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FACULTY OF ELECTRICAL AND COMPUTER ENGINEERING

GRADUTE PROGRAM IN ELECTRICAL POWER ENGINEERING

RELIABILITY EVALUATION AND DESIGN IMPROVEMENT OF POWER DISTRIBUTION SYSTEM: CASE STUDY ON HOSSANA DISTRIBUTION SYSTEM

BY

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A Thesis Submitted to Faculty of Electrical and Computer Engineering, Jimma Institute of Technology in Partial Fulfillment of the Requirement for the Degree of Masters of Science in Electrical Power Engineering

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Declaration

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

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This thesis work has been submitted for examination with my approval as a University advisor.

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Advisor's name   signature

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Mathewos Lolamo Biramo

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List of Abbreviations

ANSI	American National Standards Institute
ASAI	Average Service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
DS	Distribution system
DSS	Distribution Substation
ECOST	Expected interruption cost
EENS	Expected energy not supplied
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
ETAP	Electrical Transient Analyzer Program
FR	Feeder Reconfiguration
GMF	Gofer Meda Feeder
GoV	Government of Ethiopia
HDS	Hossana Distribution System
HV	High Voltage
IEC	International Electro-technical Commission
LOL	Line overload
LV	Low Voltage
MTBF	Mean Time Between Failure
MECORE	Monte Carlo Simulation software
MTTF	Mean time between failures
MTTR	Mean time to repair
MVA	Megavolt Ampere
MWh	Megawatt Hour
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
SOL	System Overload
TTR	Times to Failure
TTF	Times to Repair
PDF	Probability Density Function

Abstract

Most of the customer interruptions occurred due to failures in the distribution system as a result of faults on the radial distribution feeder lines and some other factors like windy rain, animal contacts and tree branch intrusion. Unreliable power distribution system was main problem in Hossana that reduced user power consumption and affected daily activity. In this thesis work evaluation of the reliability for the Hossana distribution system was done and design solution was suggested.

In this thesis the reliability evaluation for the Hossana 15 kV distribution outgoing feeders using both analytical and time sequential Monte Carlo simulation methods is done. Thus, the values for SAIFI (interruption/year), SAIDI (hours/year), CAIDI (hours/interruption), ASAI (%), EENS (MWh) and Cost of EENS (USD) respectively are 168, 395.84, 2.36, 95.48, 8740.15 and 8930150.40 in the year 2013. The ASAI value of Addis Ababa distribution was 99.425% in the year 2014 whereas it was 95.29% for Hossana city. The deviation from Addis distribution system is 4.135% deviation from the standard ranges for example from American power distribution system by 4.709% in the 2014. The customers lost electricity for about 413 hours per year in 2014. Thus, Hossana distribution system is less reliable.

Feeder Reconfiguration using ETAP 12.6 software is done to minimize the outage duration of the feeder, improve the performance of distribution system and to minimize power loss on the primary feeder. As a result of FR, the power loss was minimized by about 22.85%.

Key words: Distribution system, Reliability Evaluation, power interruption, Feeder Reconfiguration

Chapter One

Introduction

1.1. Background

The distribution system is the portion of the electric power system that carries power from transmission substations to consumers. It is the final stage in the delivery of electricity from the transmission system to end users. A distribution system network consists of feeders, distributors and service mains. Feeders are large current carrying conductors that have the capacity to carry the current in bulk to the consumer premises. A distributor is a conductor from which tappings are taken for supply to the consumers. And the service mains are the small cables between the distributors and the consumer's premises [1].

The Hossana distribution system has 33kV and 15kV primary DS, and 132 kV/33kV and 132kV/15kV substations power transformers of various ratings like 12 /6.3/3MVA that are installed to step down voltage to 33 kV and15kV for feeding to Distribution Transformers. And then the voltages are further reduced by distribution transformers to 380 volts three-phase or 220 volts single-phase supply and delivered to residential, commercial and industrial customers.

The outgoing feeders are connected in radial fashion. Mostly, 33kV and 15kV overhead conductors are used for feeding distribution transformers on each 33kV and 15kV feeder. The distribution system feeders of the existing network of the study area is radial as shown in figure 1.1 below.

Radial feeders originate at substations, serve groups of customers and are not connected to any other feeder. Power flows along radial feeders from substations to customers along a single path, which, when interrupted, results in loss of power to the customers served by those feeders. Since radial feeders are typically connected to a single substation and cannot be fed from other sources, a single fault on a point may cause entire system to be interrupted. Thus, the reliability of the radial system is less.

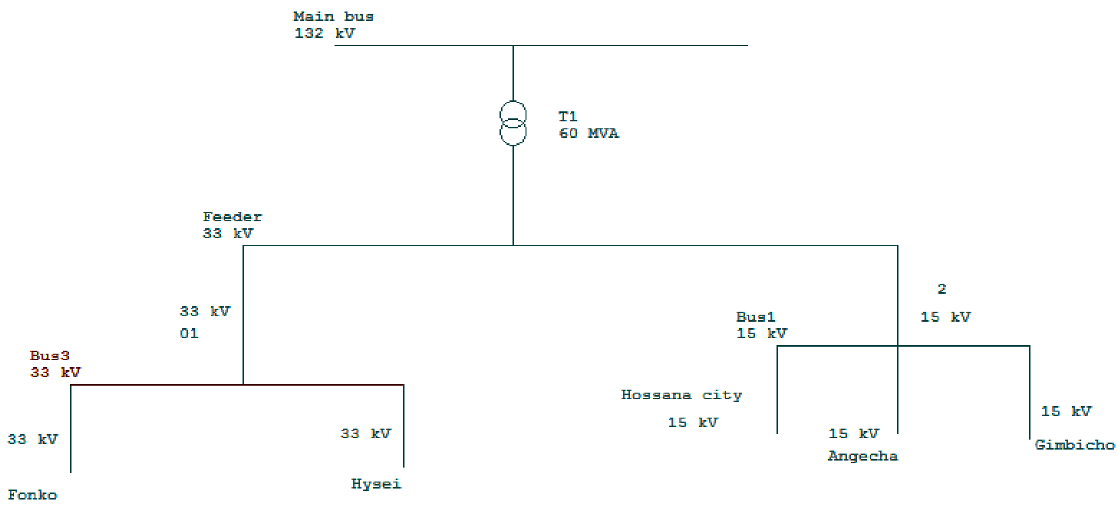

Figure 1. 1 A single line diagram existing Distribution system of Hossana

In existing system, 33kV line/feeder is used mainly for far rural areas from Hossana city which has to be extended further in order to cover all the rural customers including the small towns, Fonko and Hysei. The 15kV lines are usually used for nearby rural areas and mainly for town areas, for Hossana city, Angecha and Gimbicho towns.

1.2. Problem Statement and Motivation

Ethiopian Government has been undertaking great effort to change the country's least developed status to a medium income level within few years beginning from 2011. One of the activities among the Government of Ethiopia (GoE) has emphasized to bring changes is in strengthening and expanding Electric power supply to the urban and rural areas. Since 2003 E.C, by the efforts of EEU, EEP and GoE, the access to energy has been gradually improving by constructing new power plants as well as expanding the national Grid.

The major problem in study area is that the power delivered from distribution systems to the end-user level is not reliable. This is due to power interruption caused by distribution system failure as a result of distribution equipment outage due to aging and different types of faults on distribution feeder lines.

Unreliable power distribution have been reduced user power consumption, affected daily activity and dragged down modern life style. It has impact societal development and individuals' income. Basically, Power Distribution Reliability problem has been a major challenge in Hossana city and around the city. Since the distribution system is radial a single fault at a point causes entire system after a fault to be interrupted. Power interruptions occur several times in a day i.e. it is becoming a day-to-day phenomenon in the city. Such an interruption of power resulted in:-

- sensitive equipment damage
- low product quality and level of productivity of the customers
- increment of cost on customers
- dissatisfaction among customers

Considering the above problems on an existing power distribution system reliability and growing generation of electric power, I have got motivation to carryout evaluation of the Reliability and give a solution by reconfiguring one of the feeder of HDS, Gofer Meda Feeder (GMF) with 16-bus that enhances the level of reliability of service.

1.3. Objectives

1.3.1. General objective

The major objective of this thesis is to evaluate and design improvement of Hossana power Distribution reliability.

1.3.2. Specific objectives

The specific objectives of this research are:

- To assess and identify causes of power interruption,
- To evaluate and analyze existing system reliability of the study area,
- To compute reliability indices of the study area using both analytical and simulation techniques,
- To compare the calculated indices with standard benchmark values
- To conduct detailed analysis on the GMF 16-bus network and reconfigure Distribution Feeder using ETAP 12.6 software to minimize power loss and enhance performance and reliability of DS

1.4. Methodology

To have full information and an insight about the thesis and its nature the study has been started with reviewing the literatures related to the distribution system reliability. Recent published journals, some relevant books concerning distribution system and unpublished documents have been investigated in this work. Thus, the methodologies used in this Thesis work are:

- Interviewing experts and professionals at the substation has been conducted.
- Recorded data and existing information for the assessment has been considered to come up with a clear solution for the stated problems.
- The collected data from above mentioned areas and from the field work have been analyzed.

General methodology for this research work includes the following:

- Field visiting of existing structure of Hossana electric power distribution system
- For the purpose of analysis data from the following offices was collected:
  - Data relating to distribution planning and design of Hossana city administration
  - Data of distribution operation and maintenance schedules and experiences from Utilities
- Gathering data from EEP (Addis Ababa) to get relevant national standards and current updated information related to this research work
- Power interruption data of 3 years from January, 2013 to December, 2015 have been gathered from Hossana distribution substation records.
- Analytical methods based on mathematical models were to solve reliability indices.
- Time Sequential Monte Carlo simulation techniques have been used to simulate the overall behavior of the distribution system reliability indices.
- ETAP software has been used for Feeder reconfiguration so as to analyze active power loss and reliability enhancement.

1.5. Scope and Limitation of the thesis

The availability of power for customers from this substation is performed on the medium voltage side of the customer transformers. Although the reliability of distribution system is highly affected by outages that occur on the customer side/ secondary distribution lines, it is not possible to collect data for analysis due to lack of resource, organized data and advanced technology at the substation to view the performance of the customer side secondary distribution network. Thus, this thesis work has been done using data from primary side of distribution system of the study area.

One of the ways to improve secondary distribution performance as well as reliability is Feeder Reconfiguration. It takes so much time to reconfigure all Feeders of the study area. Thus, in this Thesis work GMF 16-bus system only is used to be reconfigured using ETAP software. The feeder was selected among three outgoing feeders of the Hosanna city because it supports high number of residential, commercial and industrial customers and most of the time this has been interrupting.

