and analytical methods based on solutions of mathematical models. The Monte Carlo techniques are normally time-consuming due to the fact that a number of drawings necessary in order to obtain accurate results. Statistical distributions of failure rates and repair times are used for the analytical approach. Analytical approach based on failure modes assessment is usual method of evaluating the reliability indices [5].

For simple radial distribution network commonly used adequate indices for evaluation are; the expected failure rate (λ), the average outage time (r), and the expected annual outage time (U). The basic theory for reliability analysis is discussed below. [8], [10]

3.3. Markov Chain Model

The two main approaches used are analytical and Monte Carlo simulation. The vast majority of techniques have been analytically based and Monte Carlo simulation techniques have taken negligible role in specialized applications [1]. Since simulation requires large amount of computing time, and analytical models and techniques have been sufficient to provide planners and designers with results needed to make objective decisions. Analytical techniques represent the system by a mathematical model and evaluate the reliability indices from this model using direct numerical solutions. They generally provide expected indices in a relatively short computing time.

A Markov model is quite popular in the quantitative reliability analysis, and that is suitable to give fair idea about reliability analysis principle. On the basis of Markov models, a simple formula can be developed that can be used to calculate the reliability of the radial distribution network [1]. The method is called like duration-frequency technique, and the starting point is the failure of the individual component. In a so-called stationary Markov process, it basically operates with two central concepts: failure frequency (λ) and repair time (r).

For example a component-wise reliability can only be in one of the following conditions;

Condition 1: component is in *function* (up);

Condition 2: component is in *repair* (down).

This is illustrated in two state model diagram in Fig.3.2 represented by *down* (component in failed state) and *up* (component is in a normal state).

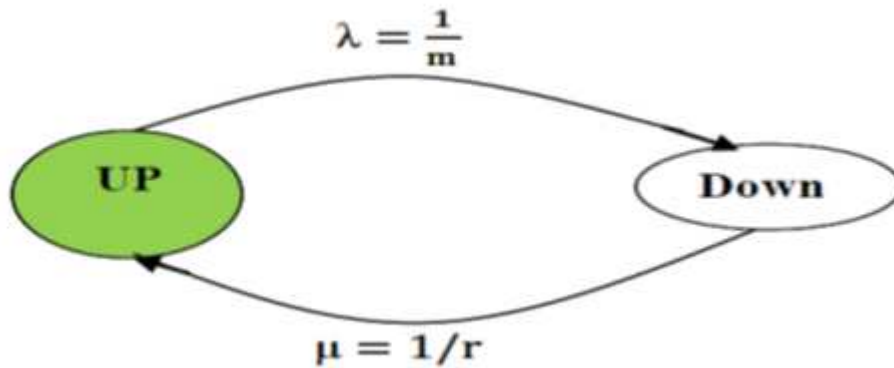


Figure3. 1 Transition diagrams of component states [1]

Where, the fault frequency or failure rate, λ , can be defined as

$$\lambda = \frac{\text{Number of outages or failures of component in a given period}}{\text{Total time the component is in operation}} \quad (3.1)$$

Fig.3.3 below illustrates expected functional and outage time for a component (so called state cycle).The system can be represented by Markov process and equations developed for the probabilities of residing in each state in terms of state transition rates are as follows[1];

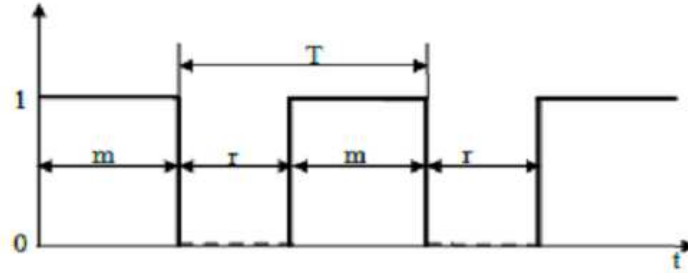


Figure3. 2Average states Cycle [1]

The average up time, m , is given by; $m = 1/\lambda$, it is also called mean time to failure (MTTF).

And, the average down time, $r = 1/\mu$, it is also called mean time to repair (MTTR) $m+r =$ mean time between failures, $MTBF = T = 1/f$, $f =$ cycle frequency

The probability of component to be in either of the two states is calculated as follows;

$$P_0 = \frac{r}{m+r} = \frac{\lambda}{\lambda+\mu} = \frac{r}{T} = \frac{f}{\mu} = \frac{\Sigma(\text{down time})}{\Sigma(\text{down time}) + \Sigma(\text{Up time})} \quad \text{Where } f = \mu \cdot P_0 \quad (3.2)$$

$$P_1 = \frac{m}{m+r} = \frac{\mu}{\lambda+\mu} = \frac{m}{T} = \frac{f}{\lambda} = \frac{\Sigma(\text{Up time})}{\Sigma(\text{down time}) + \Sigma(\text{Up time})} = f \cdot \lambda \cdot P_1 \quad (3.3)$$

Where: P_0 -Probability for a component to be in state 0(down)

P_1 -Probability of a component to be in state 1 (Up)

3.3.1Series System

The distribution systems in Ethiopia are basically designed, constructed and operated in radial system. A radial system basically consists of set of series components like; breakers, lines, switches, transformers and at the end load. All the components are connected in series as shown in Fig.3.2 and the equations needed to evaluate the basic indices are as follows [1];



Figure3. 3 Series System [1]

➤ Average failure rate of the system;

$$\lambda_s = \lambda_1 + \lambda_2 = \sum_1^2 \lambda_i \quad (3.4)$$

- Average Outage time of the system;

$$r_s = \frac{\lambda_1 r_1 + r_2 \lambda_2 + \lambda_1 \lambda_2 r_1 r_2}{\lambda_1 + \lambda_2} \quad (3.5)$$

If $\lambda_1 \lambda_2 r_1 r_2 \ll \lambda_1 r_1$ or $\lambda_2 r_2$

$$r_s = \frac{\lambda_1 r_1 + r_2 \lambda_2 + \lambda_1 \lambda_2 r_1 r_2}{\lambda_1 + \lambda_2} = \frac{\sum \lambda_i r_i}{\sum \lambda_i} = \frac{U_s}{\lambda_s} \quad (3.6)$$

- Average Annual Outage time ;

$$U_s = f_s \cdot r_s = \lambda_s \cdot r_s \quad (3.7)$$

Where λ_i is the failure rate at node i , r_i is the outage time at node i

3.3.2 Parallel System

Two or more components must be on outage at the same time in order to interrupt a load point as shown in Fig.3.5. It is assumed that the failures are independent and that restoration involves repair or replacement, the equations used to evaluate the indices of the overlapping outage are as shown below [1].

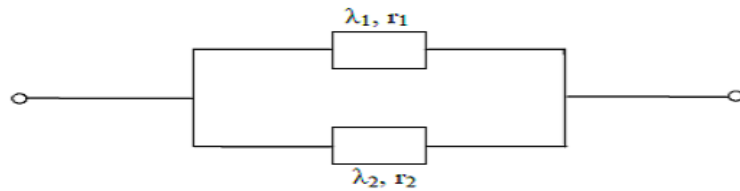


Figure3. 4 Parallel System[1]

- Average failure rate of the system;

$$\lambda_p = \frac{\lambda_1 \lambda_2 (r_1 + r_2)}{1 + \lambda_1 r_1 + \lambda_2 r_2} = \lambda_1 \lambda_2 (r_1 + r_2) \quad (3.8)$$

Where $\lambda_1 r_1$ and $\lambda_2 r_2$ usually $\ll 1$

- Average outage time of the system;

$$r_p = \frac{r_1 r_2}{r_1 + r_2} \quad (3.9)$$

If $\lambda_1 \lambda_2 r_1 r_2 \ll \lambda_1 r_1$ or $\lambda_2 r_2$

- Average Annual Outage time; $U_p = \lambda_p r_p$

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

3.4 Reliability Indices

Reliability indices are statistical aggregations of reliability data for a well-defined set of loads, components or customers. Reliability indices typically considers the number of customers, the connected load; the duration of the outage; the amount of power (in KVA or in KW) interrupted and the frequency of interruptions [9].

The most common way of defining reliability is in terms of customer and load based indices.

3.4.1 Customer Based Indices

Most utilities commonly use the following reliability indices for frequency and duration to quantify the performance of their systems [1].

- I. **System Average Interruption Frequency Index (SAIFI)** - is defined to give information about the average frequency of sustained interruptions per customer over a predefined area. It quantifies how many sustained interruptions an average customer experiences in one year;

$$SAIFI = \frac{\text{Total number of customer interruptions p.a.}}{\text{Total number of customers served}} = \frac{\sum_i N_i \lambda_i}{\sum_i N_i} \quad (3.10)$$

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

- II. **System Average Interruption Duration Index, (SAIDI)** - is commonly referred to as customer minutes of interruption or customer hours, and is designed to provide information about the average time that the customers are interrupted. It quantifies how many interruption hours an average customer experiences in one year.

$$SAIDI = \frac{\text{Total number of customer interruptions durations}}{\text{Total number of customers served}} = \frac{\sum_i U_i N_i}{\sum_i N_i} \quad (3.11)$$

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

- III. **Customer Average Interruption Duration Index (CAIDI)** - is the average time needed to restore service to the average customer per sustained interruption. It is used to measure the utility response time to interruptions.

$$CAIDI = \frac{\sum \text{Customer interruption duration p.a}}{\text{Total number of customers interrupted}} = \frac{\sum_i U_i N_i}{\sum_i N_i \lambda_i} = \frac{SAIDI}{SAIFI} \quad (3.12)$$

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

IV. **Customer Average Interruption Frequency Index (CAIFI)** - is designed to show trends in customers interrupted and helps to show the number of customers affected out of whole customer base.

$$CAIFI = \frac{\text{Total number of customer interruptions p.a}}{\text{Total number of customer interrupted}} = \frac{\sum_i N_i}{\sum_i N_o} \quad (3.13)$$

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

$$ASAI = \frac{\text{Customer hours of available service}}{\text{Customer Hours demanded}} = \frac{\sum_i N_i \times 8760 - \sum_i U_i N_i}{\sum_i N_i \times 8760} \quad (3.14)$$

Where, 8760 is the number of hours in a year.

3.4.2 Load and energy Based Indices

Two of the oldest distribution reliability indices (SAIFI and SAIDI) weigh each customer equally instead of weighing based on connected KVA [2]. From a utility perspective, the Average System Interruption Frequency Index (ASIFI) and Average System Interruption Duration Index (ASIDI) represent better measure of reliability than SAIFI and SAIDI. This is because larger KVA corresponds to higher revenue and should be considered when making investment decisions.

I. **Average System Interruption Frequency Index (ASIFI):**

$$ASIFI = \frac{\text{Connected KVA Interrupted}}{\text{Total KVA Served}} \quad (1/\text{yr}) \quad (3.15)$$

II. **Average System Interruption Duration Index (ASIDI):**

$$ASIDI = \frac{\text{Connected KVA Hours Interrupted}}{\text{Total KVA Served}} \quad (\text{hrs}/\text{yr}) \quad (3.16)$$

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

$$L_a = L_p \times f_l \quad ; \text{ Where } L_p = \text{peak load demand and } f_l = \text{load factor and}$$

$$La = \frac{\text{Total energy demanded in period of interest}}{\text{Period of interest}} = \frac{Ed}{t} \quad (3.17)$$

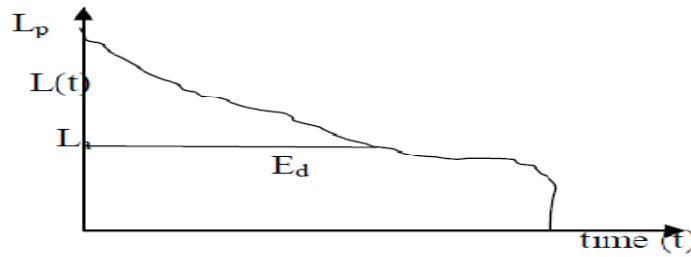


Figure 3.10 Illustration of La, LP, Ed and t [5]

Fig.3.10 shows the load duration curve of a typical load point. Always the load is dynamic; it changes with respect to time. The area under the curve $L(t)$ represents the energy consumed by the load point, E_d .

I. Energy not supplied (ENS) index

Total energy not supplied by the system,

$$ENS = \sum_i LPENS_i = \sum_i La_i X U_i \quad (3.18)$$

Where $LPENS_i$ is load point energy not supplied. La_i is the average load connected to load point i and U_i is the average outage time of load point i .

II. Average energy not supplied (AENS)

$$AENS = \frac{\text{Total Energy Not Supplied}}{\text{Number of customers served}} = \frac{\sum_i La_i X U_i}{\sum_i Ni} \quad (3.19)$$

3.5 Factors affecting reliability performance

Reliability performance varies dramatically from one system to another and this is not necessarily an indication that one system has poor performance. Many factors influence the expected reliability at a particular location or for an entire system.

Reliability indices that reflect reliability performance differ with data definitions and data classifications. Most utilities define separate indices for planned and forced events [9]. The interruption caused due to major event like storm, forest fire or a forced majeure may or may not

be considered in reliability performance. Transmission and distribution events are considered separately for reliability performance evaluation due to data classes or nature of events.

The service territory of the utility determines the nature of the events that could be expected and affect reliability performance. Geography of the service territory such as thick forest, mountainous terrain, etc is likely to cause reliability issues. Weather is an important factor that can seriously affect reliability levels. The effects of vegetation such as tree fall, branch intrusion and animal activity from birds, squirrels and pests causing ground faults affect reliability levels. Maintenance practices such as tree trimming programs and installation of animal guards could help achieve higher levels of reliability. Hence, it is obvious to expect a different reliability levels at various locations [9]

3.6 Reliability Reinforcement Techniques

Utilities must strive to maximize reliability to ensure that customer requirements are satisfied while incurring the lowest possible cost. Utilities can maximize network performance and better serve customers by carefully addressing trouble prone areas. The first step is identifying the root cause of the outages. The main strategy to improve reliability and power quality is to eliminate faults and then to minimize the effect of faults on customers [2].

Now days, utilities are receiving pressure from two stake holders to develop and re-evaluate their strategies for providing adequate reliability at suitable cost levels. Firstly, most customers expect a level of reliability which is either the same as or better reliability which they have given in the past. Secondly, company owners expect suitable rates of return, demand that all capital expenditures and operation and maintenance (O&M) expenditures should be selected in order to maximize results. These demands force utilities to have a sound strategy for balancing expenditures with appropriate level of reliability. However, it may be difficult for EEU to develop a comprehensive strategy specifically due to the following obstacles in the system and must be addressed [16].

Reliability targets

Since predictive reliability indices are not available, it will be uncertain as to which indices will be used for the future reliability targets and what value of those targets is to be used.

Data Availability

As of now, data collection mechanisms are not in place to provide the raw operating and economic data for evaluation of reliability improvement alternatives.

Reliability Analysis Software

The necessary software/analytical tools, such as predictive reliability analysis, are not available.

3.6.1 Overview of procedures

So as to develop a reliability improvement strategy applied around the world is reproduced in figure 7.1, a three step procedure for developing a reliability improvement which could be applied on the distribution systems in any utility [17].