1.6. Organization of the Thesis

The thesis is organized into five chapters which include Chapter one that presents the introduction, background, statement of the problem, objectives of the study, methodology, scope and limitation of the study and the outline of the thesis. The second chapter discusses about the theoretical background and literature review of the study topic; mainly on Electric power distribution system and its configuration, causes of power interruption, and reliability improvement strategy, reliability assessment and evaluation of power distribution system, distribution feeder reconfiguration and literature review of current research works. Chapter three presents detailed reliability analysis of the existing distribution system: data analysis, types of outages, major causes of interruption and mitigation measures, reliability indices evaluation of the existing system of the study area, comparison of reliability indices with benchmarks and customer cost paid to prevent power interruption in the study area. Chapter four discusses with reliability indices evaluation using sequential Monte Carlo Simulation method, comparison between analytical results and Monte Carlo Simulation for Hossana DS feeders, feeder reconfiguration using ETAP software and load flow analysis to minimize the loss and improve performance of the feeder. Finally, conclusion and recommendation is presented in chapter five.

Chapter Two

Theoretical Background and Literature Review

To get an insight about the performance of electric power distribution system and the associated reliability problems of the distribution system, a literature review has been carried out on some topics discussed below.

2.1. Electric power distribution system and its configuration

The distribution system is the portion of the electric power system that carries power from transmission substations to consumers. It receives the bulk energy from transmission or sub-transmission substation delivers electricity from the transmission system to end users. Thus, the primary purpose of an electric power distribution is to meet the energy demand of customers. In addition to transporting electricity, a distribution system performs the following tasks [1]:

- Transforms voltage to the appropriate level for customer use
- Regulates voltages within a limited range
- Detects faults and other abnormal situations on the distribution system and takes action to protect people and system components and
- Restores service following interruptions

The distribution system begins after the main substations and has Feeders, Distributors and Service mains as shown in figure below [2].

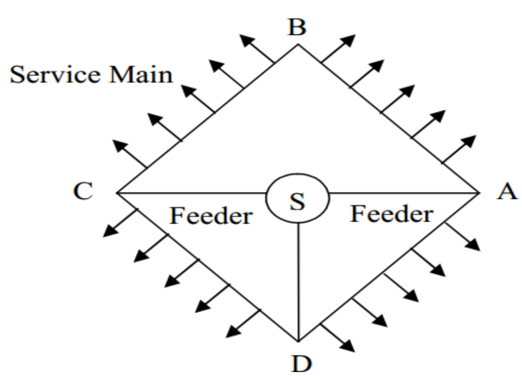

Figure 2. 1 Single line diagram of a typical low tension distribution system [2]

Feeders**:** are conductors that connect the main substations to the various distribution substations. There is no tapping from the feeders. That means the current loading of a feeder is the same along its entire length. Whereas distributors: are conductors that radiate out from the distribution substations to the customer premises. Various tappings can be taken from the distributors. Hence, a distributor has a distributed current loading along its entire length. And service mains**:** are the connecting links between the distributor and the consumer terminals.

There are two basic types of distribution substations: the primary and secondary (customer) substations. The primary substation serves as a load center where as the customer substation interfaces to low voltage (LV) network and can accommodate a number of high voltage (HV) switchgear panel and transformer to enable LV connections to the customer incoming switchboard.

A primary distribution substation is the connection point of a distribution system to a transmission or a sub-transmission network. Outgoing feeders from a primary distribution substation are typically feeding secondary distribution substations and bigger, most often industrial type, consumers directly. The voltage level for a primary distribution substation varies from country to country and depends on the whole electricity network structure and extent and historical and organizational issues.

There are two standards applied in the world for the design of distribution system [3], [4]:

- North American standards governed by ANSI and the IEEE

- The standard secondary voltage level is 208/120 Volts and 190/110 Volts

- European standards governed by IEC

- The standard secondary voltage level is 380/220 Volts and 400/230 Volts

Thus, EEP is using standards set by IEC.

Based on connection schemes distribution systems networks are classified in to three types [2]. Namely: radial, ring main and interconnected systems.

Radial distribution systems: A radial system is connected to only one source of supply and is exposed to many interruption possibilities as shown in figure 2 below. A radial distribution system consists of series components such as lines, cables, disconnectors (isolators), bus bars, etc. Radial feeders tend to have lower reliability than feeders with alternate supply capability. Feeder breaker reclosing action or temporary faults are likely to affect sensitive loads. Purely radial feeders with no alternate supply capability are usually used for small loads or rural systems.

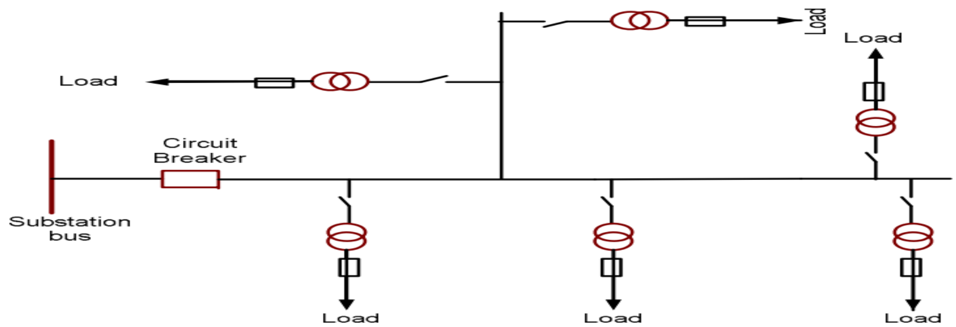

Figure 2. 2 Single line diagram of a radial distribution system

Although it is simplest distribution circuit and has the lowest initial cost, it suffers from the following drawbacks.

- ❖ The end of the distributors nearest to the feeder point will be heavily loaded.
- ❖ The customers are dependent on a single feeder and single distributor. Therefore, any fault on the feeder distributor cuts off supply to the customers who are on the side of the fault away from the substation. The reliability of this system is low.
- ❖ The customers at the distant end of the distribution would be subjected to serious voltage fluctuations when the load on the distributor is changed.

Ring main distribution system: In this system, the primaries of distribution transformers form a loop. The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation. The ring main system has the following advantages:

- There are less voltage fluctuations at consumer’s terminals.
- The system is very reliable as each distributor is fed via two feeders

In the event of fault on any section of feeder, the continuity of supply is maintained.

Interconnected distribution system: When the feeder ring is energized by two or more than two generating stations or substations, it is called inter connected system. The inter-connected system has the following advantages:

- It increases the service reliability.
- Any area fed from one substation during peak load hours can be fed from the other substation. This reduces reserve power capacity and increase efficiency of the system.

From most experiences of the world countries, distribution systems are radial in nature because of their low cost and simple design. A radial system consists of a series of components between the substation and the load points. Thus, failure of any of these components may result in outage at the load point(s). And the duration of the outage depends on the protection and sectionalizing schemes used in the distribution system. Thus, in this thesis work analyzing a radial distribution system and giving a specific solution for the problems of less reliability of radial system without changing radiality of the distribution system for the study area has been done.

Due to low quality and old components in distribution system, the interruption frequency and duration of customers are high. The distribution system needs to be planned, designed, and maintained with particular attention to prevent power interruption. Lately, to improve these problems EEU started to redesign and plan the electrical power distribution systems of some towns in the country [5].

2.2. Causes of power interruptions and Factors Affecting Reliability Performance

Most of the power outages, up to 90%, experienced by the customers are due to failures in the distribution system. It is important to consider the impact of the outages on the customer outage costs and the system reliability. An indication of the primary importance of DS reliability to the reliability of the customers' electric power service: inability to provide service at individual load points arises mainly from distribution system equipment outages. Outages by functional area are summarized as 85% of customer service hours are lost due to distribution system outages (poles, wires, cables, switchgear, etc.), 9% from substations, 4% from transmission and less than 2% is caused by generation [6], [7]**.** This is because most electric power distribution system structure is radial by nature as shown in figure 2.2 above.

There exist different contingencies in power systems that bring about power failure and system outages in distribution networks. Unlike the smart grid, the traditional power system is vulnerable to various types of failure sources resulting lack of reliable power supply. Thus, it's the sum of the different sources of power failures that reliability of a system is defined by. Among the commonly considered factors exposure to natural elements (overhead/underground conductor routing), sectionalizing capability, redundancy, conductor age and number of customers on each feeder are main ones [8], [9]. Thus, the Reliability performance of the distribution system varies from location to location and system to system. This is due to many factors influencing the expected reliability performance at a particular location or at an entire system. Among the top affecting physical factors, some are listed hereunder.

- Geographical location of service territory such as thick forest, mountainous terrain.
- Exposure of components to natural elements; for instance, transmission and/or distribution system components may be affected by being exposed to their residing physical environment
- Weather condition: Adverse weather condition such as windy rain and lightning.
- Effects of vegetation such as tree falls and branch intrusion
- Animal activity like birds and pests casuing ground faults
- Other factors include:-

- System voltage
- Feeder length and its configuration
  - ➢ The customers connected to the system farthest from the supply point tend to suffer the greatest number of outages and the greatest unavailability.
- Sectionalizing capability
- Redundancy
  - ➢ A system consisting of more than one components and the operation of only one component causes the success of the system is called a Redundant System.
- Conductor type and age
- Number of customers connected to each feeder

The availability of a stable and reliable power supply at a reasonable cost is vital for the development of a country. Thus, Electric power utilities should put great effort to improve the network so as to ensure the customers' reliability requirements and the regulators requirements at optimum cost [10].

2.3. Reliability Improvement Strategy for Distribution System

In this regard, the main improvement strategy is minimizing the number and duration of power interruption. However, *how to reduce the number of power outages* is a major problem because some of the methods that will be applied are expensive. Another big issue during carrying out improvement action for distribution system is to *know where to start when making improvement decisions.* However, at a utility where reliability indices are collected, it is easy for engineers and other operation personnel to choose a reasonable starting point for improvement.

System reliability can be improved by reducing both frequency and duration of faults. The main strategy to improve reliability and power quality to customers are to eliminate faults as fast as possible and then to minimize the effect of faults on customers even if it occurs. Various methods have been suggested for improving the system reliability, such as non-electrical and electrical techniques [11]:

i. Non-electrical improving techniques include:

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

ii. Electrical improvement techniques include:

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

Thus, in this thesis work electrical improvement technique (FR) has been done as an improvement strategy of reliability of the study area so as to reducing outage duration.

In order to assess the performance of a distribution system and to compare the effects of these alternate design and maintenance strategies, two sets of reliability indices have been defined, viz. customer load point indices and the system indices that are stated in chapter two above. The load point indices measure the expected annual frequency of outages and their duration for individual customers. The system indices measure the overall performance of the system.

2.4. Reliability Analysis and Evaluation of Power Distribution System

2.4.1. Reliability analysis of Distribution System

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

As a response of dynamic conditions, Reliability analysis is important to quantify, predict and compare reliability indices for various reliability improvement initiatives. It is also important to evaluate past performance and predict future performance of the distribution system, to identify the problematic components in the system that can impact reliability, to ensure appropriate system reliability levels, to provide effective information for regulatory bodies to set proper benchmarks, to predict the reliability performance of the system after any expansion and quantify the impact of adding new components to the system [5].

There are several techniques of distribution system reliability evaluations which have been presented by different researchers. Each of the technique uses different mechanisms and algorithms which aides to assess and improve reliability of the power delivered to the customers of industrial, commercial and domestic sectors. Reliability of distribution system is an important issue in power engineering for both utilities and customers. Techniques for reliability evaluation are important in the planning, operation or both phases of distribution system. Operation and maintenance costs due to low reliability can be reduced by adequate planning, monitoring system behavior and taking proper control actions [13].

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

Generally, reliability evaluation is important to:-

- evaluate past performance and predict future performance of the distribution system,
- identify the problematic components in the system that can impact reliability,
- ensure appropriate system reliability levels and to provide effective information for regulatory bodies to set proper benchmarks,
- predict the reliability performance of the system after any expansion and quantify the impact of adding new components to the system

2.4.2. Reliability Indices Evaluation

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

In order to evaluate the severity of a system outage, the sets of indices listed below must be calculated using the three basic indices mentioned above. The two expanded sets of indices include the number and average load of customers connected at each load point in the system and the customer interruption cost [14].

The first set is the system reliability index that includes:

- System Average Interruption Frequency Index (SAIFI)
- System Average Interruption Duration Index (SAIDI)
- Customer Average Interruption Duration Index (CAIDI)

- Average System Availability Index (ASAI)
- Average System Unavailability Index (ASUI)

The second set includes the reliability cost/worth indices:

- Expected Energy Not supplied Index (EENS)
- Expected Interruption Cost (ECOST) or Cost of EENS

Reliability indices help engineers and other operations personnel see and show an interconnected nature of the many independent system components that make up an electrical distribution system. This connection makes apparent the fact that overall system design impacts fundamental reliability. From substation and distribution design to fusing schemes, the physical factors of system design impact system reliability [8].

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

2.4.2.1. Analytical Method of Reliability evaluation

Analytical techniques represent the system with simplified mathematical models derived from mathematical equations and evaluate the reliability indices using direct mathematical solutions. The reliability indices that have been evaluated using analytical concepts are the three primary ones: average failure rate, average outage duration and average annual unavailability or average annual outage time. The reliability of a distribution system can be described using two sets of reliability parameters. These are the load point reliability indices and the system reliability indices [14].

a) Load Point Indices

Three basic reliability indices can be used to describe the degree of service continuity are the load point average failure rate (λ), average outage time (r) and the average annual unavailability or average annual outage time (U). The average failure frequency is approximately equal to the average failure rate and indicates the number of failures a load point will experience during a given period of time. The average outage time is the average duration of failure at the load point. The average annual outage time is the average total durations of outage in a year experienced at the load point. It is the product of the average frequency of failure and the average outage time. These reliability indices are expected values and represent the long-run average values [15].

$$f_s = \sum_{i=1}^{12} \lambda_i \quad \text{(Interruption/year)} \tag{2.1}$$

$$U_s = f_s r_s = \sum_{i=1}^{12} \lambda_i r_i \quad \text{(Hours/year)} \tag{2.2}$$

$$r_s = \frac{\sum_{i=1}^{12} \lambda_i r_i}{\sum_{i=1}^{12} \lambda_i} \quad \text{(Hours)} \tag{2.3}$$

Where

- f_s= Interruption frequency [interruptions/year]
- λ_i = Failure rate
- r_i= interruption duration [hours/year]
- r_s= average outage time
- Us= Annual downtime

However, that the load point indices shown above are not deterministic values but are the expected or average values of an underlying probability distribution and hence only represent the long run average values. Although these three primary indices are basically important, they do not always give a complete representation of the system behavior and response [15].

b) System Reliability Indices

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

1. System Average Interruption Frequency Index (SAIFI)

SAIFI indicates how often an average customer is subjected to sustained interruption over a predefined time interval. This index is average number of interruptions per customer served per year. It is determined by dividing the total number of customer interrupted in a year by the total number of customers served. A customer interruption is considered to be one interruption to one customer.

$$SAIFI = \frac{\text{Total number of customer interruption}}{\text{total number of customers served}} = \frac{\sum \lambda_i * N_i}{\sum N_T} \quad (2.4)$$

Where: N_i= Total number of customers interrupted,

N_T= Total number of customers served

λ_i= Number of interruptions

2. System Average Interruption Duration Index (SAIDI)

SAIDI indicates unavailability of service for a specified time. That means it is the total duration of interruption an average customer is subjected for a predefined time interval. This index is the average interruption duration for customers served during a year. It is determined by dividing the sum of all customer interruption duration during a year by the number of customers served during the year [16].

$$SAIDI = \frac{\text{Total number of customers interruption duration}}{\text{total number of customers served}} = \frac{\sum U_i * N_i}{\sum N_T} \quad (2.5)$$

3. Customer Average Interruption Duration Index (CAIDI)

CAIDI indicates the average time required to restore the service. This index is the average interruption duration for customers interrupted during the year. It is determined by dividing the sum of all customer sustained interruption duration by the number of sustained customer interruptions over a one year period.

$$CAIDI = \frac{\text{Total number of customers interruption duration}}{\text{Total number of customer interruption}} = \frac{\sum r_i * N_i}{\sum \lambda_i N_i} \qquad (2.6)$$

Where r_i- restoration time in minutes

4. The Average Service Availability Index (ASAI)

ASAI specifies the fraction of time that a customer has received the power during the predefine interval of time whereas ASUI is fraction of time that the customer not get power during the given interval of time. ASAI is the ratio of the total number of customer hours that service was available during a given time period to the total customer hours demanded. This is sometimes known as the "Service Reliability Index". ASAI is usually calculated on either a monthly basis (720 hours) or a yearly basis (8,760 hours), but can be calculated for any time period. ASAI can be calculated as,

$$ASAI = \frac{\text{Customer Hours of Available service}}{\text{Customer Hours Demanded}} * 100\% =$$

$$ASAI = \frac{8760 - \text{SAIDI}}{8760} * 100\% \qquad (2.7)$$

The complementary value to this index i.e. the Average Service Unavailability Index may also be used. This is the ratio of the total number of customer hours that service was unavailable during a year to the total customer hours demanded

$$ASUI = (100 - ASAI)\% \qquad (2.8)$$

5. Energy not supplied (EENS)

EENS specifies the average energy that is not supplied to the customer in the predefined time.

$$EENS = P_{av} * \text{t}, \quad \text{where t} = \text{SAIDI} \qquad (2.9)$$

$$\text{Cost of EENS} = \text{EENS} * \frac{\text{cost}}{\text{kwh}},$$

Past performance statistics provide valuable 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. Due to stochastic nature of failure occurrence and outage duration, it is generally based on probabilistic models.

2.4.2.2. Simulation method of Reliability Evaluation using Monte Carlo Simulation

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

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

There are two types of Monte Carlo simulation techniques: Sequential Monte Carlo technique and Non sequential technique. Sequential Monte Carlo technique is used to simulate system operating cycle obtained by combining all component cycles. That means the sequential approach simulates the basic intervals in chronological order. Thus, it is used to obtain accurate frequency and duration indices and to synthesize annual reliability index probability distribution. This makes it advantageous over non sequential technique. Two significant advantages when utilizing sequential Monte Carlo simulation method are the ability to obtain accurate frequency and duration indices, and the opportunity to synthesize reliability index probability distributions which describe the annual index variability [17]. Moreover, the time-sequential Monte Carlo simulation technique can be used on any system that is stochastic in nature. The up and down states are modeled using a random number generator and the probability distributions of the component failure and restoration processes. A sequence thus generated is used to study the distributions surrounding the expected values of the reliability indices.

The Monte Carlo simulation process begins with the generation of uniformly distributed random numbers using a uniform random number generator. Since perfect random numbers are not attainable using a computer program, pseudo-random numbers are used. The built-in random number generator has been used to create uniformly distributed pseudo-random numbers in the interval [0, 1]. The generated random numbers are then converted into values representing a non-uniform probability distribution by using the inverse transform method, composition and acceptance-rejection techniques [18].

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

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

$$f_U(u) = \begin{cases} 1 & ,0 \le u \le 1 \\ 0 & ,else \end{cases}) \tag{2.10}$$

The cumulative distribution function of the PDF in (2.10) above is given by:

$$F_U(u) = U, 0 \le U \le 1 \tag{2.11}$$

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

$$f_U(u) = \begin{cases} \lambda e^{-\lambda t} & ,0 < t < \infty \\ 0 & ,else \end{cases} \tag{2.12}$$

The cumulative PDF (probability density function) for the exponential PDF of equation (2.12) will be:

$$F_T(t) = \int_0^t \lambda e^{-\lambda u} du = 1 - e^{-\lambda t} \tag{2.13}$$

Equating equations (2.12) and (2.13) and taking the inverse transformation (natural logarithm), the generated random number can be converted in to another random number T as expressed below:

$$U = 1 - e^{-\lambda t} \tag{2.14}$$

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

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

$$T = \frac{-\ln(1-U)}{\lambda} \tag{2.15}$$

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

$$T = \frac{-\ln(U)}{\lambda} \tag{2.16}$$

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

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

In time sequential simulation, an artificial history that shows the up and down times of each element of the system is generated in chronological order using random number generators and the probability distribution of the element's failure and restoration parameters [19].

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

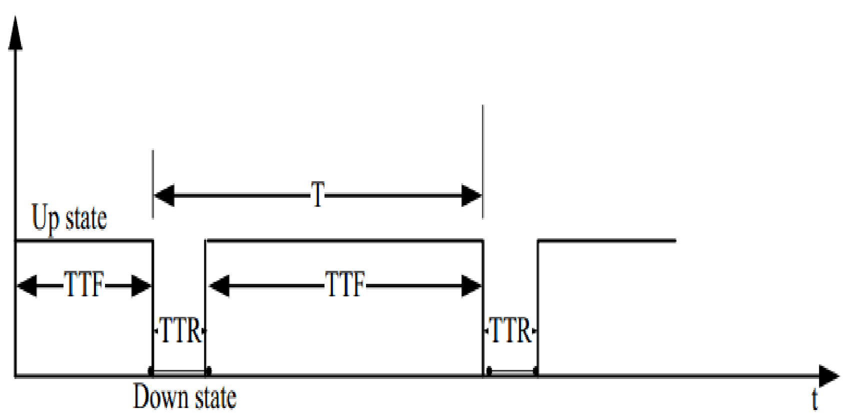

Figure 2. 3 Average state cycle

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

Thus, the sequence of operating repair cycles of the system is obtained from the history of the components using the relationship between the element states and the system states as given in equations (7) and (8) below.

$$TTF = -MTTF * \ln U \tag{2.17}$$

$$TTR = -MTTR * \ln U' \tag{2.18}$$

Used in this Thesis work to determine the distribution system reliability indices using the time sequential Monte Carlo simulation the following steps are applied:

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

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

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

Step 4: Find the element with minimum TTF

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

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

$$\lambda_i = \frac{N}{\sum TTF} \tag{2.19}$$

$$r_i = \frac{\sum TTR}{N} \tag{2.20}$$

$$U_i = \frac{\sum TTR}{\sum TTF + \sum TTR} \tag{2.20}$$

Where

- i refers to the line section
- N is the number of transitions between up and down states during the given year.