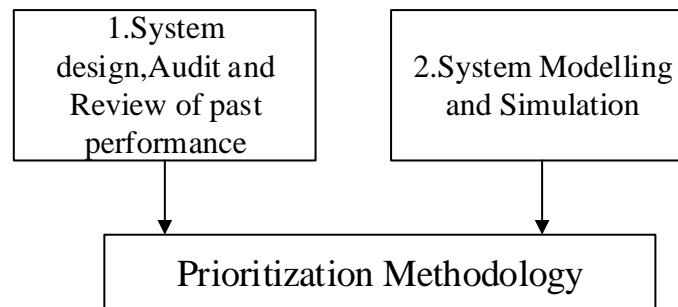


Figure6. 1 Procedure of developing Reliability Improvement [17]

- I. System design audit, review of historic performance data, and the application of good distribution engineering principles are performed to estimate the reliability impact of reliability improvement alternatives. A large part of this work is performed in the field, involves inspections and discussions with operating personnel.
- II. System modeling and simulation studies are performed to evaluate the reliability impact of characteristics such as system configuration, layout, and protection. This step involves the use of predictive reliability analysis software on distribution circuits in particular areas of the system.

III. Prioritization of reliability improvement strategies is conducted based upon the cost-effectiveness of the various reliability improvement programs. This step uses the findings of the first two steps, extrapolated to the rest of the system, in order to arrive to the most cost-effective reliability improvement alternatives.

3.6.2 System Design Audit and Review of past performance

The first step in the procedure is the system design audit and review of past performance. It generates insight into the underlying causes of poor reliability. It is recommended that the following areas be audited:

- Planning guidelines
- System design
- Construction practices
- Environmental data
- Restoration practices
- Tree-trimming practices
- Inspection practices

3.6.3 System Modeling and Simulation studies

Predictive reliability analysis software models the distribution circuit topology, probability and impact of outages, protective equipment response, post-fault switching, and time to restore service.

The advantages of creating a system model and performing simulations are;

- Weak spots and critical areas can be identified in a systematic manner.
- The largest contributors to poor reliability can be systematically identified,
- Alternative solutions, such as configuration changes, equipment additions or upgrades, improved protection and switching, etc, can be evaluated and compared in terms of their ability to cost-effectively improve system reliability.

3.6.4 Prioritization Methodology

The selection of the index, or indices, which is used in the prioritization should be based upon the utilities own metrics for reliability performance. Some of the indices frequently used to measure the benefit of reliability improvement alternatives are:

- Avoided customer-minutes of outage- This is directly related to SAIDI, and considers both the number of customers affected and the duration of interruptions.
- Avoided customer interruptions- This directly related to SAIFI, and considers both the, number of customer affected and the number of interruptions.
- Avoided kWh of outage- This considers the kW demand of customers, and the duration of the interruption, but not necessarily the number of customers.
- Cost of Energy Not Supplied (CENS)-This considers the cost of energy not supplied, however the cost of interruption have to be obtained.

The projected benefits of alternatives can be determined through system modeling and predictive reliability assessment. This method is good for examining the benefits of system configuration changes, addition of protective devices or sectionalizing devices, automated switching, addition of distributed generation (DG) and other system design changes.

3.7 Outage Mitigation Techniques

After developing the reliability improvement strategy, it is significant to apply the interruption mitigation techniques in order to obtain better results. Hence it is important to investigate the root cause and apply mitigation techniques. The mitigation techniques can be basically classified into two categories [18]: electric and non-electric. Electric mitigation techniques have a direct impact on the distribution system and affect the distribution system analysis while non-electric mitigation techniques do not have any impact on other engineering analysis tools and can be evaluated solely with reliability studies. It is therefore necessary to apply both the techniques in order to gain better improvement in reliability of the system which is detailed below.

3.7.1 Non Electric Mitigation Techniques

Non electric mitigation techniques do not have any impact on other engineering analysis tools and can be evaluated solely with reliability studies. Types of non-electric mitigation technique include: Vegetation management and installation of lightning arresters, animal protection guards, maintenance, and crew management.[17]

- Vegetation Management/tree trimming practice
- Animal Guards
- Maintenance Strategy
- Crew placement and management

3.7.2 Electric Mitigation Techniques

These techniques have direct impact on the distribution system and affect the distribution system analysis. These techniques include: addition of protective devices (reclosers and fuses) and switching devices (manual and automated switches), system reconfiguration and feeder re-conductoring, etc. [19]

- Reclosing devices, Sectionalizers and Switches
- System Configuration
- Covered Overhead conductor

CHAPTER FOUR

GENERAL CAUSES OF POWER OUTAGES

4.1 INTRODUCTION

According to IEEE100-1992, an interruption to service is the isolation of an electrical load from the system supplying that load, resulting from an abnormality in that system. The abnormality in the system can either be a malfunction of a system component, a fault or a system operation due to maintenance or repair. Interruptions, independent from the cause, are generally undesired, as they leave energy unserved and customers without service. Most of the time, interruptions occur because the system is reacting to a fault. A fault or short-circuit is defined by IEEE100-1992 as an abnormal connection of relatively low impedance, whether made accidentally or intentionally, between two points of different potential [23], [25].

Over-loading, earth fault and short circuits are the major cause of interruptions in shashemene distribution system. These major faults are classified in to two main categories: temporary and permanent faults. Temporary faults account for the majority of faults in distribution systems. Temporary faults can occur for many reasons, but may include tree or animal contact and weather as the main contributors. Temporary faults can be easily solved, with little or no intervention from the system itself. Many are self-clearing, such as a branch or animal contact, which burn and fall off, conductors slapping together in severe wind or insulation flashover due to contamination. Lightning is also a temporary fault. Lightning arrester failure, on the otherhand, can become a permanent fault. Other temporary faults are simply cleared once a trip from the substation is issued. Instantaneous reclosing de-energizes the line for a short duration of time, which allows the arc or contact path to disappear, which in turn eliminates the fault path. Once the circuit is re-energized, the system resumes normal operation. Permanent faults, on the other hand, are those that cannot be solved with reclosing action and will not self-clear. Equipment malfunction, cable failure, downed lines or persistent tree contact can all produce permanent faults. It is important to point out, that some tree contact can cause permanent faults, such as a tree falling on a line [12].

There are many principal causes of electrical failure; such as dust and dirt accumulation, moisture, loose connections, and friction of moving parts, aging of conductors, clearance from trees and limbs and structures, equipment over loading, frequency and so on. An effective maintenance program should aim to minimize these effects by keeping equipment clean and dry, keeping connections tight.

4.2 Equipment Failures

Each piece of equipment on a distribution system has a probability of failing. When first installed, a piece of equipment can fail due to poor manufacturing, damage during shipping, or improper installation [1].

4.2.1 Transformers

Transformers impact distribution system reliability in two related ways: failures and overloads. Catastrophic transformer failures within substations can result in interruptions to thousands of customers. Loading has a significant influence on transformer life and is a critical aspect of distribution reliability, but most catastrophic transformer failures are due to faults that occur downstream of the transformer secondary bushings.

4.2.2 Overhead Lines

Due to high exposure, most overhead line damage is caused by external factors such as vegetation, animals, and severe weather. Bare conductor is able to withstand much higher temperatures than insulated conductors and damage due to high currents is less of a concern. Regardless, high currents do impact the reliability of overhead lines in several ways. High currents will cause lines to sag, reducing ground clearance and increasing the probability of phase conductors swinging into contact. Higher currents can cause conductors to anneal, reducing tensile strength and increasing the probability of a break occurring. Fault currents, if not cleared fast enough, can cause conductors to melt and burn down.

4.2.3 Underground Cables

A major reliability concern pertaining to underground cables is electrochemical and water treeing. Treeing occurs when moisture penetration in the presence of an electric field reduces the dielectric strength of cable insulation. [2].

4.2.4 Circuit breakers

Circuit breakers are complicated devices that can fail in many different ways. They can spontaneously fail due to an internal fault, spontaneously open when they should not, fail to open when they should, fail to close when they should, and so forth.

4.2.5 Insulators and Bushing

Insulator and bushing failures are associated with dielectric breakdown. A dielectric breakdown in an insulator allows current to arc across the device. A dielectric breakdown in a bushing allows current to arc from the internal conductor to the outside of the device. Sometimes these currents will be small or self-extinguishing. At other times these currents lead to a low impedance arc, resulting in a short circuit and a potentially catastrophic failure of the insulator.

4.2.6 Surge Arresters

Surge arresters come in two basic forms: silicon carbide and metal oxide varistors (MOVs). Silicon carbide is the older of the two technologies and requires an air gap to avoid excessive currents during normal operation. Silicon carbide arresters tend to fail more often than MOVs due to the presence of air gaps. Moisture entering an air gap can cause corrosion and reduce the voltage withstanding strength of the gap. Further, thermal expansion of water vapor under heat can result in damaging mechanical stress to the interior of the arrester and can result in catastrophic failure during normal or overvoltage situations. Other failure modes include bad or aged blocks and direct lightning strikes [2].

4.3 Animals

Animals are one the largest causes of customer interruptions for nearly every electric utility. The common classes of animals involved in reliability problem are birds, snakes, rats, large animals, etc. Problems and mitigation techniques are as varied as the animals involved.

4.4 Severe Weather

Severe weather can take many forms and is the most frequent cause of customer interruptions for many utilities.

4.5 Trees

Trees are one of the top three causes of customer interruptions for most utilities (animals and lightning being the other two).[17]

4.6 Human factors

In addition to equipment, animals, trees and weather, humans are directly responsible for many customer interruptions.

4.6.1 Scheduled Interruptions

It is sometimes necessary to interrupt customer service when performing work on radial distribution systems. The scheduled interruptions may be due to maintenance and system expansion.

4.6.2 Human Errors

Mistakes by utility workers often result in customer interruptions. Examples are many and varied, but can generally be classified into switching errors, direct faults, and indirect faults.

4.6.3 Vehicular Accidents

Vehicular accidents are a major reliability problem along congested thoroughfares. A speeding automobile striking a wooden distribution pole will usually cause the pole to lean, causing unsafe line clearances and requiring repair. These collisions may also result in a fault by causing conductors to swing together, sagging lines into the ground or snapping the pole entirely. Cranes are another common cause of faults and interruptions.

4.6.4 Dig-ins

A dig-in occurs when excavation equipment cuts through one or more underground cables. They cause a substantial number of interruptions and are usually associated with construction sites.

4.6.5 Mischief and Vandalism

Another reliability concern arises when thieves steal conductor wire to sell as scrap metal. Removal of ground wire, counterpoise and substation grounding may not directly result in interruptions, but may cause safety concerns and compromise protection schemes.

CHAPTER FIVE

ELECTRIC SERVICE INTERRUPTIONS CUSTOMER COST

5.1. OVERVIEW

Providing adequate electrical supply to its customers *economically* at a reasonable level of reliability is the basic function of modern electric power system. The determination of what is reasonable level of reliability has been based on past experience and judgments, though somewhat arbitrarily [5].

Rapid increase in power demand where supply growth is constrained by scarce resources, environmental problems and other societal concerns is the main problem facing electricity utilities in developing countries today. This forced the utility for more extensive justifications of new system facilities, and improvements in production and use of electricity.

System planning based on reliability cost/worth evaluation approach will provide an opportunity to justify one of the most scrutinized and vulnerable economic sectors [5].

5.2 Reliability Cost and Worth

The financial losses and economic impact are not confined to the utility or the major industrial user, but impacts indirectly on the entire community and the environment. Power system outages affect more on businesses than any other user of electricity [9]. When outage occurs in the distribution system, the impact of this outage is not restricted to loss of revenue by utility or loss of energy utilization by the customer but there is indirect cost imposed on customer and the environment due to outage [1, 4].

The basic concept of reliability cost/reliability worth is shown in Fig.5.1. The figure shows that the system cost generally increases with higher investment cost in equipment and facilities which provide higher reliability and the customer interruption costs will decrease. The total cost to the society is the sum of these two costs. Reliability cost/worth analysis is performed to find this optimal point. The exact value of this optimal point cannot be found; but the approximate point of optimal reliability can be calculated.

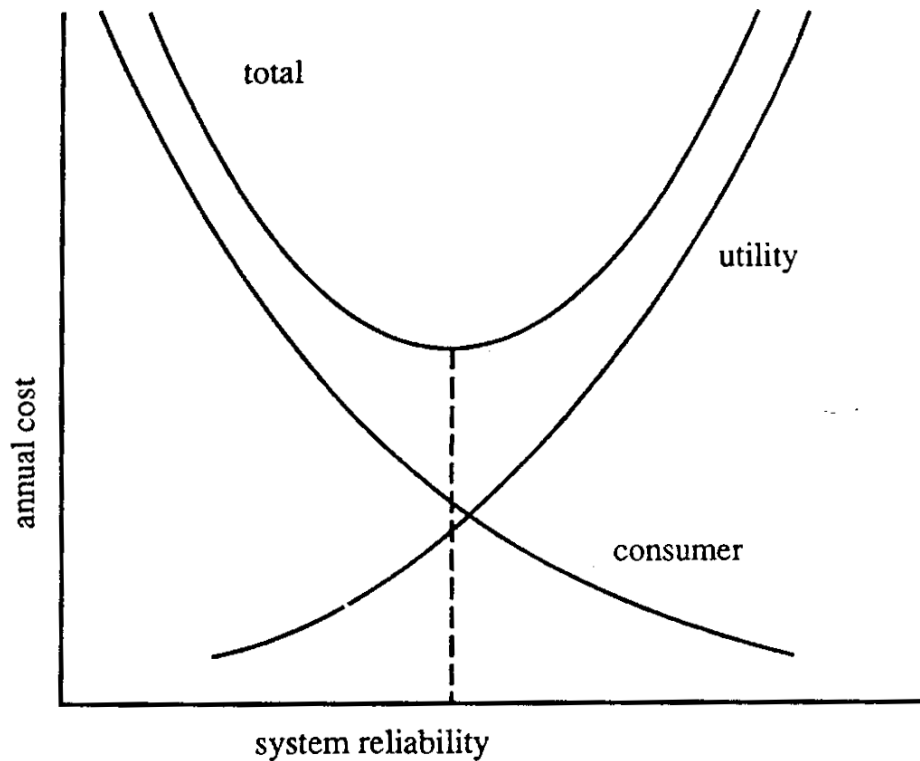


Figure 5.1 Investment VS System Reliability

5.2 Outage Cost Evaluation

5.2.1 Outage cost analysis

For development and economic growth Access to electricity supplies at reasonable cost and quality levels has become a basic condition.

Power interruption costs in both the utility and the customer sides. The size of the economic losses due to interruptions depends on categories of the customers that experience interruptions. Customers in Shashemene city are roughly divided into three categories: residential, commercial, and industrial customers.

For industries, electricity supply interruption costs are strongly related to production losses and to costs to restore production. In addition, interruptions also cause property damages and revenue loses for industries, commercial customers and for private individuals. Extensive continuing blackouts put the vulnerable society for extra expenses. It is difficult to estimate the exact value interruption costs and economical loses of each customer since they have different properties.

On the utility side power interruption cost is estimated by differentiating the type of the customers interrupted whether they are residential, commercial or industrial. Electricity utilities recorded many data and use different reliability indices for measuring their system performance. In the case study area, Shashemene city, power interruptions data are usually recording in the form of interruption duration, interruption frequency and load (MW) reading of each feeder on each hour.

From these data it is easy to know the reliability indices, System Average interruption Frequency index (SAIFI), System Average interruption Duration index (SAIDI) and Expected Energy Not Supplied (EENS) of sustained interruptions experienced by customers of each feeder in a year.

The basic factor used for cost estimation is the tariff (price in Birr or Dollar per KWH) for different types of customers.

Table 5.1 Ethiopian Electric Utility electricity tariff [14]

No	Customer Category & Block Identification	Monthly Consumption(KWH)	Birr/kWh
1	Domestic		
	Flat Rate		0.4735
	1 st Block	0-50	0.273
	2 nd Block	51-100	0.3564
	3 rd Block	101-200	0.4993
	4 th Block	201-300	0.55
	5 th Block	301-400	0.5666
	6 th Block	401-500	0.588
	7 th Block	Above 500	0.694.3
2	General/Commercial		
	Flat Rate		0.6723
	1 st Block	0-50	0.6088
	2 nd Block	Above 50	0.6943
3	Low Voltage Time of Day industry		
	flat Rate		0.5778
	Peak		0.7426

	Off-Peak		0.5453
4	High Voltage Industry@15KV		
	flat Rate		0.4086
	Peak		0.5085
	Off-Peak		0.3933
5	High Voltage Industry@132KV		
	flat Rate		0.3805
	Peak		0.4736
	Off-Peak		0.3664
6	Street Lighting Tariff		
	flat Rate		0.4843

Based on the Ethiopian Electric Utility Estimation manual, which is currently applicable, interruption cost or unsold electricity is calculated as:

Interruption Cost= $\frac{1}{4}$ x (Total capacity of interrupted transformers (KVA)) x (Total interrupted Hours) x 0.8 x 0.4407) ETB[11].

As shown in the equation above to calculate the interruption cost: summing up the Kilo Volt Ampere (KVA) of the interrupted transformers and multiplying by power factor (0.8) and then divided by one fourth (1/4) gives the average interruption power (Kilo Watt). One fourth indicates the average load used from the capacity of the transformer during the interruption period. Multiplying the load (KW) by total interruption duration (Hr.) and then multiplying by the price per KWh (0.4407 Ethiopian Birr) gives unsold energy or interruption cost. The tariff 0.4407 is taken from the average of the first block tariffs of domestic and commercial customers, which most Ethiopian electricity customers are assumed to be grouped.

For city line, Energy not supplied (MWh) is calculated for three years from interruption frequencies, interruption Durations (Hr.) and the Load (MW) before interruptions from the substation recorded data. The cost of energy not supplied is calculated and summarized in Table 5.2 based on exchange rate of the Commercial Bank of Ethiopia on 21 November, 2016 which equates One US Dollar (USD) to 27.5Ethiopian Birr (ETB).

Interruption Cost= sum of (load before interruption (MW) x1000 x interruption duration (Hrs) x 0.0363636USD)

$$\text{Interruption Cost} = \sum_{i=1}^n L_i \times I_{D_i} \times 1000 \times 0.0363636 \text{ USD}$$

Where assumed as, i = interruption event n = all sustained interruptions within a year in the same system

L_i = the load (MW) recorded from the relay at substation on the nearest hour before event i

I_{D_i} = Interruption Duration (hr.) for event i

For year 2009: The unsupplied Energy from Appendix is 39,485kwh

$$\text{Interruption Cost} = 39485 \text{ kwh} \times 0.4407 = 17,401.0395 \text{ ETB}$$

By the same procedure the interruption cost for years 2007, 2008&2009 E.C is calculated and summarized in Table below

Table 5.2 Unsold electricity cost [11]

Year	Unit	2007	2008	2009	Average of three years
EENS	MWH	11,422.39	19,974.03	39,485.00	23,627.14
Interruption cost	ETB	5,033,847.2730	8,802,555.02	17,401,039.50	10,412,480.5980
Interruption cost	USD	183,048.99	320,092.91	632,765.07	378,635.6581

5.3. Evaluation of Investment Cost

A major feature of planning in almost all activities is reduction of cost. Criteria on service quality and standards must be met and guidelines must be followed, but the goal is to minimize the cost. Every alternative plan contains certain costs: equipment, installation labor, operating, maintenance, losses, and many others as well. Alternatives vary not only in the total cost, but often, equally important, when the costs are incurred - how much must be spent now, and how much later? [15]

Utility planning focused on finding the lowest cost alternative to serve all the customers and as the sole provider of electric service the utility assumed a "resource portfolio management" function for its customers, meaning that it had an obligation to determine and implement the least-cost use of energy efficiency and other resources, which led to integrated resource planning [16].

CHAPTER SIX

RESULTS, ANALYSIS AND DISCUSSION

6.1 INTRODUCTION

Quantitative reliability evaluation of a distribution system can be done by measuring the past performance and predicting the future performance. Past performance statistics provides important reliability profile of the existing system. However, distribution planning involves the analysis of future systems and evaluation of system reliability when there are changes in; configuration, operation conditions or in protection schemes. This estimates the future performance of the system based on system topology and failure data of the components.

The reliability assessment is carried out for the existing system and predictive reliability analysis for the future system with the help of Electrical transient and analysis program (ETAP) software. A number of alternatives such as placement of *disconnectors, load break switch, auto reclosing circuit breakers, system reconfiguration, reconductoring*, etc have been simulated.

For the existing system, the reliability indices are both calculated and simulated. For predictive reliability analysis of the future system, the reliability indices are simulated. Calculated values are obtained based upon the historical failure data, and the number of customers connected and affected by the outage.

6.2 Reliability Assessment of the existing system

For existing reliability assessment outage histories are used to compute indices that reflect past/present performance. Furthermore, the outage history of the system is used to compute the failure rate and repair duration of distribution system components.

6.2.1 Contribution of Distribution System to reliability Indices

One year outage data 2009 E.C is collected from EEU Shashemene District. The interruption data includes the interruption due to the shedding order from EEU Grid and from distribution system failure. Accordingly, calculated historical reliability indices of Shashemene Power Distribution system is presented in table 6.1 below.

Table 6.1 calculated reliability index

Indices	Contribution from distribution system	Contribution from the Grid side	Total
SAIDI	814.37	105.90	920.26
SAIFI	556.83	50.83	607.65

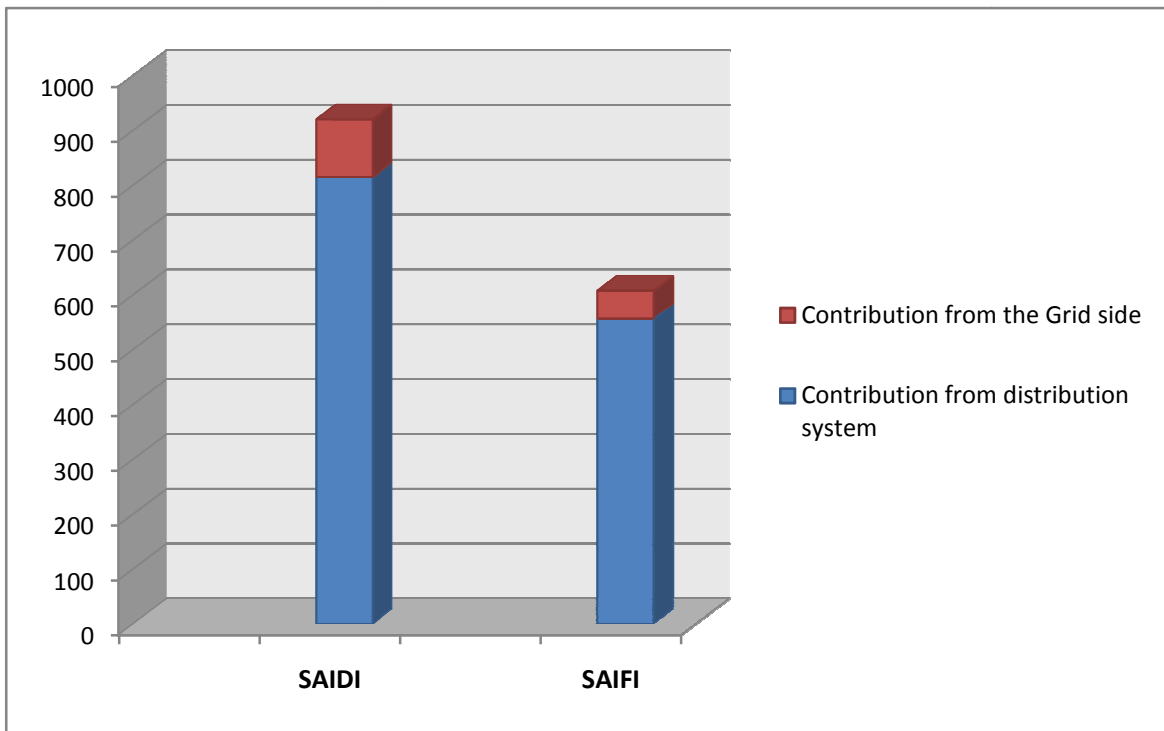


Figure 6.1 Contribution of Bulk Power system and distribution system failure to system indices

As indicated in table 6.1 and fig 6.1 both distribution system and Bulk power system (Grid) failures contribute for customer interruptions. Failures in Shashemene Distribution System contribute 88.5% to SAIDI and 91.6% to SAIFI. This shows that the distribution is the major contributor to long duration and frequency of interruptions. From this we can conclude that the response rate of EEU’s Grid crew is comparatively better than that of distribution workers.

Furthermore, one can conclude that the distribution system under study is complex and unsectionalized so that it is difficult to find the fault point in short time.

In Shashemene Power Distribution System most customers are residential followed by commercial and govt. and public service. All of these customers are affected more by interruption duration than interruption frequency. This means the customers in the area are sensitive to SAIDI which is more of the result of distribution failure.

6.2.2 Comparison of Reliability Indices with Benchmarks

Reliability benchmarks are the standards against which analyzed or measured reliability is judged. The purposes of reliability benchmarks are to define minimum average reliability performance, by feeder type, for a distribution network and provide a basis against which a distribution network service provider's reliability performance can be assessed.

The benchmarks were calculated using the IEEE Guide for electric power distribution reliability indices – IEEE Standard 1366-2003.

Reliability analysis and calculations for the Addis Ababa distribution system had not been done for the indices (such as SAIFI, SAIDI, CAIDI, and ASAI).

A benchmark of SAIDI, CAIDI, SAIFI and ASAI for nine countries is shown in Table 6.2. From the calculation and analysis considered in reliability evaluation of shashemene distribution system has an average value of SAIDI=920.26hrs, SAIFI=607.65 interruptions/customer.

Table 6.2 Benchmarks for Reliability Indices [30]

No	Country	SAIDI (Minutes/Year)	SAIFI (Interruptions/Customer)
1	United States	240	1.5
2	Austria	72	0.9
3	Denmark	24	0.5
4	France	62	1
5	Germany	23	0.5
6	Italy	58	2.2
7	Netherland	33	0.3
8	Spain	104	2.2
9	UK	90	0.8
10	Ethiopia	20hr	25
11	shashemene	920.26hr	607.65

A lower number for SAIDI, and SAIFI index indicates better reliability performance; i.e., a lower frequency of outages or shorter outage duration. A higher SAIDI and SAIFI index number indicates worse performance. Comparing the average SAIDI and SAIFI of shashemene distribution with the benchmarks shows that has worse performance.

6.2.3 Contribution of Feeders to Reliability Indices

Feeders located at different geographical areas have different failure rates and restoration times. This is because the failure rate of a line depends on factors such as tree density, animal availability, age of construction, and human factors. And restoration time or repair duration of distribution equipment depends on the response of the crew in the area, the complexity of feeder locations, etc. The following table shows the percentage contribution of each feeder for SAIDI and SAIFI of the system under consideration.

Table 6. 3 **Contribution of feeders to SAIDI and SAIFI of the system**

Indices	Contribution of feeders in %					
	F1 (wendogenet)	F2 (shashemene)	F3.1 (arsinegele)	F3.2 (arsinegele)	F4 (water pump)	F5 (kofele)
SAIDI	13.5	10.6	12.7	17.4	16.7	29.3
SAIFI	15.1	12.3	14.1	13.2	13.2	32.0

As it can be shown in table 6.3 feeders F5 contribute more for SAIDI and SAIFI than other feeders in the distribution system. Feeder F5 contributes 32% for SAIFI and 29.3% for SAIDI. This is because this feeder has many laterals and one longest lateral of this feeder passes through dense forest area. This lateral is vulnerable to tree contact and phase to phase or three phase fault.

The feeders F4 feeder passes through dense forest to supply the water pump. This makes the connected customers vulnerable to frequent and long duration interruptions.

Furthermore, feeder F3.2 contributes for 13.2% SAIFI and 17.4% for SAIDI. In terms of SAIDI contribution, it is second feeder next to F5. This is because this feeder has many laterals and one longest lateral of this feeder passes through dense forest area. This lateral is vulnerable to tree contact and phase to phase or three phase fault.

6.2.4 Computation of Component's Failure Rate and Repair Duration

The failure rate of a component is the average number of failures per annum for a unit component while the repair duration (time) is defined as the average time it takes to restore component operation after a permanent failure of the component.

Three year fault data is collected from EEU Shashemene District Office. So as to model the distribution system for predictive reliability assessment, the collected data is organized to give the failure rate/frequency of feeders and their laterals. The component's failure rate may be either temporary or sustained.

If the interruption duration is longer than or equal to five minutes, the failure is sustained; otherwise temporary.

The sustained failure rate (λ_s) of a distribution system component can be calculated as:

$$\lambda_s = \frac{\text{Total number of sustained failures recorded}}{\text{Number of components considered} \times \text{number of years of recorded data}} \text{ 1/year} \quad (6.1)$$

The number of components in equation (6.1) indicates the total number of the same components under operation in the system in the observation time. The component may include transformer, feeder, lateral, cable, bus bar, etc. For a given line, feeder and lateral the total length of the line, feeder or lateral can be taken as the number of components in the system. The length of the feeders (F1-F5) including their laterals is tabulated in table 1.1.

And the average repair duration (also called time to repair) of a component is given by:

$$r = \frac{\text{Total sustained interruption due to component failure}}{\text{Number of sustained failures recorded}} \text{ hr} \quad (6.2)$$

By using the collected failure data, feeder lengths in table 1.1 and equation 7.1 and 7.2, λ_s and r for all feeders in the system is tabulated in table 1.2. For comparison purpose, the tabulated values can be shown graphically in fig 1.9.

The repair duration of line/feeder depends on the response rate of crew, the line complexity (number of laterals), total length of the line, etc. As it can be observed in table 1.1 of chapter 1, it can be concluded that as the feeder exposure increases the repair duration becomes larger and larger. The bar graph in fig 7.3 shows the existing feeder length dependence of repair duration of feeders.

Table 6.4 Feeders length and repair duration

Feeder name	Exposure (circuit- km)	Repair duration (hours)
F1(wendogenet)	24.9	1.332
F2(shashemene)	46.525	0.916
F3.1(arsinegele)	30.70	1.06
F3.2(arsinegele)	27.5	1.613
F4(water pump)	24.175	1.577
F5(kofele)	30.85	1.565

Shorter and simple feeders such as F1 and F4 have shorter repair duration; but longer feeders such as F2 and F3.1 have relatively longer repair duration. This is because when fault occurs on long and complex feeder, it is difficult to trace and find the fault location in short period of time.

Having identified all the above reliability problems in the system the following section focuses on development of reliability improvement mechanisms in Shashemene Power Distribution System.

6.3 Predictive Reliability Analysis

Predictive reliability assessment determines the long term behavior of distribution systems by combining component failure rates and duration of repair, restoration, switching and isolation activities for a given network configuration of a distribution system.