Step 7: Finally, Evaluate the system indices using equations (2.1) to (2.10)

2.5. Customer Cost of Electric Service Interruptions

The main objective of modern electric power system is to provide an adequate electric supply to its customers as economically as possible at a reasonable level of reliability. That means, it is important to recognize that reliability and economy must be treated together in order to perform objective cost benefit studies. In other words to maximize the reliability, utility should balance their reinforcement cost for reliability improvement and the customer cost for poor reliability. Therefore, the optimal level of reliability is said to be achieved when the sum of utility cost and the customer cost are minimum. The total cost is the sum of the utility/investment cost and the customer cost.

Determination of outage cost is to understand the nature of faults and variety of customer impacts that would be resulted due to electric service interruption. The impact of interruption/outage costs can be broadly classified into direct and indirect costs. Direct costs are those arising directly from the electrical interruption and relate to such impacts as lost industrial production, spoiled food or raw materials, personnel leisure time, injury or loss of life. Indirect costs are related to impacts arising from response to the interruption, such as crime during blackouts (short term), business relocation (long term) and civil disobedience and looting during an extended blackout [10].

2.6. Distribution Feeder Reconfiguration using ETAP software

Electrical Transient Analyzer Program (ETAP) software provides engineers, operators, and managers a platform for continuous functionality from modeling to operation. ETAP offers a suite of fully integrated electrical engineering software solutions including arc flash, load flow, short circuit, transient stability, relay coordination, cable capacity, optimal power flow, reliability assessment and so on. Its modular functionality can be customized to fit the needs of any company, from small to large power systems. In this Thesis ETAP is used to analyze the load flow so as to reconfigure the distribution feeder to improve distribution system reliability.

A primary feeder or distribution system feeder carries power from the main distribution substation to the secondary substation. The secondary feeder is an extension of the main feeder to reach widely distributed areas. A circuit breaker is usually present in the main feeder. Manual sectionalizing equipment such as disconnects or isolators are also installed at strategic locations on the main feeder for isolating the faulted sections and restoring supply to the healthy sections. The time required for performing isolation and switching actions while a faulted component is being repaired is known as the restoration time [20]. The location and installation of number of Auto re-closer, Tie-switches, Load break switches and sectionalizes either manual or automatic helps to reduce fault rate, repair time and sectioning time which directly reduces the impacts on the system when fault occurs.

Most distribution systems are configured radially with manual or automatic switching operations so that all of the loads are supplied. Although the configuration is expected to reduce power loss, increase system security and enhance reliability, failure of any of the series component in the radial configuration may result in outage at the load point(s). The duration of the outage depends on the protection and sectionalizing schemes used in the distribution system.

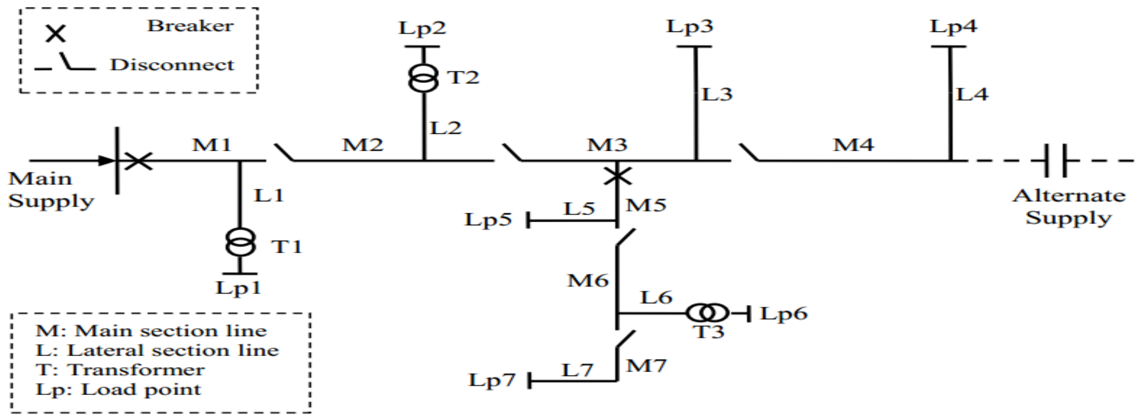

Figure 2. 4 A radial distribution system

A radial distribution system receives the main power supply from a transmission or sub-transmission system. It consists of a primary or main feeder and lateral sections or distributors as shown in figure 4. The main feeder is sectionalized (M_1, M_2, etc.) by disconnects or isolators to isolate faulted sections. Load points LP_1, LP_2, etc. are connected to the main feeder through lateral sections L_1, L_2, etc. A circuit breaker is usually installed at the beginning of the main feeder from the substation and also at certain lateral sections to protect important equipment or load points. Fuses are usually used in lateral sections to isolate failures on the lateral section from the main feeder. An alternate supply is sometimes provided to restore service in case of failure.

Feeder reconfigurations (FR) are defined as altering the topological structures of distribution feeders by changing the open/closed states of the sectionalizing and tie switches. If both tie and sectionalizing switches are closed at the same time, the losses would be minimized greatly; but it complicates the system's protection against overcurrent and again the system loses radiality, which in most cases is used in distribution network. Thus, FR is performed by opening the normally closed sectionalizing switches and closing the normally open tie switches of the network. These switching operations are performed in such a way that the radiality of the network is maintained and all of the loads are energized [21].

Consider the following example for illustration of the FR processes: a distribution system with three main feeders (F_1, F_2, and F_3) is shown in figure below. When a fault occurs on a line section, say m_3, its FB_1will open and leave all the customers that are supplied by this feeder (m_1-m_5) in an outage state.

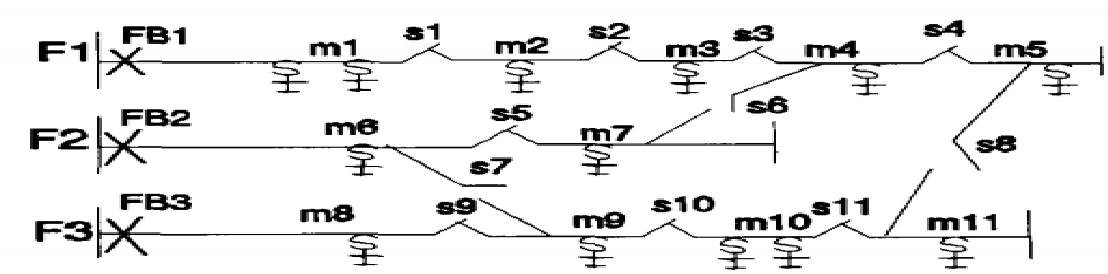

Figure 2. 5 Configuration of a distribution system

Where - FB= feeder breaker, - S_1-S_5 and S_9 –S_{10} are sectionalizing switches

- m= main line, - S_6, S_7 and S_8 are tie switches

If the outage is caused by a failure on $m_{3,}$ service can be restored to the upstream customers (who are served directly or laterally by m_1 and m_2) by opening S_2 to isolate the fault and closing FB_1. And the service can be restored to the downstream customers (who are served by m_4 and m_5) by opening S_3 and closing S_6 and S_8. However, if both S_6 and S_8 are closed at the time, S_4 has to be open to avoid a loop and keep the network's rediality.

During normal operating conditions, the network is configured to reduce the system power loss and relieve the network from overloads. Whereas during faulted conditions, the network can be reconfigured so that large number of customers retain electrical service. Reducing the real power losses is network reconfiguration and relieving the overloads is called load balancing.

For this Thesis work, during normal operation condition, sectionalizing switches of the network remain in their closed states (NC) whereas tie switches (NO) remain in their open states. But during abnormal/faulted condition, when a feeder or a component fails, some of the NC sectionalizing switches will be in their open states and at the same time NO tie switches will be in their closed states so as to transfer part of or all isolated branch of network to another branch/ feeder. A whole or part of a feeder will be served from another feeder by closing a tie switch linking the two while an appropriate sectionalizing switch must be opened to maintain radial structures. Thus, FR is an important operational tool as well as a fault management technique.

Minimizing of active (real) power losses is one of the essential aims for any electrical DS to improve the system properties and meet customer demand. Among the different ways to minimize the active power loss some are network (Feeder reconfiguration), Capacitor placement and Using distributed generation [22].

Feeder reconfiguration is very important to:

- Reduce real power loss (resistive line losses)
- Enhance the quality and reliability of the distribution system
- Relieves the overloading of the network components (load balancing)
- Restore power to outage participations of a Feeder

2.6.1. Load flow studies and Power losses of the distribution system using ETAP

The principal information from the load flow analysis includes bus voltage magnitude, phase angle and real and reactive power flowing through each branch. The key parameters that are monitored during simulation are voltage profile, equipment loading and losses.

In this Thesis work GMF 16-bus system is used to analyze load flow and evaluate the effect of FR using ETAP software to simulate the model. The input data is provided by using IEC standard 132/15kV considering the characteristics and type of conductor material used for Overhead power distribution system. Due to the nature of fast convergence of Newton-Raphson (NR) method, it is used to verify the results that will be obtained. Matrix equations that is used for each iteration is given in equation (2.21). Assume bus -1 is swing bus and all buses are load buses.

$$\begin{bmatrix} \Delta P2 \\ . \\ . \\ \Delta Q33 \end{bmatrix} = \begin{bmatrix} \frac{\partial P2}{\partial \delta 2} & \frac{\partial P3}{\partial \delta 3} & \cdots & \frac{\partial P2}{\partial V33} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ \frac{\partial Q33}{\partial \delta 2} & \frac{\partial Q3}{\partial \delta 3} & \cdots & \frac{\partial Q33}{\partial V33} \end{bmatrix} * \begin{bmatrix} \Delta \delta 2 \\ . \\ . \\ \Delta V33 \end{bmatrix} \tag{2.21}$$

The power loss in electric power distribution system is the difference between energy delivered to the distribution system and received by the consumers as shown in equations.

One of the sources of power losses in overhead distribution system is copper loss, which is a function of current through the lines (feeders). The level of power loss is influenced by different factors such as network reconfiguration, load characteristics, substation in service and power quality. Thus, this loss can be reduced by Feeder/network reconfiguration by using ETAP software. It is calculated for each branch of distribution system using the power flow solution of ETAP. Consider a simplified distribution system given below for the analysis of the power losses on a distribution system.