When performing predictive reliability analysis of the distribution system the following steps should be followed.

- Collection of accurate component outage data
- Modeling of distribution system by predictive reliability software.

6.3.1 Component Outage Data

To evaluate distribution system reliability assessment Component reliability data is one of the most important aspects. Without good data, the answers provided by complicated analyses and sophisticated computer programs are baseless. Good information is still hard to come by, but

most utilities are recognizing the importance of component reliability data and are undertaking collection efforts by both manual and automated methods.

From the fault statistics recorded in EEU’s Shashemene District Office, it is possible to find the line (feeder and laterals) outage data. Further analysis of the outage data gives the failure rate and repair duration of lines. The failure rate and repair durations of lines is presented in table 6.3 below.

But the outage data of transformers, bus bars, circuit breakers is not found recorded. Therefore, the failure rate and repair duration of these components is taken from literature [2]. Therefore the failure rate and repair duration of power transformers in the substation, all bus bars (132 kV& 15 kV) and circuit breaker reliability data is presented below.

Table 6.5 Failure rate and repair time of distribution substation component [2]

S.No	Types of equipment	Failure rate (1/transformer/year)	Average repair duration(hrs)
1	132/15KV transformer	0.005	170
2	132KV bus bar	0.038	36
3	15Kv bus bar	0.0192	73
4	Circuit breakers	0.03	80

6.3.2 Modeling of Shashemene Power Distribution System Using ETAP Software

Modeling of the distribution system using predictive reliability analysis software is main step in developing the reliability improvement strategy. In this thesis work, **Electrical Transient and Analysis Program** (ETAP)are used for modeling and simulation.[20]

ETAPis the most comprehensive analysis tool for the design and testing of power systems available. Using its standard offline simulation modules, ETAP can utilize real-time operating data for advanced monitoring, real-time simulation, optimization, energy management systems, and high speed intelligent load shedding. ETAP allows you to easily create and edit graphical one-line diagrams. The software uses to analyze different electrical analysis, like reliability, short circuit, load flow, arc flash, protection coordination and others[20].For reliability analysis, the one line diagram of the system in the study area is drawn using ETAP software.The one line

diagram of the overall distribution system in the study area is shown in fig.6.4 below. Each component in the system is modeled in such a way that it is suitable for historical and predictive reliability assessment of the distribution system. The reliability model of each component (line/feeder, transformer, bus bar) includes mainly failure rate and repair duration. In addition component ratings of voltage, current, power and parameters such as resistance and reactance and line length are necessary. The failure rate and repair duration of components is presented in table 6.4 and table 6.5 above.

Each rural woreda town and villages out of shashemene city are taken as individual load points irrespective of the number of transformers in each area. But other load points in shashemenetown are taken from 15/0.4 kV distribution transformers. Each load point is also modeled by its average load demand, number of connected customers and cost functions.

The estimated and measured average load demand, number and type of customers connected to load points considered in the system is presented in Appendix B.

6.3.3 Reliability Reinforcement Mechanisms

As already mentioned in chapter 6 of section 6.3 there are two types of reliability reinforcement/mitigation techniques. But the geographical location and the overall construction of one feeder differs significantly from the other. Therefore, the reliability reinforcement mechanism used for one feeder may not be used for the other. For example the alternative used for improvement of arsinegele line may not be used for wendo genet or alaba.

Therefore, the reliability reinforcement alternatives for each feeder and of Shashemene Power Distribution System as a whole is investigated and developed in the coming sections.

6.3.3.1 Base Case

To compare the benefit of each of reliability reinforcement mechanisms it is better first to have the knowledge of the performance of the existing system. In table 6.1 above, the calculated performance of the existing system is presented. But since the reinforcement alternatives are evaluated through the simulation software it is necessary to simulate the existing system using ETAP simulation software.

The set of indices from simulation of the existing system without any reinforcement is called base case. The base case indices of Shashemene power Distribution System are presented in table 6.5 below.

Table 6.6 Reliability indices of the existing system (base case)

Indices (with unit measures)	values
SAIFI(1/customer/year)	590.832
SAIDI(Hour/customer/year)	760.014
CAIDI(Hours)	1.286
ASAI (%)	91.32
ENS(MWh/year)	11336.85
AENS(MWh/customer/year)	0.4751

The values of above indices are significantly different from that of calculated values in table 6.1. This is because the calculation of indices in table 6.1 considers not only forced outages but also scheduled outages which can be happened due to maintenance or other system expansion purpose. From the simulation result presented in table 6.6, we can say that an average customer will be without electric power for above 31 days/year due to failure of distribution system.

In simulating the system, maintenance and failures of protection devices are not considered; only failures of lines, bus bar and power transformers are taken in to consideration. The line failure normally includes line to ground faults, line to line short circuit; three phase fault and pole failures, and distribution transformer 15/0.4kV failures.

In addition to system base case, base cases for all feeders are required since thereinforcement mechanisms are applied for individual feeders. This can be done by taking each feeder and its connected load as a system.

Table 6. 7 Individual feeder base case

Indices	Feeders					
	F1 (wendogenet)	F2 (shashemene)	F3.1 (arsinegele)	F3.2 (arsinegele)	F4 (water pump)	F5 (kofele)
SAIFI(1/customer/year)	584.42	837.14	583.00	517.48	545.52	418.07
SAIDI(Hour/customer/year)	794.91	927.93	790.69	633.63	769.63	538.73
CAIDI(Hours)	1.36	1.108	1.356	1.224	1.411	1.289
ASAI (%)	90.93	89.41	90.97	92.77	91.21	93.85
ENS(MWh/year)	620.71	3142.35	2667.36	810.44	3225.34	806.67
AENS(MWh/customer/year)	0.4073	0.7016	0.4663	0.2302	0.5895	0.2562

Hereafter the reliability improvement mechanisms will be developed for each feeder in the system.

I. Wendo Genet (F1) Distribution Sub System

The following single line diagram shows the F1 feeder and its laterals including 8 load points connected to it. The total exposure of the feeder and its laterals is around 24.9 circuit kilometers. This makes difficult to trace the fault or the failed equipment when there is fault or failure in one of its laterals.

Out of 8 load points connected to this feeder, most of the loads are very important so that power failure at any time costs these customers. Among the very important loads are; wendo genet university, Hotels, Cereal Grinders, Schools, etc.

These customers are mainly affected by the duration of interruption. Therefore for this area instead of decreasing the interruption frequency it is better to focus on decreasing the interruption duration. The following are the proposed alternatives that can be used to reduce the interruption duration and frequency in the system.

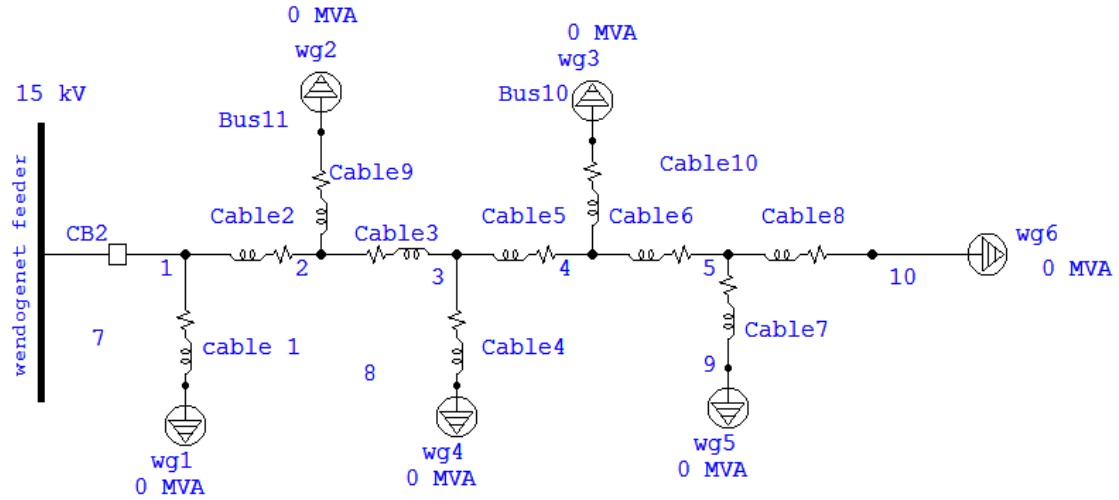


Figure 6. 2 Wendo Genet distribution subsystem

- a) Alternative 1- fuse placement on laterals lines between lines 2-3 and 5-10
- b) Alternative 2- Installation of Auto-Reclosers Circuit Breaker lines 5-10
- c) Alternative 3- Alternative 3- Changing the existing overhead lines which go to water reservoir and wendo genet villages to covered overhead line /line reconductoring.(lines 1-2-3-4-5)

a) Alternative 1- fuse placement on laterals lines between lines 2-3 and 5-10

The following table shows the change in indices when fuses are placed on laterallines such as 2-3 and 5-10

Table 6. 8 simulation output with installation of fuses

Indices	Base values	With Alternative 1	Percentage change (%)
SAIFI(1/customer/year)	584.42	511.957	-12.39
SAIDI(Hour/customer/year)	794.91	733.87	-7.67
CAIDI(Hours)	1.36	1.433	5.36
ASAI (%)	90.93	91.62	0.75
ENS(MWh/year)	620.71	489.10	-21.20
AENS(MWh/customer/year)	0.4073	0.3209	-21.21
EIC(METB/year)	0.274	0.216	21.16

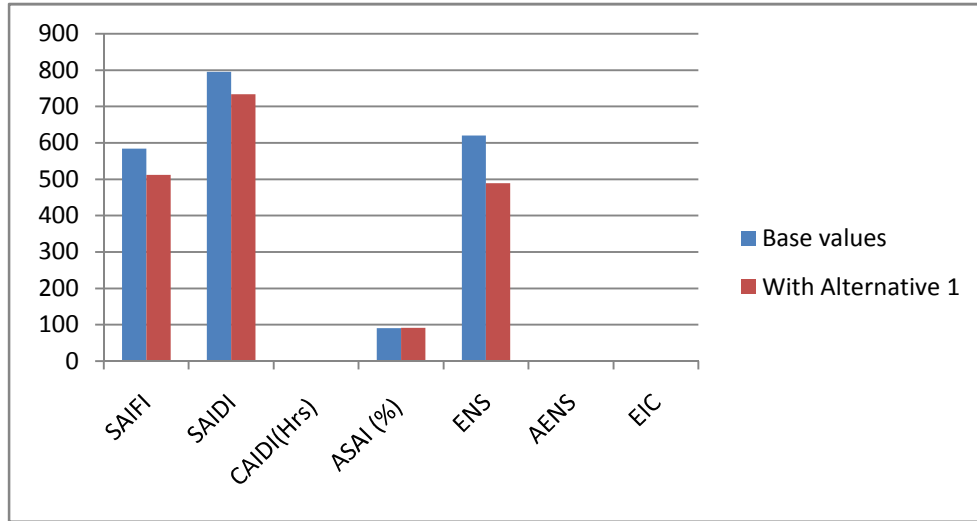


Figure 6. 3 Reliability Improvements by Alternative 1

From Figure 6.3 it can be observed that installation of fuses on laterals fuses are placed on laterallines such as 2-3 and 5-10 results in significant reduction in SAIFI, SAIDI, ENS, etc. Furthermore, installation of fuses can avoid the interruption of upstream customers when fault occurs downstream of fuse by clearing the fault. Installation of all two fuses at the same time at mentioned laterals will reduce the expected customer interruption cost from the existing **0.274 million Birr/year to 0.216 million Birr/year. Therefore it will save ETB58, 000/year with one time installation cost of ETB 8085.00.**[21]

But the fault occurs repeatedly in lines downstream of fuse locations; therefore, fuses must be replaced repeatedly and becomes unmanageable. Consequently fuse placement is not feasible in this case.

b) Alternative 2- Installation of Auto-Reclosers Circuit Breaker between lines 5-10

Table 6. 9 simulation output with Autoreclosure

Indices	Base values	With Alternative 2	Percentage change (%)
SAIFI	584.42	512.04	-12.38
SAIDI	794.91	734.80	-7.56
CAIDI	1.36	1.435	5.51
ASAI	90.93	91.61	0.74
ENS (MWh/year)	620.71	500.23	-19.41
AENS	0.4073	0.3282	-19.42
EIC(METB/year)	0.274	0.220	-

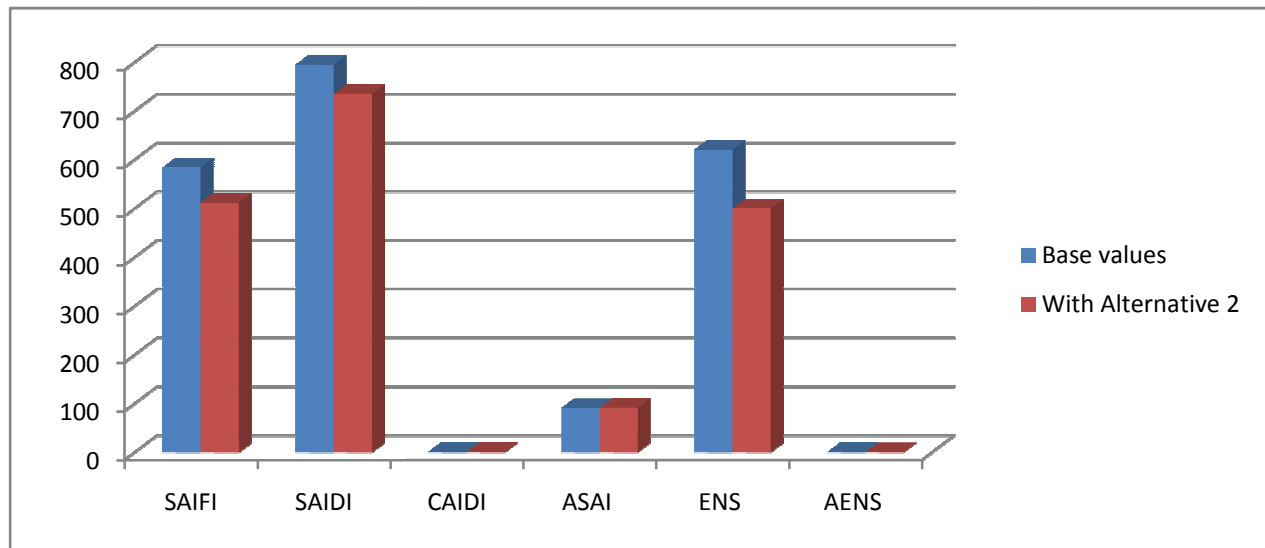


Figure 6. 4 Reliability by Alternative 2

As it can be observed from table 6.9 and Fig 6.4 installation of ARCB in line segment between bus 15&17 results in significant reduction in SAIFI. Furthermore, it helps to reduce the EIC by ETB54,000/year with an installation cost of ETB 179,226.23[21]. Therefore, the installation cost of ARCB on line bus **15&17** will be paid back within less than Four year. It also increases the immeasurable satisfaction of customers and the utility will sell 120.4MWh/year of additional energy.

c) Alternative 3- Changing the existing overhead lines which go to water reservoir and wendo genet villages to covered overhead line /line reconductoring.

Since lines which go to water reservoir and wendo genet villages pass through dense forest areas, changing these bare overheadlines to covered overhead lines is expected to reduce the fault rate of the feeder F1 by half. This can be presented in the following table.