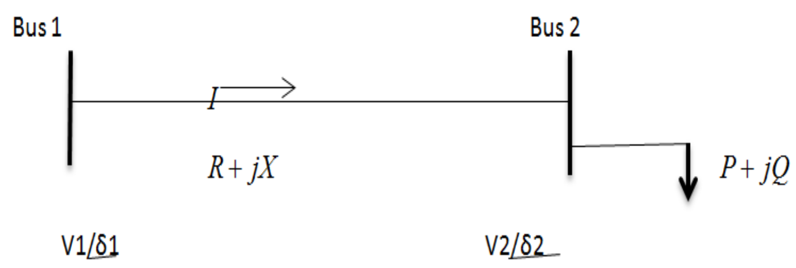

Figure 2. 6 A single line diagram for two bus system

The current flowing through the impedance is:

$$I = \frac{V_{1(\delta 1)} - V_{2(\delta 2)}}{R + jX} \quad (2.22)$$

The power flowing (load consumption) in to bus 2 is given by

$$P_2 - Q_2 = V_2 * I^* \quad (2.23)$$

$$|I|^2 = \frac{P^2 + Q^2}{V^2} \quad (2.24)$$

There are two types of power losses in the distribution feeder:

- Real (active) power losses is given by

$$P_{loss} = \sum_{i=1}^{n} |Ii|^2 * R_i \quad (2.25)$$

- Reactive power losses

$$Q_{loss} = \sum_{i=1}^{n} |Ii|^2 * X_i \quad (2.26)$$

Alternative equation for active power loss in all feeders (branches) can be obtained by substituting (2.25) in to (2.26):

$$P_{loss} = \sum_{i=1}^{n} \left(\frac{P_i^2 + Q_i^2}{V_i^2} \right) * R_i \qquad (2.26)$$

2.6.3. Proposed Methodology for Feeder Reconfiguration

During normal operation, the distribution Feeder switches (sectionalizing switches) are configured so that the network is radial and each bus is connected to a single substation. Thus, during FR the radiality of the network must be maintained and all connected loads must be energized. However, the great problem of feeder switches reconfiguration so as to minimize the power loss and associated customers' cost is the optimal switch reconfiguration. That means obtaining optimum location of Tie switch that provides optional path for those customers found after a fault line point and minimizes the power loss.

ETAP 12.6 is used for load flow calculation of before and after reconfiguration states. The ratings of all equipment under study are selected by IEC (metric) standard at 50Hz. An exhaustive search technique is used to obtain optimum switching configuration of the test system.

Reconfiguration of a radial distribution networks to optimize the power distribution process in the feeders and for voltage profile improvement was presented in this paper. And it presents three different methods in exhaustive search techniques for loss reduction by FR: minimum branch current, minimum voltage difference and voltage difference based closing/opening switch [4].

In this Thesis minimum branch current exhaustive search technique is used for FR. The proposed exhaustive search method that is applied in the thesis is given below:

- Give input for all branches, buses and transformers
- Run load flow by using ETAP for base case (radial configuration) and record all branch currents
- Connect all open /tie/ switches and run load flow for meshed configuration by using ETAP and list out all branch currents

- From the result of meshed configuration, select the branch with minimum current and open it
- Check whether the number of opening sectionalizing switches equal to the number of loop in the network
- Check whether radial structure is maintained
- Obtain branch currents for final configuration and compare with the base case branch currents.

2.7. Literature Review of Recent Research papers

Challenges facing power distribution system reliability that stems from design phase were reviewed on the review work of [22]. Considering the challenges, power distribution system planning should be based on service reliability and uncertainty consideration of distribution system because there are different factor affecting reliability performance. Thus, Power distribution company needs higher reliable and lower operational costs that are forcing companies to continuously search for ways to improve their performance.

An approach to identify weather specific contributions to system reliability has presented in [23]. The two-stage restoration technique incorporating normal and adverse weather effect considerations in reliability cost/worth evaluation of distribution systems was incorporated. The adverse weather conditions exert the physical stresses on transmission or distribution lines resulting in increased coincident failures of multiple circuits that cause tremendous system damages and lower reliability performance [23].

The traditional power system is vulnerable to various types of failure sources that results in unreliable power supply except the smart grid. It’s the sum of the different source of power failure that reliability of a system is defined by including faults at the end user level. Therefore, improvement measures must be taken in distribution system to fulfill demand of end-users’ [9].

The improvement cost and costs paid by customers for poor reliability ought to be balanced. Since the Smart grid technology is nice to supervise the network, it is costly to implement in utility level. Thus, using other cost effective means of improvement mechanisms can be applied instead. In addition to that, according to the customers' demand, the reliability assessment must be done considering both existing and future expansion. The alternative design having optimal cost and minimum outage must be incorporated considering present and future load growth.

The system modeling and simulation study that was carried out on a distribution system [10] which consists of 33kV and 11kV network in Bhutan using a computer program called NetBas/Lesvik to run load flow and reliability analysis. In this assessment, the evaluation of the performance of the present system and prediction of reliability of the future system considering load growth and system expansion was done. Then, the alternative which gives low SAIDI, SAIFI and minimum breakeven costs were considered [10].

Assessment of the reliability performance of the 33kV Kaduna Electricity Distribution Feeders in the Northern Region of Nigeria was held in [8]. The daily outages data of the feeders of the 16 months (January, 2011 to December, 2012) were collected and used to compute the monthly reliability indices for the feeders. Monthly reliability indices were tabulated incorporating the Actual Energy Loss, Forced outage hour (FOH), failure rate, Mean time between failures (MTBF), Mean time to repair (MTTR) and the availability. The high forced outages recorded are indications of unreliable performance [8].

To have accurate values for the distribution system and minimize the uncertainty of power outage for area under study it is better to use probabilistic reliability analyzing software like Monte Carlo simulation techniques must be used rather than the analytical evaluation.

The power system reliability evaluation using Monte Carlo Simulation software (MECORE) focusing on probabilistic (stochastic) techniques in composite power system adequacy assessment has been presented in the paper. The major advantage of the MECORE is that, it gives detailed knowledge of the probability distributions of reliability indices**.** It can also be used to calculate both the average values of the various indices and the frequency and probability distribution of these parameters [25].

Since the Distribution system is not loaded beyond its limit and system adequacy is the static condition analysis, it is not a big issue in reliability study. In addition to that, both analytical and simulation methods have to be used so as to compare reliability indices of both methods.

The [26] has presented the methodology to evaluate reliability indices using both analytical method and time sequential Monte Carlo simulation method. Reliability models to evaluate the distribution system reliability using Monte-Carlo simulation method and an algorithm for computer program to implement these techniques in VC++ are used in this work. General distribution system elements, operating models and radial configurations are considered in the program. Overall system and load point reliability indices and expected energy not served are computed using these techniques [26].

The results of a joint investigation undertaken in collaboration with a local utility to study the reliability issue based on data collected from feeders, true losses in some primary and secondary feeders are obtained. These losses are compared with the estimated losses obtained by the methods presently in use. In view of the large discrepancies observed between measured and estimated values, two new schemes for estimating losses in primary and secondary distribution networks have been developed. The measured values are used to highlight the reliability of the new estimation methods [27].

An effective method to reconfigure a radial power distribution system of an IEEE 33-bus test system using genetic algorithm was described [28]. Reconfiguration is done to enhance reliability and to reduce losses. The reliability at the load points is evaluated using probabilistic reliability approach. For finding minimal cut sets and losses different algorithms are used. To maximize the reliability and to reduce the losses, the status of the switch is controlled using genetic algorithm.

However, [29] has presented the Feeder Reconfiguration in four selected Distribution Networks of IEEE 33-bus using an iterative algorithm in ETAP 12.6. And in [30], Network reconfiguration method which was employed on 83-Bus and 74-Bus radial distribution system in Yangon city for loss reduction. Reconfiguration conditions are modeled and simulated by ETAP 7.5. An exhaustive search technique was applied to achieve the minimal loss switching scheme. The main objective in feeder (network) reconfiguration was to restore as much load as possible by transferring essential load of the out-of-service to the nearby healthy feeder. This method reduced the losses by 5% as compared to the existing methods and it improved the voltage regulation [29].

Reliability evaluation and analysis using different approaches have been discussed above in review. In this thesis work both techniques, analytical and simulation approaches were applied and the results were compared with benchmarks. Having the indices are important for planning, design and maintenance purposes. After obtaining the reliability indices, reliability improvement measures have been applied in cost effective ways like keeping radiality of the network.

Chapter 3

Reliability Analysis of the Existing Distribution System

3.1. Data collection and Analysis of Hossana Distribution System

Using the collected data from the distribution substation (in Appendix A**)** is summarized in table 3.1 below. The three years monthly power interruption frequencies and interruption durations are plotted in figure 3.1 - figure 3.6 as shown below using data from table 3.1, 3.2 and 3.3.

Table 3. 1 Monthly Outage Frequencies and Durations of the three Feeders in 2013

Feeder	Month	J	F	M	A	M	J	J	A	S	O	N	D
Hos.	F	25	50	26	23	29	32	28	60	15	30	62	22
	D	25.99	112.9	36.53	63.45	43.61	61.2	35.51	47.22	21.11	20.98	55.98	67.78
Ang.	F	14	24	20	22	23	32	28	41	20	17	35	27
	D	4.91	28.6	60.9	53.56	60.18	47.02	19.77	100.1	101.8	41.23	28.51	54.65
Gim.	F	16	14	8	15	9	11	10	20	10	21	44	22
	D	18.05	21.5	9.5	22.92	14.47	5.79	6.82	27.02	18.4	12.02	20.7	28.39

Table 3. 2Monthly Outage Frequencies and Durations of the three Feeders in 2014

Feeder	Month	J	F	M	A	M	J	J	A	S	O	N	D
Hos.	F	30	48	46	25	35	26	21	35	8	32	110	76
	D	33.77	74.87	42.98	40.6	79.31	53.04	30.71	35.97	12.18	52.67	171.9	30.39
Ang.	F	20	30	33	26	34	30	16	21	10	39	48	42
	D	24.89	97.71	71.61	48.04	133.11	78.98	37.16	40.09	14.82	90.9	59.52	72.18
Gim.	F	32	43	25	25	31	8	12	16	5	26	29	48
	D	14.4	75.14	19.2	20.55	23.55	4.03	8.17	18.01	5.28	28.44	15.92	78.66

Table 3. 3 Monthly Outage Frequencies and Durations of the three Feeders in 2015

Feeder	Month	J	F	M	A	M	J	J	A	S	O	N	D
Hos.	F	33	27	28	32	35	45	31	42	49	110	76	40
	D	25.04	26.03	48.1	112.01	83.89	65.19	83.14	44.4	66.77	170.9	30.39	53.71
Ang.	F	25	27	23	32	25	24	21	25	36	48	42	32
	D	30	29.34	46.56	101.22	94.02	76.78	48.71	38.72	98.3	59.52	72.18	45.66
Gim.	F	11	16	28	27	22	29	29	22	34	29	48	29
	D	8.4	11.62	44.94	59.57	35.82	51.63	49.41	17.57	31.94	15.92	78.66	12.46

Where F= frequency of interruption in Number

D= Duration of interruption in Hours

LOL= line Overload

SOL= system overload

Outage Frequencies and Durations of the three feeders per Month of each year is plotted in each single chart as shown in fig 3.1 to 3.6 below to compare and see which feeder is interrupted mostly.

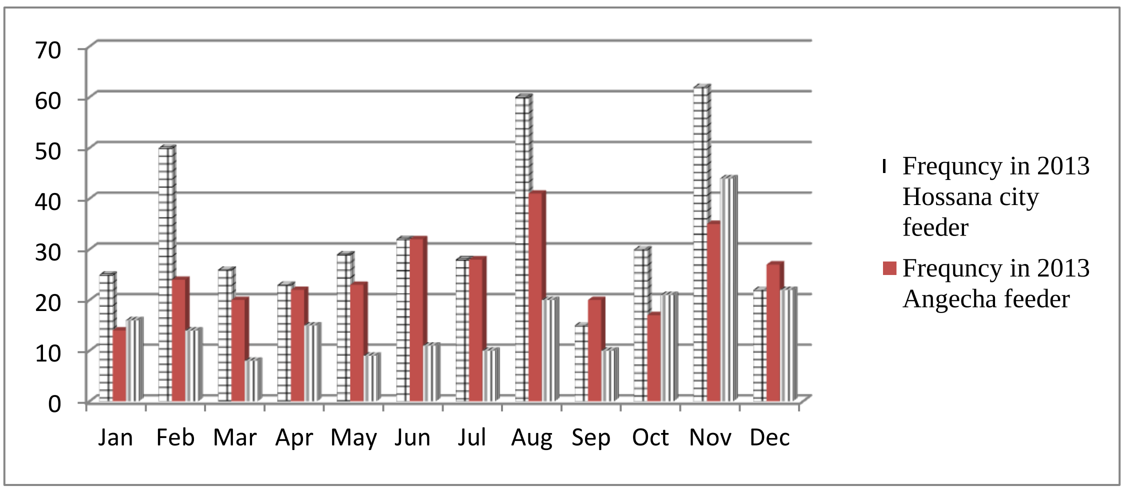

Figure 3. 1 Monthly Interruption Frequency of three feeders in 2013

The distribution system has experienced most outage in February, August and November months of the year 2013. The causative agents for the interruption were windy rain and operational cases. The most interrupting feeder among the three feeders was Hosanna city feeder and the highest frequency of interruption occurred in November due to operation (appendix A).

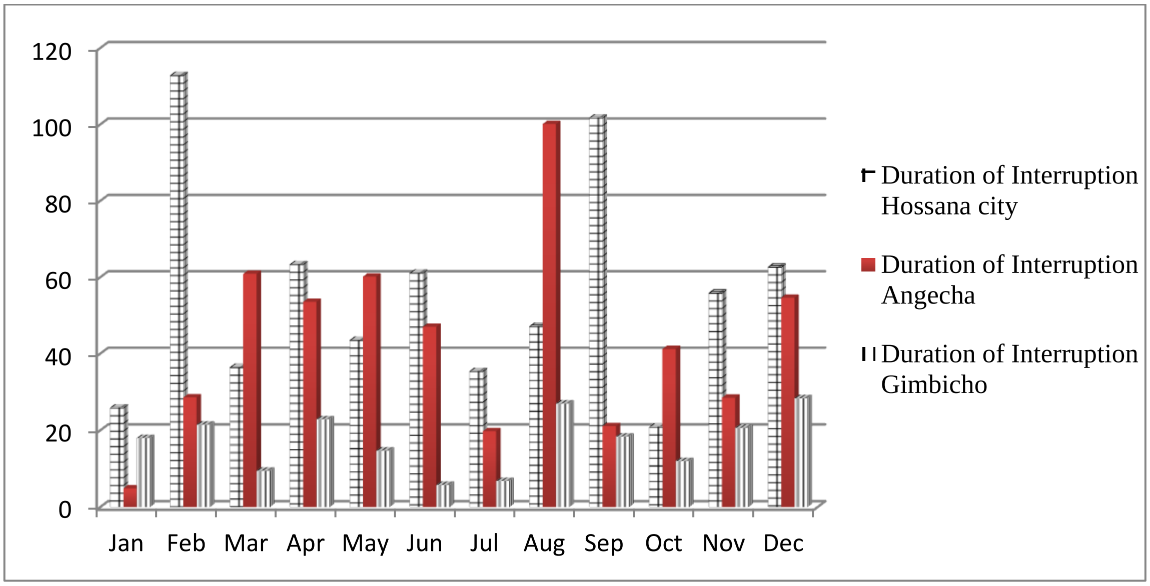

Figure 3. 2 Monthly Interruption Duration of the three feeders in 2013

As it is observed from figure 3-2 the feeder having longest interruption duration among the three feeders was Hosanna city feeder and the longest duration of interruption happened in February Month in 2013 (appendix A). Thus, the restoration time was longer.

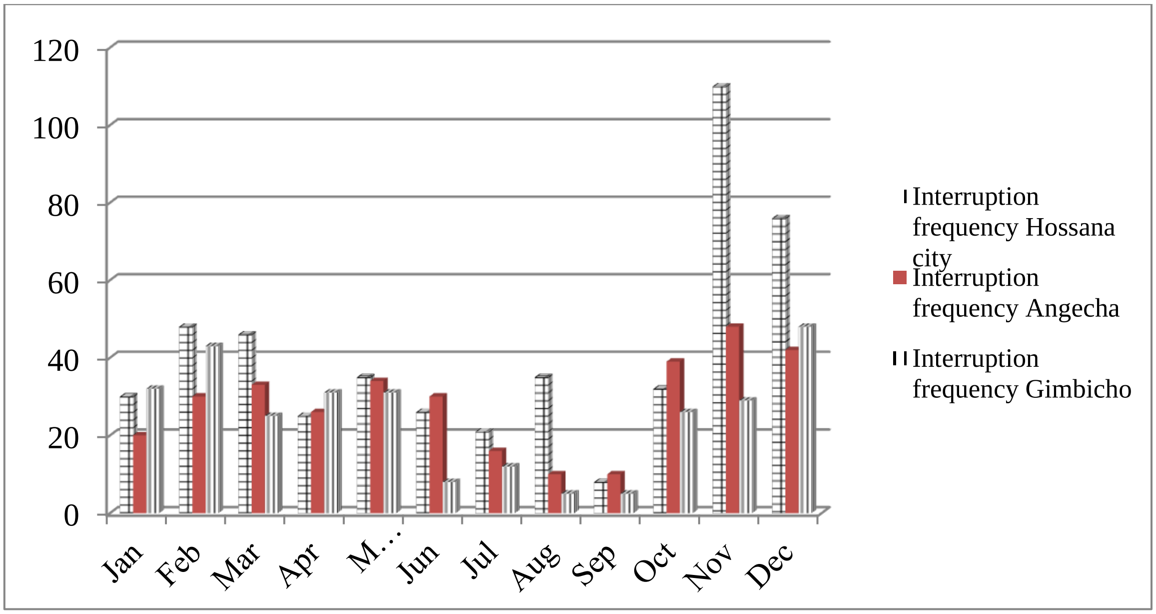

Figure 3. 3 Monthly Interruption Frequency of the three feeders in 2014

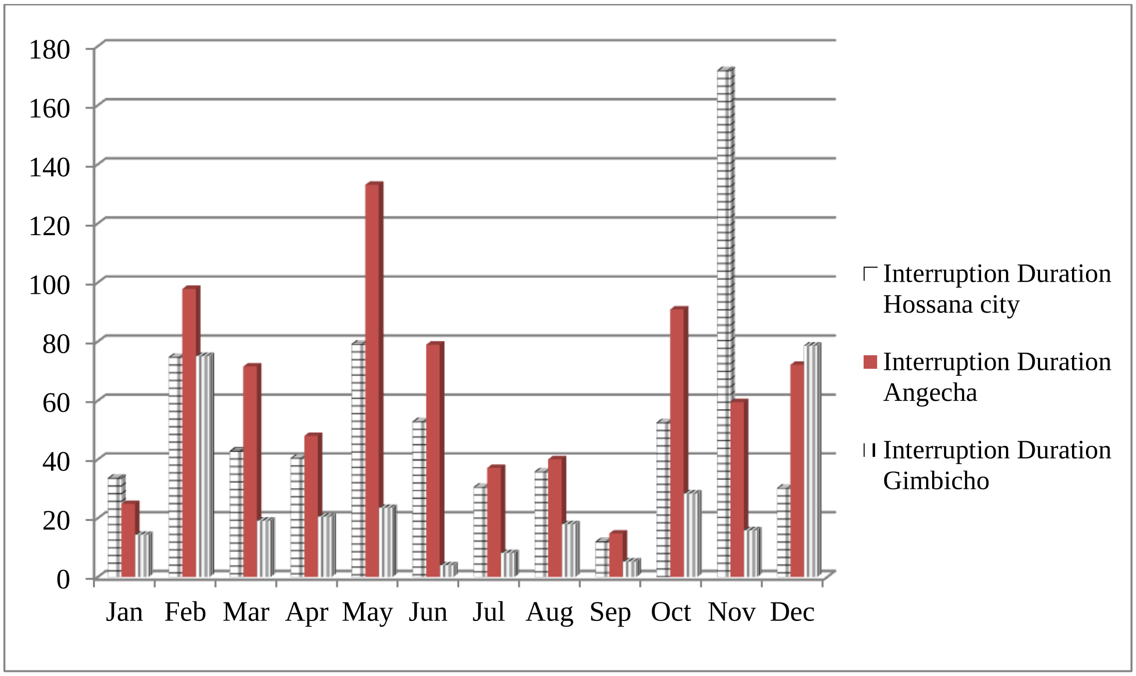

Figure 3. 4 Monthly Interruption Duration of the three feeders in 2014

From figures 3-3 - 3-4 it is seen that the highest outage frequency and longest outage duration occurred on Hossana city feeder in November month. The cause of outage in the month was temporary short circuit.