Table 6. 10 simulation output with reconductoring

Indices	Base values	With Alternative3	Percentagechange (%)
SAIFI	584.42	265.62	-12.38
SAIDI	794.91	536.41	-7.56
CAIDI	1.36	2.019	5.51
ASAI	90.93	93.88	0.747
ENS(MWh/year)	620.71	418.83	-19.41
AENS	0.4073	0.2748	-19.42
EIC(METB/year)	0.274	0.185	-32.48

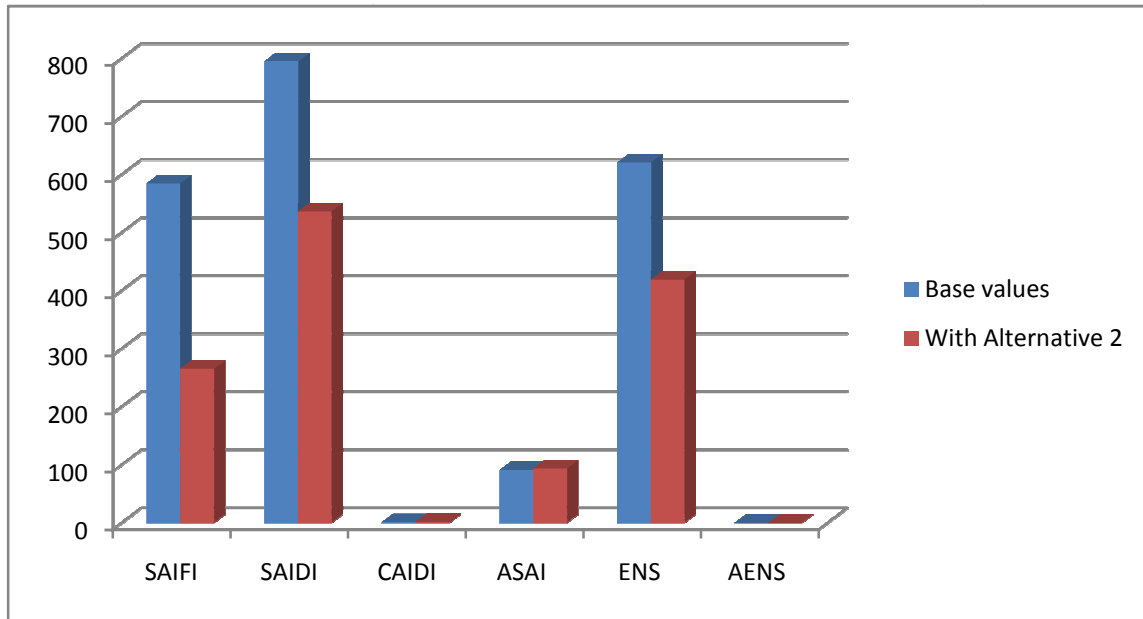


Figure 6. 5 Reliability Improvements with Alternative 3

From table 6.10 and Fig6.5 we can observe that changing the existing overhead lines 1-2-3-4 will significantly improve the reliability of feeder system F1 in particular. But this alternative will save around ETB 88,965/year with installation cost of ETB 862,495.20. The utility will benefit in selling 201.88MWh of energy which might not be sold because of interruption. [21]

II. Shashemene town (F2) Distribution Sub System

The following single line diagram shows the F2 feeder and its laterals including 65 loadpoints connected to it. The total exposure of the feeder and its laterals is around 46.525 circuitkilometers. This makes difficult to trace the fault or the failed equipment when there is fault or failure in one of its laterals.

Out of 65 load points connected to this feeder, most of the loads are very important so that power failure at any time costs these customers. Among the very important loads are; Hospital, Hotels, Cereal Grinders, Water Pump of the town, Car Fuel Stations, Colleges, Schools, etc. These customers are mainly affected by the duration of interruption. Therefore for this area instead of decreasing the interruption frequency it is better to focus on decreasing the interruption duration.

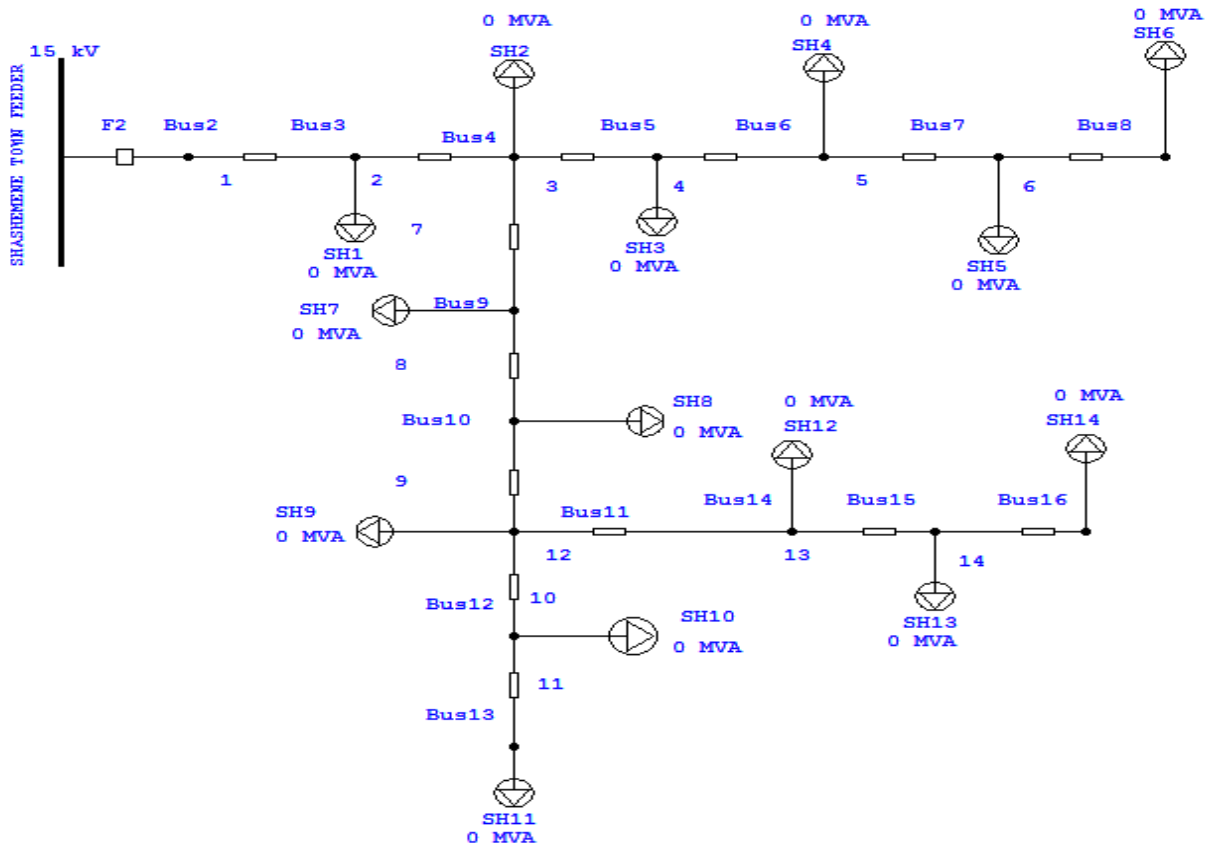


Figure 6. 6 single line Diagram of shashemene Feeder

The following are the proposed alternatives that can be used to reduce the interruption duration and frequency in the system.

- a) Alternative 1- fuse placement on laterals lines between lines 4,7and12
- b) Alternative 2- Installation of Auto-Reclosers Circuit Breaker in line segment 6and 14
- C) Alternative 3- Alternative 3- Changing the existing overhead lines to covered overhead line /line reconductoring.

a) Alternative 1- fuse placement on laterals lines 4, 7and 12

The following table shows the change in indices when fuses are placed on laterallinesegment such as 4, 7 and 12

Table 6. 11 simulation output with installation of fuses

Indices	Base values	With Alternative 1	Percentage change (%)
SAIFI	837.14	494.66	40.91
SAIDI	927.93	632.79	31.81
CAIDI	1.10	1.279	-15.43
ASAI	89.41	92.78	-3.77
ENS (MWh/year)	3142.35	2174.31	30.81
AENS	0.7016	0.4854	30.82
EIC(METB/year)	1.385	0.958	-

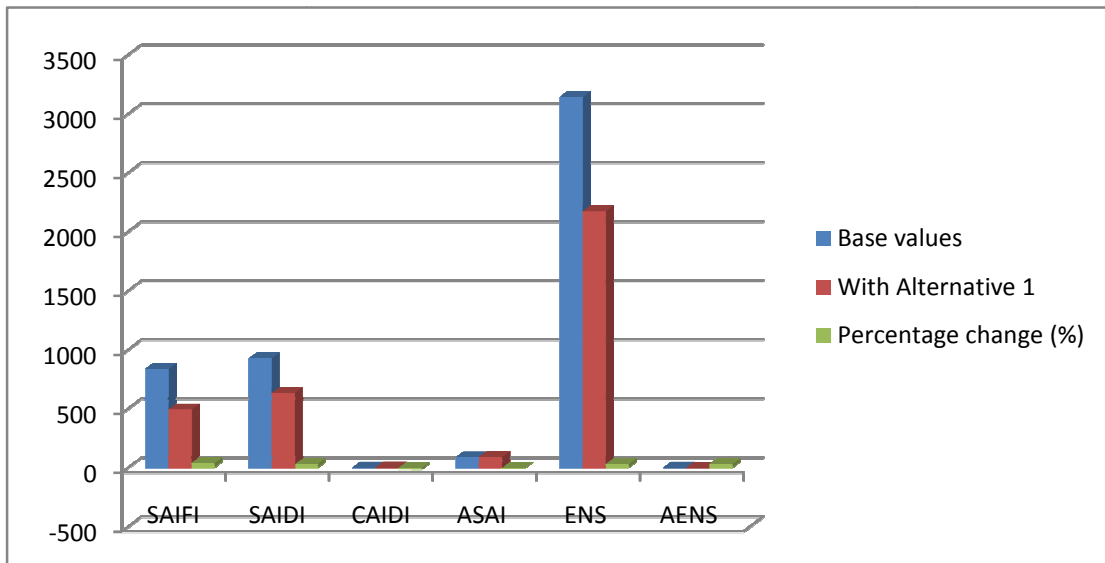


Figure 6. 7 Reliability Improvements by Alternative

1

From table 6.11it can be observed that installation of fuses on laterals fuses are placed on laterallines segment such as 4, 7and 12 results in significant reduction in SAIFI, SAIDI, ENS, etc. Furthermore, installation of fuses can avoid the interruption of upstream customers when fault occurs downstream of fuse by clearing the fault. Installation of all two fuses at the same time atentioned laterals will reduce the expected customer interruption cost from the

existing 1.385 million Birr/year to 0.958 million Birr/year. Therefore it will save ETB 427,000/year with one time installation cost of ETB 12,127.50[21]

But the fault occurs repeatedly in lines downstream of fuse locations; therefore, fuses must be replaced repeatedly and becomes unmanageable. Consequently fuse placement is not feasible in this case.

b) Alternative 2- Installation of Auto-Reclosers Circuit Breaker in line

The two reclosers are placed by considering length of the feeder, number of customers and criticality of the location.

Table 6. 12 simulation output with auto-reclosure

Indices	Base values	With Alternative 2	Percentage change (%)
SAIFI	837.14	457.34	45.36
SAIDI	927.93	602.03	35.12
CAIDI	1.108	1.316	-18.77
ASAI	89.41	93.13	-4.16
ENS(MWh/year)	3142.353	2028.294	35.45
AENS	0.7016	0.4528	35.46
EIC(METB/year)	1.385	0.894	35.45

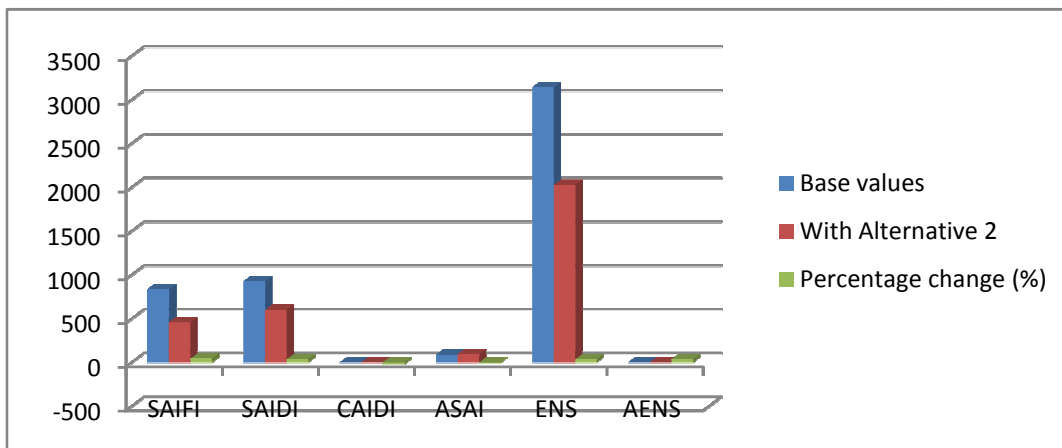


Figure 6. 8 Reliability Improvements by alternative 2

As from the results can be observe that from table 6.12 and Fig.6.8, installation of ARCB in line segment 6 and 14 results in significant reduction in SAIFI. Furthermore, it helps to reduce the EIC by ETB 491,000/year with an installation cost of ETB 358,452.46[21]. Therefore, the installation cost of ARCB on line segment 6 and 14 will be paid back within less than a year. It also increases the immeasurable satisfaction of customers and the utility will sell 114.06MWh/year of additional energy.

C) Alternative 3- Changing the existing overhead lines to covered overhead line /line reconductoring.

Since lines **1-2, 3-4 and 7-8** the backbone of the feeder, changing these bare overhead lines to covered overhead lines is expected to reduce the fault rate of the feeder F2 by 37.5%. This can be presented in the following table.

Table 6. 13 simulation output with reconductoring

Indices	Base values	With Alternative 3	Percentage change (%)
SAIFI	837.14	522.85	37.54
SAIDI	927.93	662.13	28.64
CAIDI	1.108	1.266	-14.26
ASAI	89.41	92.44	-3.39
ENS (MWh/year)	3142.353	2213.37	29.56
AENS	0.7016	0.4942	29.56
EIC(METB/year)	1.385	0.975	29.6

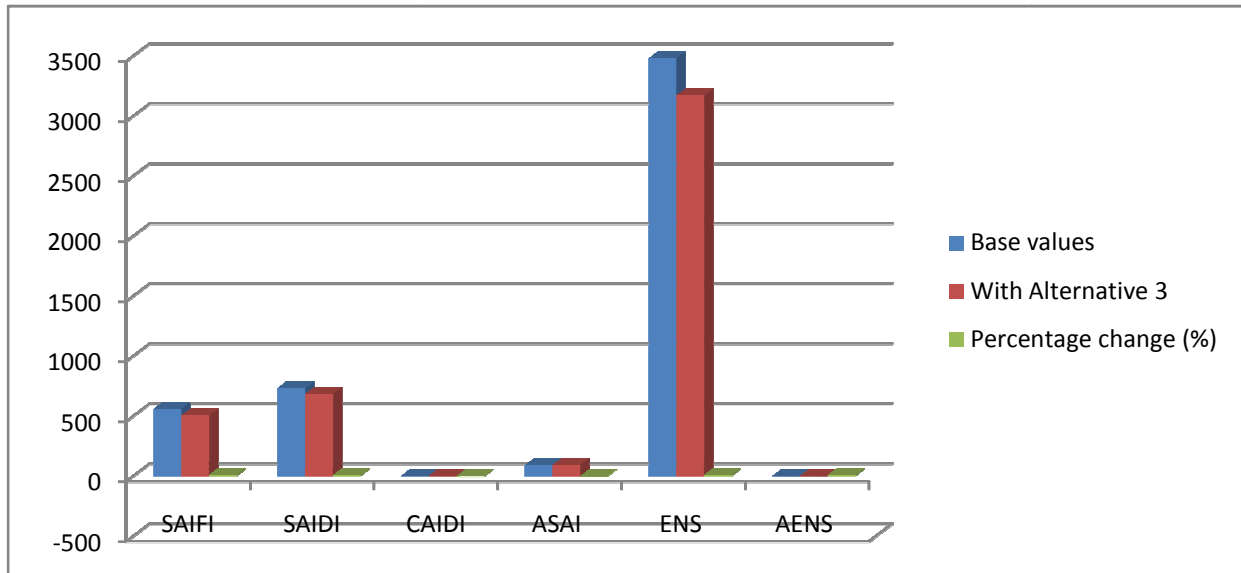


Figure 6. 9 Reliability Improvement by Alternative 3

From table 6.13 and Fig 6.9It can be observed that changing the existing overhead lines **1-2, 3-4 and 7-8**will significantly improve the reliability of feeder system F2 in particular. But this alternative will save around ETB 410,000/year with installation cost of ETB 596,750. [21]

In addition the utility will benefit in selling 928.98MWh of energy which might not be sold because of interruption.