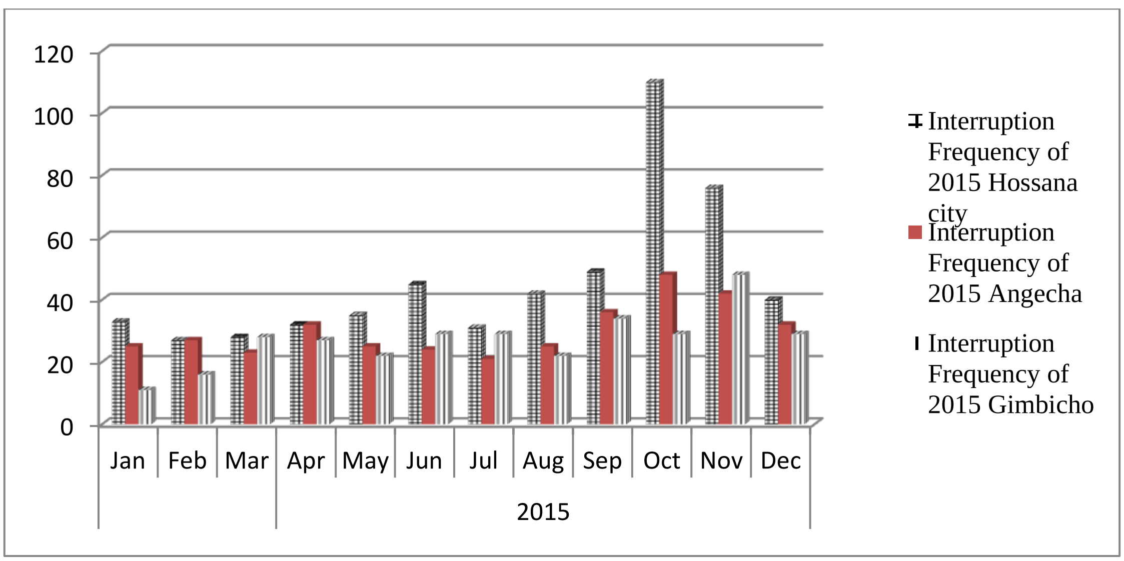

Figure 3. 5 Monthly Interruption Frequency of the three feeders in 2015

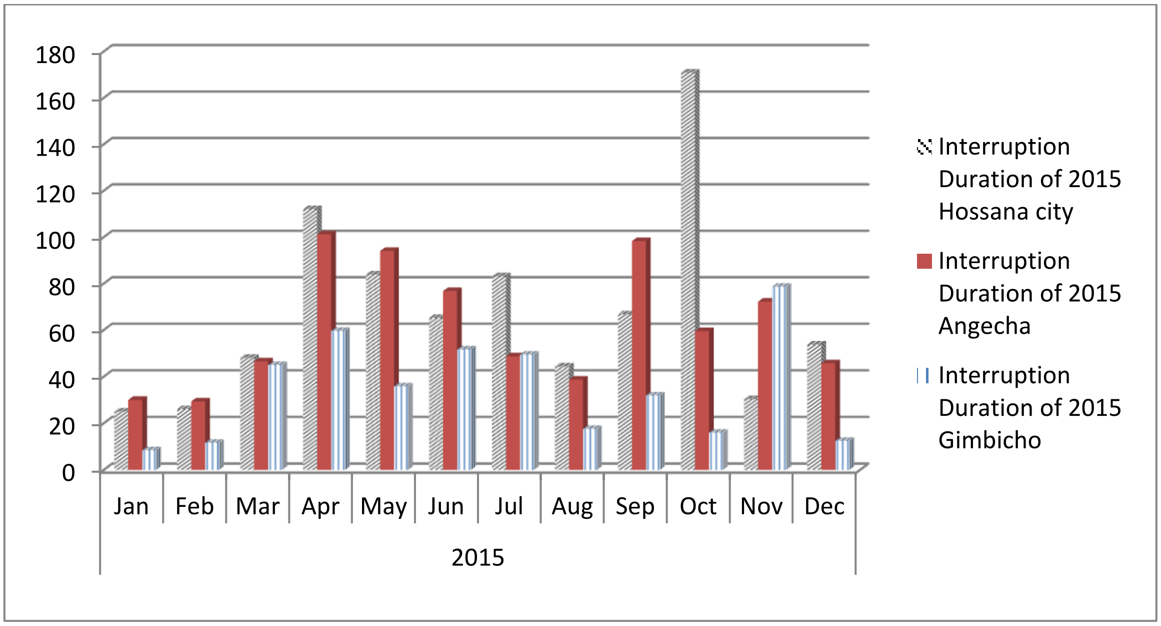

Figure 3. 6 Monthly Interruption Duration of the three feeders in 2015

As it can be seen from figure 3.1 - 3.6 and tables 3.1- 3.3 above, both interruption frequency and Duration in the three consecutive years are highest for Hossana city feeder among the three feeders of the study area. The main cause for the interruption was distribution faults as discussed in following part.

3.2. Types of Outages in Hossana Distribution Outgoing Feeders

An outage describes the state of a component when it is not available to perform its intended function due to some event directly associated with that component. Outages are generally classified as forced or scheduled depending on whether it results from tripping of the feeder or it is deliberately taken out of service. The outage can also be temporary or permanent based on its nature and duration of stay in state of outage.

Transient or Temporary Forced Outages: are outages for which the causes are not permanent. For instance, when a branch of tree touching the line as a result of windy air. The outage could be for less than 3 minutes. For such outages, the circuit breakers remain closed when relays are reset and lines reclosed.

Permanent Outage: This is an outage which lasts for more than 3 minutes before restoration. For such outages the circuit breakers are open during the period of outage. Example: breakdown of an overhead line due to tree falling on it.

In order to give special attention during planning, operation and design stages to start to improve reliability, it is good to identify which type of fault that occurs on the distribution system affect the reliability of the system more. By observing the data collected from each feeder and taking the total frequency and duration of outage for each type of fault per year of the Hossana Distribution system, numerical values are summarized in tables 3.4, 3.5 and 3.6 below.

Table 3. 4 Summary of feeders average Frequency and Duration of interruption for 2013

Feeder Name	Frequency and Duration of interruption										Total	
	E. Fault		Short Circuit		LOL		SOL		Operation		F tot	D total
	F	D	F	D	F	D	F	D	F	D		
Hos.	35	62.16	214	341.2	6	0	20	82.1	122	101.8	402	587.27
Ang.	24	24.98	129	314.8	12	6.71	20	98.87	113	159.8	297	605.24
Gim.	23	9.83	49	60.66	10	1.48	12	56.98	107	73.58	198	202.53
Total	82	96.97	392	716.7	28	8.19	52	237.95	342	195.2	897	1395.0

Table 3. 5 Summary of feeders average Frequency and Duration of interruption for 2014

Feeder Name	Frequency and Duration of interruption										Total	
	Earth Fault		Short Circuit		LOL		SOL		Operation		F total	D total
	F	D	F	D	F	D	F	D	F	D		
Hos.	78	76.18	62	345.43	6			142.9	196	88.52	380	655.39
Ang.	56	127.31	130	413.9	1	1.0	39	150.15	122	84.65	348	649.7
Gim.	37	62.9	62	120	22	9.3	13	41.24	164	81.07	298	314.51
Total	171	266.39	254	879.33	29	12.66	90	334.29	482	174.24	1026	1619.6

Table 3. 6 Summary of feeders average Frequency and Duration of interruption for 2015

Feeder Name	Frequency and Duration of interruption										Total	
	Earth Fault		Short Circuit		LOL		SOL		Operation		F	D
	F	D	F	D	F			D	F	D	F	D
Hos.	145	163.55	133	254.71	6	2.36	100	260.2	134	132.12	602	812.94
Ang.	83	155.86	103	269.35	0	0	59	220.91	84	94.89	359	741.01
Gim.	69	84.78	57	94.86	22	9.3	34	131.66	124	106.64	346	427.24
Total	297	404.19	293	618.92	28	11.66	193	612.77	342	333.65	1307	1981.19

Moreover, using table 3.1 above for the types of faults in the year 2013, the types of faults which have more effect on the reliability of the study area are identified and described in table 3.7 below.

Table 3. 7 Summary of types of faults and their effects on reliability of HDS

No.	Category of faults	Type of fault	F(No.)	D(Hrs)
1	Distribution faults	Earth Fault	82	96.97
		Short circuit	392	716.70
		Line over load (LOL)	28	8.19
Sub-total			**502**	**821.86**
2	Others	System over load (SOL)	52	237.95
		Operation	342	195.23
Sub-total			**394**	**433.18**
Overall			**896**	**1255.04**
% distribution fault			56.03%	65.48%
% others			43.97%	34.52%

As it is observed from the table above most of the faults (F=56.03% and D=65.48%) are due to distribution faults. That means due to Earth fault, Short circuit and line overload. The remaining (F=43.97% and D=34.52%) faults are due to system overload and operational faults. Thus, the utility of the study area should pay special attention for minimizing the distribution faults due to short circuit, Earth faults and line overloads.

3.3. Major Causes of Interruptions in the Existing Distribution System

In order to improve reliability, it is important to know the most contributing factors to the power outage in the system. From historical data and oral interviews of the maintenance team of the Hossana distribution substation the most contributing agents of power outage are windy rain resulting to short circuits, maintenance, component failure due to aging, vegetation and animal contact. Loose connections and poor insulations caused the component to be failed by windy rain. As identified above in part 3.2, most of the faults are distribution faults like Earth fault, Short circuit and line overload and others as system overloading and operational. Thus, the study area distribution system reliability can be improved by reducing both frequency and duration of the distribution faults. The main strategy to improve reliability and power quality to customers are to eliminate faults as fast as possible and then to minimize the effect of faults on customers even if it occurs.

Among the general strategies to reduce power interruption of Hossana distribution system so as to improve reliability the following are basic ones. They are [8], [13]:

- Substitution of aged distribution equipment with equivalent newer ones
- Replacement of the equipment with high failure rates by others having low failure rates
- Increasing the number of maintenance staff
- Periodical evaluation of the performance of components:
    - To identify problematic components in the system that can impact reliability
    - To predict the reliability performance of the system after any expansion and quantify any impact of adding new components to the system.
- Distribution system automation and Feeder reconfiguration
- Performing tree trimming along the right-of-way for overhead lines
- Installing animal guards on distribution circuits
- Installation of lightning arresters,
- Replace insulated cable instead of bare conductor
- Insulation cover at bushing , Drop out fuse

3.4. Reliability Indices Evaluation of the Existing System for the study area

The Distribution Reliability indices help utility engineers and managers at electric utility organizations to decide how to spend the money to improve reliability of the system by identifying the most effective actions like feeder reconfigurations.

The availability of power for customers from this substation is performed on the medium voltage side of the customer transformers (15kV). Although the reliability of distribution system is highly affected by outages that occur on the customer side/ secondary distribution lines, it is not possible to collect data for analysis due to lack of resource, organized data and advanced technology at the substation to view the performance of the customer side secondary distribution network.

The frequency and duration of interruption of each feeder for the years 2013, 2014 and 2015 are summarized in tables 3.8, 3.9 and 3.10, respectively. The interruption of each feeder is recorded when the outgoing circuit breaker is open and all customers connected to the respective feeder are de-energized. The other interruptions such as those occurred at each load point of transformer and service lines of customers are not included due to lack of data recorded and unavailability of advanced technology to record data.

Table 3. 8 Total outage frequency and outage duration of feeders in 2013

Feeder Name	Outage frequency (No./yr)		Outage duration(hrs/yr)		No. of Customers Connected
	Perm.	Temp.	Perm.	Temp.	
Hossana	168	75	395.84	7.62	8110
Angecha	109	32	336.97	2.88	5540
Gimbicho	42	14	69.05	1.35	5720

Table 3. 9 Total outage frequency and outage duration of feeders in 2014

Feeder Name	Outage frequency (No./year)		Outage duration (hrs/year)		No. of Customers Connected
	Perm.	Temp.	Perm.	Temp.	
Hossana	176	76	412.23	9.36	8613
Angecha	143	43	529.33	4.88	5690
Gimbicho	75	28	179.76	3.14	6740

Table 3. 10 Total outage frequency and outage duration of feeders in 2015

Feeder Name	Outage frequency (No./ year)		Outage duration (hrs/ year)		No. of Customers Connected
	Perm.	Temp.	Perm.	Temp.	
Hossana	195	186	410.2	13.45	8770
Angecha	135	88	401.43	23.78	6050
Gimbicho	95	31	164.01	15.63	6875

The permanent average power outage frequency and duration of the feeders in 2013, 2014 and 2015 are used to evaluate reliability indices. The reliability indices for each feeder are calculated using formulas (2.1-2.9) in chapter two above and summarized in table 3.11 below.