III. Arsinegele feeder (F3.1&F3.2) Distribution Sub System

The following single line diagram shows the F3.1 and F3.2 feeders and their laterals including 36 load points connected to them.

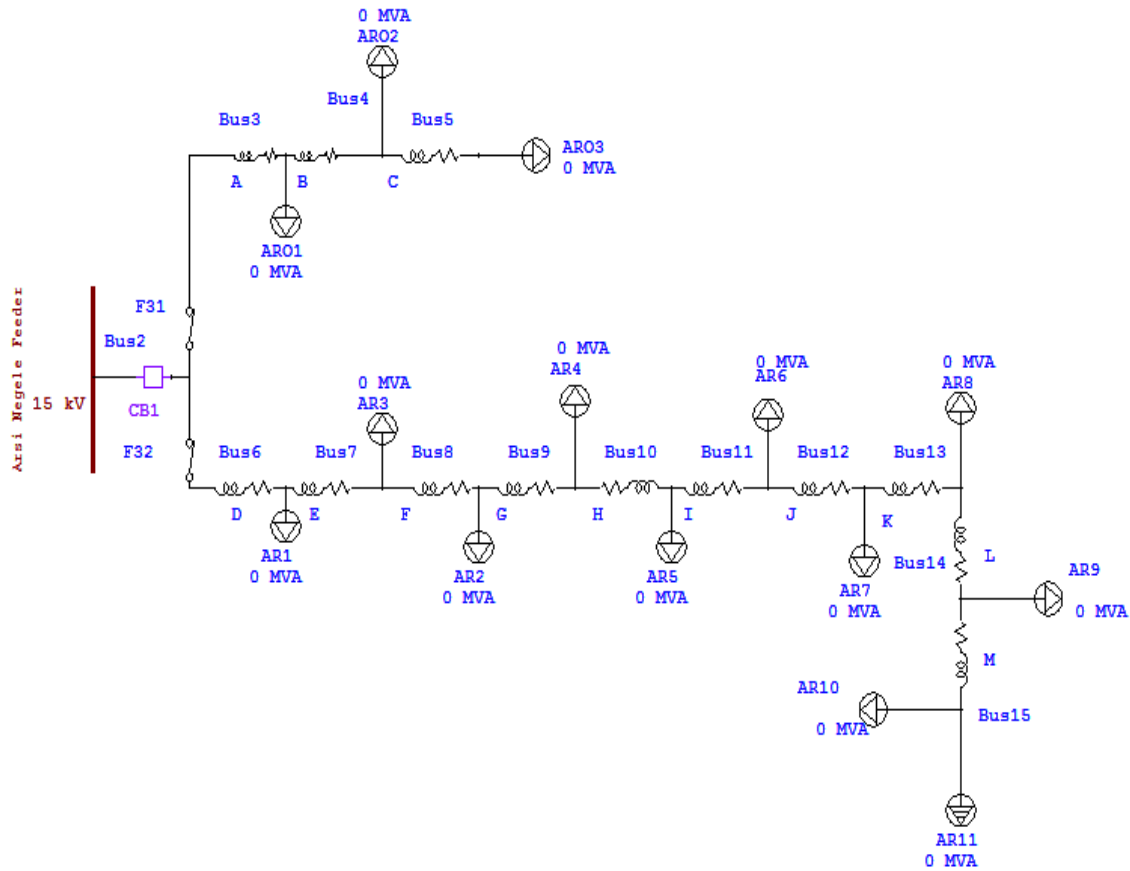


Figure 6. 10 Arsi negele distribution Subsystem

These feeders are comparatively longer than other feeder. And the total line exposure is around 58 circuit kilometers. Although fault rate of these two feeders is less than that of the previous two feeders, the system needs some reinforcement mechanisms to increase the reliability of the system. The possible reliability reinforcement mechanisms are:

- a) Alternative 1-Using a separate Circuit breakers for F2 and F3 feeder
- b) Alternative 2-installation of manual off load disconnectors at the beginning of lines E-F and B-C

Each alternative is evaluated in the following sections.

- a) **Alternative 1-Using a separate Circuit breakers for F3.1 and F3.2 feeder**

At present feeders F3.1 and F3.2 share the same circuit breaker; therefore when F3.1 fails, F3.2 will also be de-energized for at least 5 minutes until the disconnecter is opened by the operator and vice versa. This problem can be solved by using separate circuit breakers for each feeder.

The simulation result of adding one circuit breaker is displayed below in table 7.11.

Table 6. 14 Simulation output using separate circuit breaker

Indices	Base values	With Alternative 1	Percentage change (%)
SAIFI	558.04	503.5	9.77
SAIDI	731	684.05	6.42
CAIDI	1.31	1.359	-3.74
ASAI	91.66	92.19	-0.58
EENS	3478.51	3170.5	8.85
AENS	0.3764	0.3431	8.85
EIC(METB/year)	1.533	1.397	-

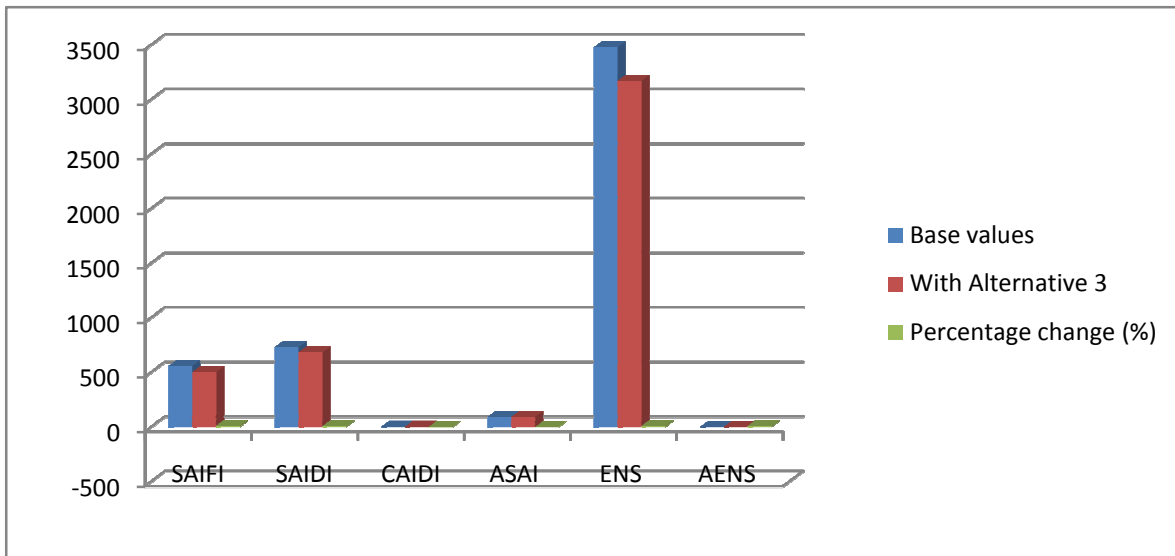


Figure 6. 11 Reliability Improvement by Alternative 1

Even if the change in SAIDI and SAIFI are reduced by 9.77% and 6.42% respectively. Installation of 15 kV OCB will save ETB 136,000/year. Therefore in less than a year's period the CB will return its investment cost of ETB 137, 500 [21]. Doing this the utility can decrease ENS by more than 8.85%.

b) Alternative 2-installation of manual off load disconnectors switch at the beginning of lines J-K and B-C

Installation of manual disconnectors switch at the beginning of lines J-K and B-C has two advantages. Firstly, it can be used for easily tracing the fault location by sectionalizing the lines. Secondly, since F3.1 has longer internal laterals, any expansion or maintenance on laterals can be done by opening the disconnector at the beginning of line J-K. Therefore, loads AR1, AR2, AR3, AR4, AR5 and AR6 will not be affected.

This can be shown in table below

Table 6. 15 simulation output with manual disconnector switch

Indices	Base values	With Alternative 2	Percentage change (%)
SAIFI	558.04	534.308	4.44
SAIDI	731	704.887	3.70
CAIDI	1.31	1.319	-0.68
ASAI	91.66	91.95	-0.32
EENS	3478.51	3131.903	11.07
AENS	0.3764	0.3389	11.07
EIC(METB/year)	1.533	1.38	9.98

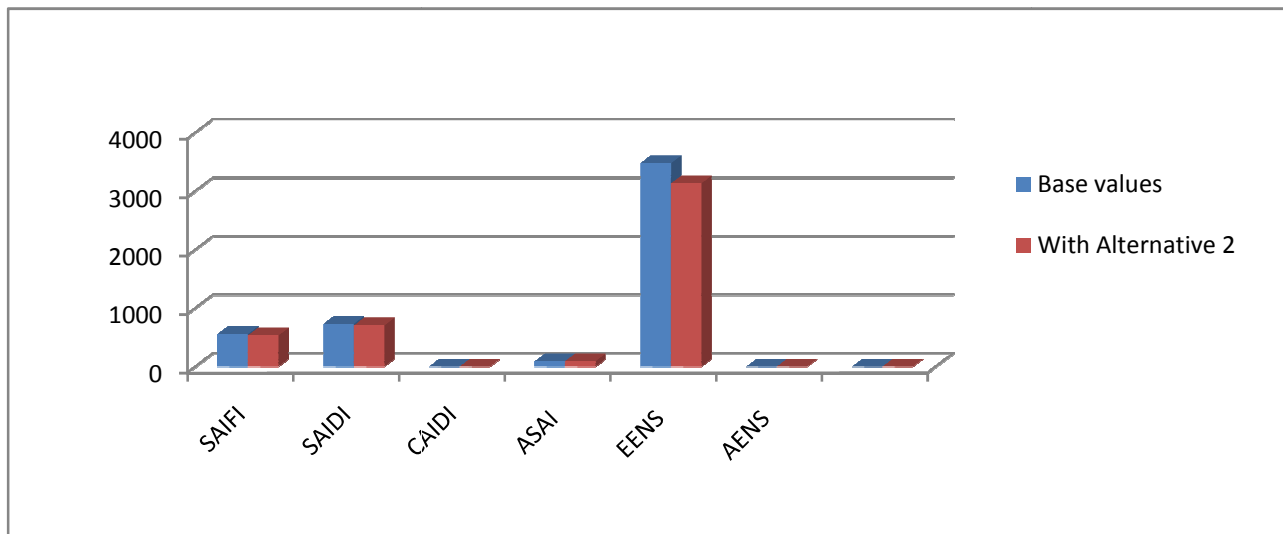


Figure 6. 12 Reliability Improvement by Alternative 2

As it can be observed that installation of off load disconnect switches one at the beginning of lines J-K and B-C Exit of shashemene city to Arsinegele will decrease the EIC by ETB

67,427.10 annually with installation cost of ETB 86,804.94[21]. In addition disconnect switches are important for maintenance or expansion operation in isolating the circuit under operation. In that the advantage becomes significant.

IV. Water Pump feeder(f4) Distribution Sub System

The following single line diagram shows the F4 feeder and its laterals including 35 loadpoints connected to it. The total exposure of the feeder and its laterals is around 24.2 circuit kilometers. This makes difficult to trace the fault or the failed equipment when there is fault or failure in one of its laterals.

Out of 35 load points connected to this feeder, most of the loads are very important so that power failure at any time costs these customers. Among the very important loads are; Hotels, ethiotelecom tower, Water Pump of the town, bus Stations, flour factories, Colleges, Schools, etc. These customers are mainly affected by the duration of interruption. Therefore for this area instead of decreasing the interruption frequency it is better to focus on decreasing the interruption duration.

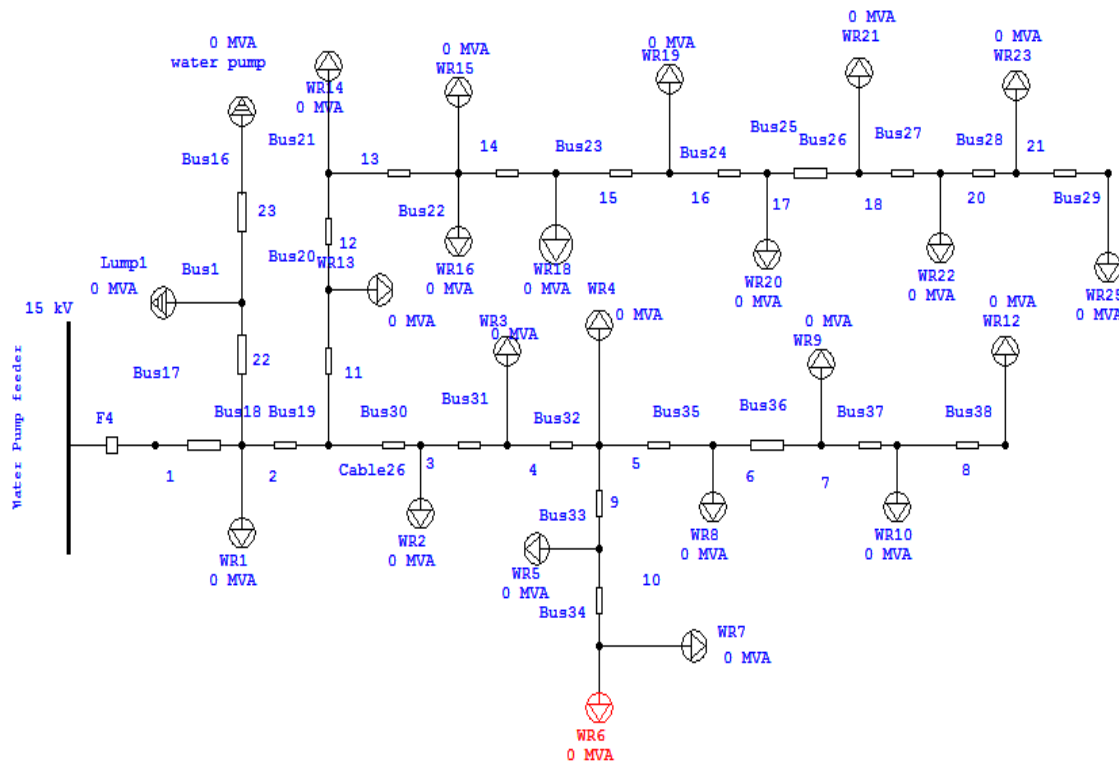


Figure 6.13 Shashemene Town water Pump distribution subsystem

The system needs some reinforcement mechanisms to increase the reliability of the system. The possible reliability reinforcement mechanisms are:

- a) Alternative 1- Changing the existing overhead lines to covered overhead line /line reconductoring.
- b) Alternative 2-installation of Automaticdisconnectors switch at the beginning of lines 4-5 and 14-15

Each alternative is evaluated in the following sections.

a) Alternative 1- Changing the existing overhead lines to covered overhead line /line reconductoring.

By changing the existing bare overhead to covered overhead lines of lines of the water pump (1-22-23), changing these bare overhead lines to covered overhead lines is expected to reduce the fault rate of the feeder F4 by**15%**. This can be presented in the following table.

Table 6.16 simulation output reconductoring existing line

Indices	Base values	With Alternative 1	Percentage change (%)
SAIFI	538.48	458.15	14.9
SAIDI	729.05	663.00	9.06
CAIDI	1.354	1.447	-6.86
ASAI	91.68	92.430	-0.818
EENS	6357.952	5728.81	9.895
AENS	0.4322	0.3894	9.903
EIC(METB/year)	2.802	2.525	-

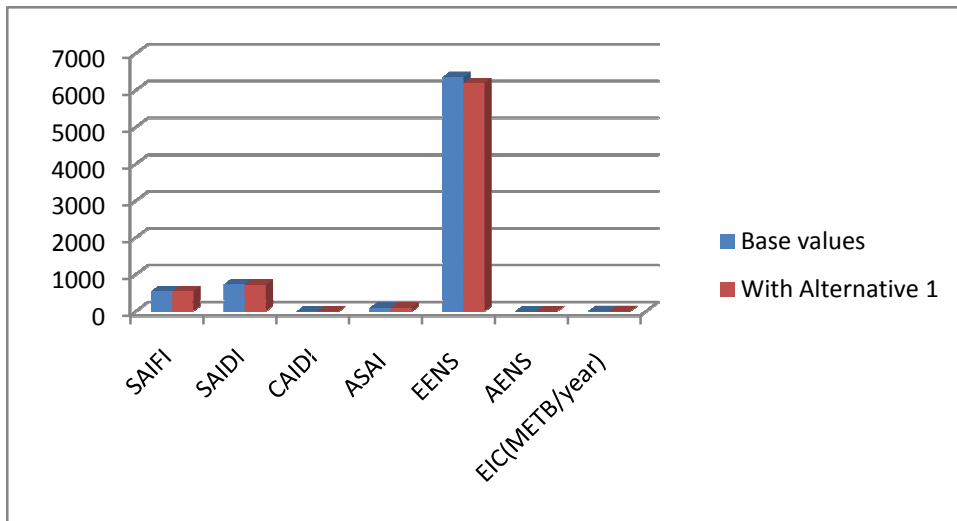


Figure 6.14 Reliability Improvements by Alternative 1

From table 7.16 and Fig 7.14 it can be observed that changing the existing overhead lines **1-22-23** will significantly improve the reliability of feeder system F4.

But this alternative will save around ETB 277,000/year with an installation cost of ETB 1,558,562.2. In addition, the utility will benefit in selling 629.14 MWh of energy which might not be sold because of interruption.

b) Alternative 2-installation of Automatic disconnectors switch at the beginning of lines 4-5 and 14-15

Installation of manual disconnectors switch at the beginning of lines 4-5 and 14-15 has two advantages. Firstly, it can be used for easily tracing the fault location by sectionalizing the lines. Secondly, since F4 has longer internal laterals, any expansion or maintenance on laterals can be done by opening the disconnector at the beginning of line 4-5 & 14-15. Therefore, the upward loads will not be affected.

This can be shown in table below

Table 6.17 simulation output with installation of disconnect switch

Indices	Base values	With Alternative 1	Percentage change (%)
SAIFI	538.48	538.480	0.000
SAIDI	729.05	715.890	1.805
CAIDI	1.354	1.329	1.846
ASAI	91.68	91.830	-0.164
EENS	6357.952	6195.322	2.558
AENS	0.4322	0.4211	2.568
EIC(METB/year)	2.802	2.730	2.569

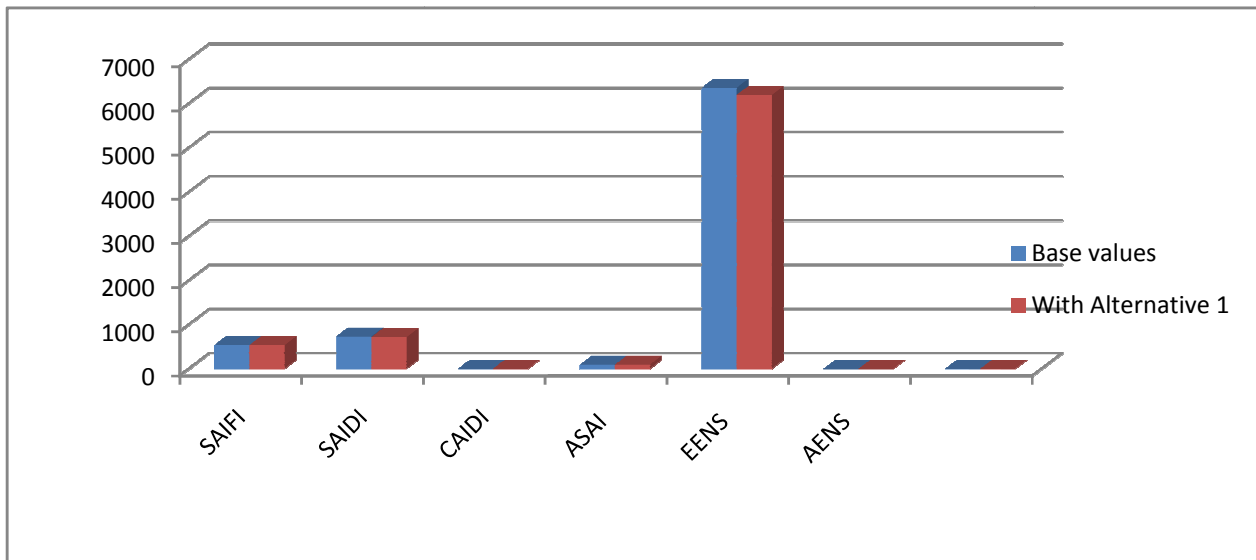


Figure 6.15 Reliability Improvement by alternative 2

As it can be observed that installation of off load disconnect switches one at the beginning of lines 4-5 and 14-15 will decrease the EIC by ETB 72,000.00 annually with installation cost of ETB 86,804.94.00. In addition disconnect switches are important for maintenance or expansion operation in isolating the circuit under operation. In that case the advantage becomes significant.

V. Kofele feeder (F5) Distribution Sub System

This feeder is the shortest feeder in shashemene town Power Distribution System. The length of the line is about 4.85 circuit kilometer. There is no clear cause of fault on this feeder. But most of the interruptions to the connected load is due to 15/0.4 kV transformers failures and due to falling of old poles. Therefore inspection of the poles and 15/0.4 kV transformers may be the solution.

Table 6. 18Summary of results after mitigation for each feeder

Indices	Feeders							
	F1		F2		F3		F4	
	Base case	after mitigation	Base case	after mitigation	Base case	after mitigation	Base case	after mitigation
SAIFI (1/customer/year)	584.4	265.62	837.1	457.34	583	503.5	545.5	458.15
SAIDI (Hour/customer/year)	794.9	536.41	927.93	602.03	790.6	684.05	769.6	663
EIC(1000 birr)	407.3	270	701.6	452.8	460	343.1	589.5	389.4

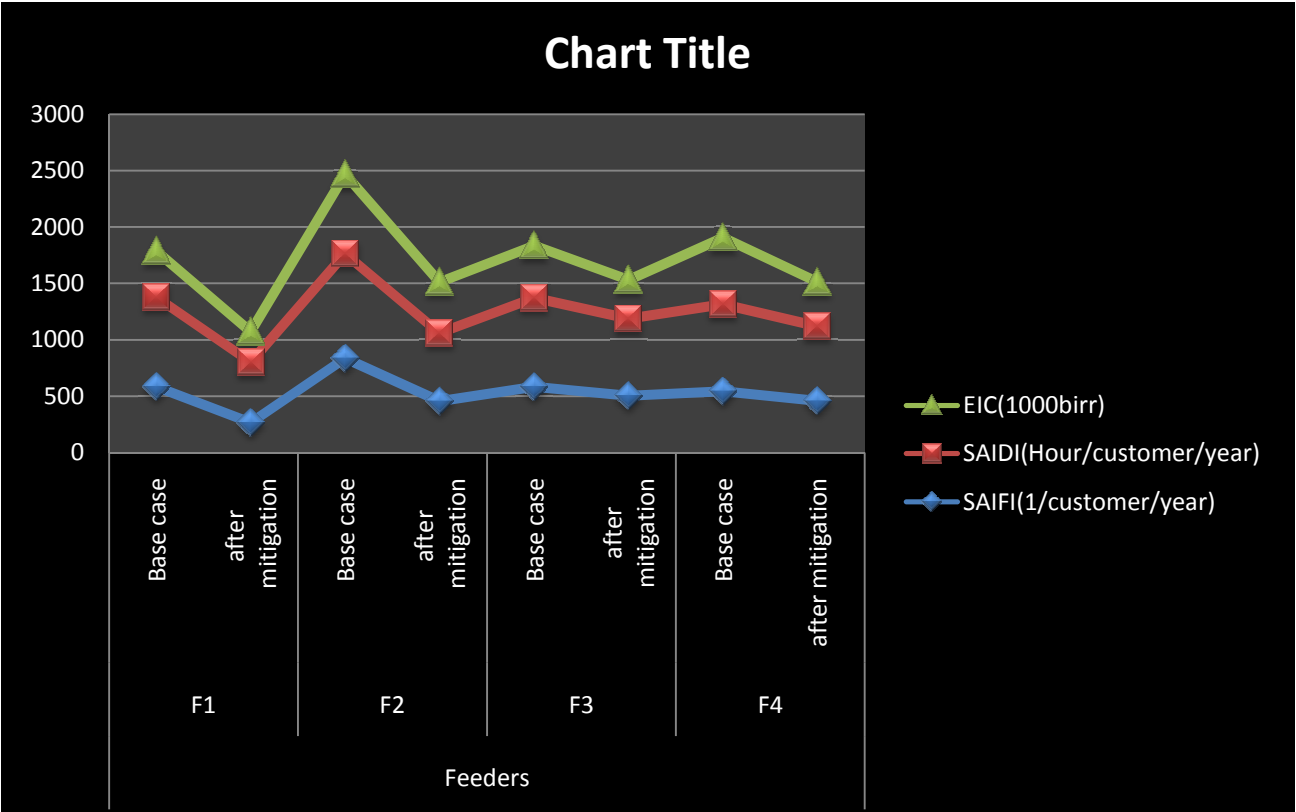


Figure 6. 16Summary of results after mitigation for each feeder

The above table and figure shows the summary of reliability assessment undertaken on 15kV sub-systems by considering different reliability reinforcement mechanisms. Using line reconditioning for wendogenet (F1) feeder the SAIFI, SAIDI and EIC reduced by 12%, 7.5% and 32% respectively. For shashemene city feeder (F2) using Autoreclosure SAIFI, SAIDI and EIC reduced by 45%, 35% and 35 % respectively. For Arsinegele feeder(F3) using separate CB the SAIFI, SAIDI and EIC reduced by 9.7%,6.4% and 8.8% respectively and water pump feeder(F4) using covered conductor SAIFI, SAIDI and EIC reduced by 14.9%,9% and 9.8% respectively

CHAPTER SEVEN

CONCLUSION, RECOMMENDATIONS AND FUTURE WORK

7.1 CONCLUSIONS

This research paper was conducted in one of the oldest cities of Ethiopia, shashemene city, which has an old and poor electrical distribution system. The system modeling and simulation study is carried out on five of the 15kV distribution feeder to evaluate the performance of the present system and also predictive reliability analysis for the future. The interruption data of years 2009 E.C has been used as a base years. From the substations fault record, it is concluded that most of the failures in the distributionSystem are due to short circuits, earth fault, over load, operation and system over load.

The single line diagram of the existing system was modeled in computer software and assessed.

Different alternatives or cases were outlined for improving the reliability of the study area. Each alternative includes a summary of the reliability indices reduction benefits and a cost-effectiveness analysis

SAIFI and SAIDI are used as the main driver for evaluating of each alternative. EENS was also monitored during this process.

As observed from simulation of Wend genet Distribution Subsystem, the system can be improved by reconductoring of the lines from bare overhead to covered overhead conductors. Using line reconductoring for wendogenet feeder the SAIFI, SAIDI and EIC reduced by 12%, 7.5% and 32% respectively. For shashemene city feeder using Autoreclosure SAIFI, SAIDI and EIC reduced by 45%, 35% and 35 % respectively.

For Arsinegele feeder using separate CB the SAIFI, SAIDI and EIC reduced by 9.7%,6.4% and 8.8% respectively and water pump feeder using covered conductor SAIFI, SAIDI and EIC reduced by 14.9%,9% and 9.8% respectively.

For kofele Distribution Subsystem can be improved best by periodical pole inspection and tree trimming practices.

7.2 RECOMMENDATIONS AND FUTURE WORK

So as to attain better results for predictive reliability analysis, to judge the existing performance and to improve the reliability in the system the following recommendations are presented below.

- The existing data recording system should be transformed from manual to computer aided system. All the events should be specific and the step restorations made should be recorded accordingly so that true reliability indices are obtained. The cause of power failure should be specified as it can be tree, animals, lightening, etc.
- It will better for the utility to have the one line diagram of the distribution system with all distribution equipments recorded. The number, type and load demand of customers connected to each distribution transformer should be recorded.
- The utility have to listen to customers about their reliability needs.
- The utility should develop periodical pole inspection and tree trimming practice that will prevent failures from occurring instead of the present traditional corrective measures.
- EEU must also develop the culture of reliability reinforcement in the system in addition to the current goal of electricity to all.
- Practical implementation of the recommended alternative solution is also important to improve the reliability of the power distribution system.
- Distributed generation as one of reinforcement methods.
- Protection device optimal placement

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Appendix A

Calculated load Point data –Average load, Number and type of customers connected

S/N	Load Point	transformer capacity (KVA)	Load in KVA	Estimated Average Load (kVA)	No. of Customers	Type(s) of Customer(s)
1	WG1	100	95	80.75	130	Govt+commercial+residential
2	WG2	100	80	68	1	Govt
3	WG3	100	95	80.75	130	Industrial+Residential+commercial
4	WG4	200	190	161.5	288	Industrial
5	WG5	100	95	80.75	1	Commercial
6	WG6	25	19	16.15	1	commercial/tele
7	WG7	800	760	646	1260	Residential + Commercial
8	HA1	200	190	161.5	296	Residential + Commercial
9	HA2	100	95	80.75	125	commercial
10	HA3	200	190	161.5	250	commercial
11	HA4	200	175	148.75	288	commercial
12	HA5	200	155	131.75	1	commercial
13	HA6	200	190	161.5	230	Residential + Commercial industrial
14	HA7	200	128.9	109.565	290	Residential + Commercial
15	HA8	200	190	161.5	275	Industrial+Residential+commercial
16	HA9	200	185.5	157.675	119	commercial residential
17	HA10	200	178.9	152.065	1	Residential
18	HA11	315	299.25	254.3625	1	Agricultural
19	HA12	200	190	161.5	1	Commercial
20	HA13	200	190	161.5	1	Industrial
21	HA14	100	95	80.75	65	Commercial
22	HA15	315	288	244.8	390	Residential
23	HA16	200	198.5	168.725	1	Industrial
24	HA17	630	598.5	508.725	1	Industrial
25	HA18	100	97.5	82.875	130	Govt
26	HA19	200	188.5	160.225	1	Industrial

27	HA20	630	598.5	508.725	1	Industrial
28	HA21	200	179.85	152.8725	1	Industrial
29	HA22	200	190	161.5	1	Industrial
30	HA23	25	19	16.15	1	Commercial
31	HA24	100	79.25	67.3625	1	Industrial
32	HA25	100	95	80.75	120	Industrial
33	HA26	25	19	16.15	1	Govt
34	HA27	315	274.5	233.325	60	Commercial
35	HA28	200	190	161.5	1	Commercial
36	HA29	315	189.65	161.2025	250	Industrial+Commercial+residential
37	HA30	315	299.25	254.3625	275	Industrial+Commercial+residential
38	HA31	315	185.45	157.6325	213	Industrial+Commercial+residential
39	HA32	200	190	161.5	175	Industrial+Commercial+residential
40	HA33	315	277.85	236.1725	425	Residential + Commercial
41	HA34	315	298.55	253.7675	385	Residential + Commercial
42	HA35	25	23.75	20.1875	1	Commercial
43	HA36	100	95	80.75	120	Residential + Commercial
44	HA37	315	299.25	254.3625	267	Commercial
45	HA38	100	95	80.75	95	Commercial
46	HA39	25	23.75	20.1875	1	Govt
47	HA40	1655	1572.3	1336.4125	2640	Residential + Commercial+industrial
48	HA41	25	23.75	20.1875	1	Commercial
49	HA42	100	95	80.75	75	Commercial
50	HA43	100	95	80.75	123	Residential + Commercial
51	HA44	200	190	161.5	165	Govt+residential+commercial
52	HA45	200	190	161.5	210	Residential +commercial
53	HA46	200	190	161.5	195	Residential +commercial
54	HA47	100	95	80.75	1	Govt
55	HA48	50	47.5	40.375	1	Commercial
56	HA49	25	23.75	20.1875	1	Commercial
57	HA50	100	95	80.75	96	Industrial residential

58	HA51	200	190	161.5	1	Industrial
59	HA52	100	95	80.75	85	Commercial+residential
60	HA53	200	190	161.5	210	Residential
61	HA54	200	190	161.5	185	Residential
62	HA55	315	299.25	254.3625	200	Commercial+residential
63	HA56	200	190	161.5	185	Commercial+residential
64	HA57	630	598.5	508.725	1	Govt
65	HA58	100	95	80.75	130	Industrial residential
66	HA59	100	95	80.75	125	Residential + Commercial
67	HA60	200	190	161.5	213	Residential + Commercial
68	HA61	25	23.75	20.1875	1	Commercial
69	HA62	315	299.25	254.3625	415	Residential + Commercial
70	HA63	200	190	161.5	165	Residential + Commercial
71	HA64	25	23.75	20.1875	1	Govt
72	HA65	200	190	161.5	195	Residential Commercial+industrial +
73	AN1	200	190	161.5	1	Agricultural
74	AN2	100	95	80.75	85	Commercial
75	AN3	25	23.75	20.1875	1	Govt
76	AN4	50	47.5	40.375	1	Commercial
77	AN5	100	95	80.75	67	Industrial
78	AN6	100	95	80.75	1	Commercial
79	AN7	200	190	161.5	142	Govt
80	AN8	200	190	161.5	126	Industrial
81	AN9	50	47.5	40.375	1	Commercial
82	AN10	25	23.75	20.1875	1	Commercial
83	AN11	50	47.5	40.375	1	Industrial
84	AN12	100	95	80.75	112	Residential Commercial
85	AN13	100	95	80.75	131	Residential Commercial
86	AN14	100	95	80.75	129	Residential Commercial
87	AN15	200	190	161.5	1	Govt
88	AN16	315	299.25	254.3625	1	Commercial

89	AN17	200	190	161.5	153	Industrial
90	AN18	315	299.25	254.3625	326	Industrial
91	AN19	315	299.25	254.3625	397	Industrial
92	AN20	100	95	80.75	124	Industrial
93	AN21	25	23.75	20.1875	1	Commercial
94	AN22	50	47.5	40.375	1	Commercial
95	AN23	315	299.25	254.3625	1	Commercial
96	AN24	100	95	80.75	1	Commercial
97	AN25	25	23.75	20.1875	1	Commercial
98	AN26	25	23.75	20.1875	1	Commercial
99	AN27	100	95	80.75	138	Industrial residential
100	AN28	25	23.75	20.1875	1	Commercial
101	AN29	315	299.25	254.3625	1	Govt
102	AN30	200	190	161.5	1	Commercial
103	AN31	200	190	161.5	159	Commercial+residential
104	AO32	100	95	80.75	1	Govt
105	AO33	315	299.25	254.3625	461	Residential + Commercial
106	AO34	1915	1819.3	1546.3625	3059	Residential + Commercial+industrial
107	WP1	315	299.25	254.3625	416	Commercial+residential
108	WP2	200	190	161.5	1	Industrial
109	WP3	100	95	80.75	69	Industrial residential
110	WP4	200	190	161.5	1	Industrial
111	WP5	100	95	80.75	145	Commercial+residential
112	WP6	100	95	80.75	126	Commercial+residential
113	WP7	315	299.25	254.3625	1	Govt
114	WP8	100	95	80.75	1	Govt
115	WP9	200	190	161.5	198	Commercial+residential
116	WP10	200	190	161.5	1	Govt
117	WP11	25	23.75	20.1875	1	Commercial
118	WP12	50	47.5	40.375	1	Commercial
119	WP13	315	299.25	254.3625	456	Govt+residential

120	WP14	200	190	161.5	213	Residential + Commercial
121	WP15	200	190	161.5	225	Industrial residential
122	WP16	200	190	161.5	214	Industrial residential
123	WP17	315	299.25	254.3625	1	Commercial
124	WP18	25	23.75	20.1875	1	Commercial
125	WP19	100	95	80.75	68	Commercial+residential
126	WP20	315	299.25	254.3625	156	Residential + Commercial
127	WP21	315	299.25	254.3625	412	Residential + Commercial
128	WP22	315	299.25	254.3625	325	Industrial residential
129	WP23	200	190	161.5	197	Commercial+residential
130	WP24	315	299.25	254.3625	467	Residential + Commercial
131	WP25	200	190	161.5	197	Commercial+residential
132	WP26	200	190	161.5	178	Industrial residential
133	WP27	200	185	157.25	139	Residential +residential
134	WP28	200	159.95	135.9575	175	Govt+residential
135	WP29	100	95	80.75	82	Industrial residential
136	WP30	200	190	161.5	219	Residential + Commercial
137	WP31	200	187.65	159.5025	234	Residential + Commercial
138	WP32	315	299.25	254.3625	428	Residential + Commercial
139	WP33	25	23.75	20.1875	1	Commercial
140	WP34	100	95	80.75	123	Residential + Commercial
141	WP35	1180	1121	952.85	1	Commercial
142	KF1	100	87	73.95	127	Industrial
143	KF2	200	190	161.5	1	Govt
144	KF3	25	23.75	20.1875	1	Commercial
145	KF4	315	283.25	240.7625	427	Residential + Commercial
146	KF5	200	190	161.5	189	Govt
147	KF6	50	47.5	40.375	61	Residential + Commercial
148	KF7	100	95	80.75	1	Commercial
149	KF8	1660	1577	1340.45	2647	Residential + Commercial

Appendix B

Shashemene substation Interruption data from 2007 to 2009 E.C

Item No.	Substation Name	Feeder Name	2007 E.C Frequency and Duration of Interruption												Frequency of Interruption (No.)	Duration of Interruption (Hr.)
			DPEF		DPSC		DTEF		DTSC		TLP		OP			
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]
1	Shashemene	1 (15 kv)	43	64.9	33	36	21	1.41	25	1.39	5	7.07	110	72.32	237	183.1
2	Shashemene	2 (15 kv)	26	30.2	48	86.9	21	1.12	36	1.74	5	7.07	124	79.94	260	207.02
3	Shashemene	3.1 (15 kv)	28	49.2	38	87.4	15	0.61	29	1.89	5	7.07	101	65.91	216	212.12
4	Shashemene	3.2(15 kv)	42	57.1	34	104.8	17	0.69	33	1.5	5	7.07	74	76.71	205	247.99
5	Shashemene	4 (15 kv)	44	146.1	44	110.1	19	1.15	31	2.34	5	7.07	84	93.07	227	359.95
6	Shashemene	5 (15 kv)	47	187.4	27	52.8	28	1.73	28	1.92	5	7.07	67	64.49	202	315.51
Sum																
			230	535.1	224	478.1	121	6.71	182	10.78	30	42.4 2	560	452.4 4	1347	1525.69

S.n o.	Substa tion Name	Feeder Name	2008E.C Frequency and Duration of Interruption														Frequen cy of Interrup tion (No.)	Duratio n of Interru ption (Hr.)
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		OP			
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]
1	Shashe	1 (15 kv)	40	186.8	38	70.9	16	0.83	26	1.31	32	31.0	21	62.81	166	119.6	339	473.4
2	Shashe	2 (15 kv)	39	104.82	32	43.7	11	0.56	14	0.6	32	30.0	22	57.22	169	130.3	319	367.4
3	Shashe	3.1 (15 kv)	37	71.4	43	63.7	7	0.41	12	2.62	32	45.5	23	48.67	135	121.2	289	353.6
4	Shashe	3.2 (15 kv)	81	87.7	39	110.1	19	1.45	16	0.96	23	12.4	7	16.43	69.6	80.0	254.65	309.1
5	Shashe	4 (15 kv)	81	275.7	39	110.1	19	1.45	16	0.96	23	12.4	7	16.43	69.6	80.0	254.65	497.1
6	Shashe	5 (15 kv)	89	428.7	46	157.8	25	1.17	32	2.06	23	12.4	7	17.63	78.6	104.6	300.65	724.4
Sum			367	1155.3	237	556.5	97	5.87	116	8.51	165	143.9	87	219.19	687.9	635.7	1756.95	2725.2

sno	Substation Name	Feeder Name	2009 E.C Frequency and Duration of Interruption														Frequency of Interruption (No.)	Duration of Interruption (Hr.)
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		OP			
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]
1	Shashemene	1 (15 kv)	64	280	64	95	23	1.06	31	1.46	49	42.9	54	111.6	265	211.4467	550	743.47
2	Shashemene	2 (15 kv)	58	162	47	63	22	1.06	32	1.51	49	42.9	68	124.1	174	190.1067	450	584.19
3	Shashemene	3.1 (15 kv)	103	110	83	237	35	2.5	39	12.07	45	76.8	53	104.8	155	154.6133	513	698.64
4	Shashemene	3.2 (15 kv)	187	272	118	315	32	1.5	60	3.27	51	34.5	9	13.8	26	318.5765	483	958.68
5	Shashemene	4 (15 kv)	187	334	118	215	32	1.5	60	3.27	51	34.5	9	13.8	26	318.5765	483	919.95
6	Shashemene	5 (15 kv)	233	350	164	264	68	6.29	83	11.47	209	235.5	112	267.4	461.95	481.6801	1166.95	1616.65
Sum			832	1509	594	1188	212	13.91	305	33.05	454	467.0	305	635.4	1107.95	1675	3645.95	5521.61

- N.B.:- DPEF- Distribution Permanent Earth Fault
DPSC- Distribution Permanent Short Circuit
DTEF- Distribution Temporary Earth Fault
DTSC- Distribution Temporary Short Circuit
TLP-Transmission Line Problem (Failure on 45 KV,66KV,132Kv ,230Kv and 400KV)
SOL- System Over Load (When Generated power is below the total Demand)
GUP- Generating Unit Problem (Generation Unit Failure)
DLOL- Distribution Line Overload (When Medium Voltage Feeders are loaded beyond their capacity or CT ratio)
PTOL- Power transformer Overload (When the load is beyond the capacity of Substation transformer)
OP- Operational (When Medium Voltage feeders are interrupted Volentarly for maintenance, Load transfer, new transformer errection, etc.)

Appendix C

Summary of reliability indices calculated from interruption report of EEU(2007 to 2009 EC)

SUMMARY OF REALIBILTY INDICES OF CITY FEEDER FOR YEAR 2007-2009 EC					
Reliability indices	Units	2007	2008	2009	average of three years
SAIFI	Int./customer/yrs	224.5	380.2	607.7	404.11
SAIDI	hrs./customer/yrs	254.3	454.2	920.3	542.92
CAIDI	hrs./interruption	1.13	1.195	1.514	1.28
EENS	MWH	11,422.39	19974	39486	23627.42

Appendix D

1KM 15kv H.T Line Extension					
Stock No.	Material Description	Unit	Qty	Unit Price	Total Cost
09-01-530	C/ POLE 12D 20 12MT LENGTH	EACH	5.7	7847.04	44728.128
09-01-490	C/ POLE 11C 18 10MT LENGTH	EACH	32.3	5784.67	186844.841
09-03-200	SUSPENTION CROSS ARM 2MT	EACH	38	853.2	32421.6
03-01-000	15 KV insulator HT	EACH	136.8	382	52257.6
03-01-200	PIN 18/5	EACH	136.8	51.85	7093.08
09-03-670	15KV TIE STRAP	EACH	102.6	384.96	39496.896
09-07-010	15 KV SUPPORT BRACKET	EACH	51.3	14.53	745.389
12-02-860	BOLT &NUT WITH M12X50	KG	38	40.65	1544.7
09-03-240	CROSS ARM 15KV DAED END	EACH	3.8	872.88	3316.944
03-01-600	INSULATOR CHAIN 16MM SOCKET	EACH	34.2	121.63	4159.746
03-01-700	SOCKET EYE 16MM SOCKET VOLPATO	EACH	11.4	26.95	307.23
03-01-710	BALL EYE 16MM BOLT VOLPATO 3055]	EACH	11.4	27.59	314.526
09-03-420	COLLARS SMALL	EACH	11.4	94.48	1077.072

09-03-430	COLLARS BIG	EACH	7.6	131.08	996.208
03-01-430	CLAMP STRAIN 16MM	EACH	11.4	120.57	1374.498
04-07-170	Clamp // groove 25-95mm2	EACH	11.4	12.91	147.174
12-02-310	Washer 5/8 in	kg	3.8	25.3	96.14
04-04-930	AAC.ALL ALUMINIUM CONDUCTOR 95MM	mt	5890	41.21	242726.9
18-01-000	CEMENT	KG	5130	5.54	28420.2
18-01-230	SAND MODJO	MT3	22.8	550	12540
18-01-250	GRAVEL TRACHETIC	MT3	19	575	10925
Sub-total Material Cost					671,533.87
Labour Cost					89262
OH Costs(A+B+C+D+E)					101699.324
Grand total					862,495.20