Table 3. 11 Summary of Reliability indices for each Feeder from 2013 to 2015

Feeder Name	Index	Year		
		2013	2014	2015
Gimbicho	SAIFI (inter./year)	42	75	95
	SAIDI (Hour/year)	69.05	179.76	164.01
	CAIDI (hour/inter.)	1.64	2.4	1.73
	ASAI (%)	99.21	97.95	98.13
	EENS (MWh/year)	2,593.52	8,089.20	9,496.18
	Cost of EENS(Birr/yr)	7625736	4853520	5697708

Feeder Name	Index	Year		
		2013	2014	2015
Angecha	SAIFI (inter./year	109	143	135
	SAIDI (Hour/year)	336.97	529.33	401.43
	CAIDI (hour/inter.)	3.09	3.7	2.97
	ASAI (%)	96.15	93.96	95.42
	EENS (MWh/year)	9,138.63	13,603.8	10,116.04
	Cost of EENS (Birr/YR)	5483178	8162280	6069624
Hossana	SAIFI (inter./year	168	176	195
	SAIDI (Hour/year)	395.84	412.23	403.8
	CAIDI (hour/inter.)	2.354	2.342	2.103
	ASAI (%)	95.48	95.29	95.31
	EENS (MWh/year)	14883.58	18576.47	23750.58
	Cost of EENS(Birr/yr)	8,930150.4	11,145,882	14,250,348

3.5. 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. A benchmark of SAIFI, SAIDI, CAIDI and ASAI for nine countries is shown in Table 3.12.

Different utilities typically keep track of customer reliability by using reliability indices. These are average customer reliability values for a specific area. The result shown in table 4.11 is calculated based on data of feeder's service area. A lower number for SAIDI, SAIFI and CAIDI value indicates better reliability performance; i.e., a lower frequency of outages or shorter outage duration. Higher values of SAIFI, SAIDI and CAIDI indicate worse performance.

The System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) are the main indicators for the performance of power networks. From the result summarized in table 3.11 the value of SAIFI and SAIDI are extremely higher than the benchmark values for different countries. In addition to that, it is clear that SAIFI and SAIDI are increasing from year to year. Customer Average Interruption Duration Index (CAIDI) is an indication of repair time of the faults caused for interruption. That means the number of failure outages is very high and takes long time to repair the system. On the other hand, the availability of power (ASAI) has been reducing as seen above; for example it was 95.48% in 2013 and reduced to 95.31% in 2015 for Hossana city feeder. As seen from table 3.12, Hossana Distribution system has deviations from benchmark /standard values of the reliability indices. For example in the year 2003, ASAI value of US was 99.91% whereas it was 95.29% for Hossana City feeder in 2014. The deviation was 4.62%. Similarly, the deviation from Germany's ASAI value is 4.7099%.

Table 3. 12 Benchmark of SAIDI, SAIFI, CAIDI and ASAI for nine countries [7]

No.	Country	SAIFI(Int./Customer)	SAIDI (Min./year)	CAIDI (Min./outage)	ASAI (%)
1	United States	1.5	240	123	99.91
2	Austria	0.9	72	112	99.97
3	Denmark	0.5	24	70	99.981
4	France	1	62	58	99.97
5	Germany	0.5	23	50	99.9999
6	Italy	2.2	58	106	99.9991
7	Netherlands	0.3	33	75	99.97
8	Spain	2.2	104	114	99.968
9	UK	0.8	90	100	99.964
10	AA, Ethiopia, 2014	43.8(int./yr)	3024	2280	99.425
11	Hossana city feeder, Ethiopia, 2014	176 (int./yr)	24,733.8	140.52	95.29

Though a typical customer expects to have power at all time (100% availability), in reality, a utility is able to make power available between 99.9 and 99.999% of the time. For instance, in America average customers may be dissatisfied if he/she is without electricity for more than 53 minutes per year [7]. However, the Average System Availability Index (ASAI) was 95.48%, 95.29% and 95.31%, for years 2013, 2014 and 2015, respectively for the Hossana distribution system. Moreover, the ASAI value of one of the local city, Addis Ababa was 99.425% in the year 2014 [21]. The deviation from the standard utility range (in 2012) is about 0.574% whereas the deviation from the standard utility range for Hossana city feeder is 4.709% in 2014. The costumers lost electricity for 50.31 hours per year in 2014 in Addis Ababa. But, the customers of Hossana city lost electricity for 412.5084 hours per year or 24768.504 minutes per year in the same year.

The reliability indices of the study area should be compared with the reliability benchmarks so as to be in conformity with standard-driven reliability values regardless of the expectations and perceptions of the customers. In general, the comparison of reliability indices values of the study area feeder with the benchmarks shows that the study area has worse performance and less/not reliable as stated in the problem statement.

3.6. Customers cost paid to prevent power interruption in the study area

Table 3. 13 Electricity tariff of Ethiopian Electric Power Corporation (EEPCO) [32]

Customers	Monthly consumption(kWh)	Price Rate (Birr/kWh)
Residential	0-50	0.2730
	51-100	0.3564
	101-200	0.4993
	201-300	0.5500
	301-400	0.5666
	401-500	0.5880
	Above 500	0.6943
Commercial	0-50	0.6088
	Above 50	0.6943
Industrial (15 kV)		0.4086
Industrial (132kV)		0.42

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

$$EENS = Peakload * time \tag{4.1}$$

$$\text{Cost of EENS} = \text{Peak load} * \text{time} * \frac{\text{cost}}{\text{kWh}} \tag{4.2}$$

Where EENS = Expected Energy Not Served

Taking an average price of 0.6 Birr per kWh for the electricity according to EEPCO, the average energy not supplied and average cost of energy not supplied due to power interruption per year for each outgoing feeder of Hossana Distribution system (HDS) are calculated using the above equations **(**3.1**)** and **(**3.2) and tabulated in table below:

Table 3. 14 Summary of total load and outage duration of the three feeders

No.	Name of Feeder	Peak Load (MW)			Time of outage (Hr.)		
		2013	2014	2015	2013	2014	2015
1	Hossana	37.6	45.5	57.9	395.84	412.23	410.2
2	Angecha	27.1	25.9	25.2	336.97	529.33	401.43
3	Gimbicho	22.1	25.9	26.3	69.05	179.33	164.01

Where - Peak load = the total peak load per year

- Time of outage = total time of power interruption per year in this Thesis.

Using values in table 3.14, we can get the values of EENS and Cost of EENS for each Feeder per year as shown in table below.

As explained the most interrupting feeder among the three feeders of Hossana 15kV distribution was Hossana city feeder. That means its outage cost also accounts highest in the three consecutive years, 2013 to 2015 as observed in table 3.15 below.

Table 3. 15 Expected energy Not Supplied and cost due to EENS per each feeder

No	Name of Feeder	EENS (MWh)			Cost of EENS (USD/year)		
		2013	2014	2015	2013	2014	2015
1	Hossana	14883.58	18756.47	23750.58	330746.311	411995.518	527790.67
2	Angech	9,138.63	13,603.78	10,116.04	203080.59	302306.25	224800.8
3	Gimbich	1282.905	4644.647	4313.463	33911.12	103214.38	95854.74

Chapter Four

Simulation, Result and Discussion

4.1. Simulation

4.1.1. Evaluation of Reliability Indices Using Monte Carlo Simulation Method

Both expected values and probability distribution of the indices are analyzed using sequential Monte Carlo Simulation technique. For all figures obtained from TSMCS:
X-axis represents expected value of the index and Y-axis represents the probability distribution (cumulative distribution) of the reliability index.

The basic parameters needed to evaluate the indices are TTF and TTR that are generated from a uniform random number generator. For this study 1000 iterations have been carried out in order to simulate both load point and system indices. The following figures show the probability distribution of reliability indices in 2013. The figures for 2014 and 2015 are found at appendix C**.**

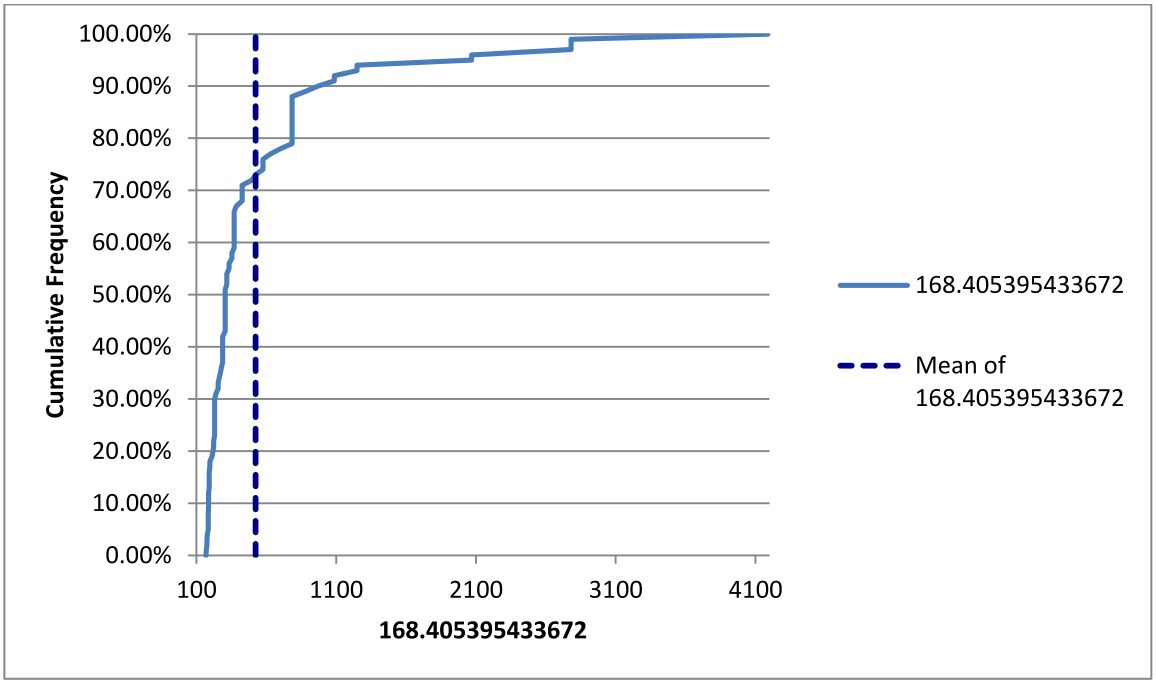

Figure4. 1 Cumulative Distribution of SAIFI value for the year 2013

As it has been observed from figure 4.1 the expected value of SAIFI in 2013 is 168 interruptions / year. And its simulated value was 168.405 interruption / year when it is observed from probability distribution. The error between them is 0.24% only. On the other hand, from the plot of figure 4-2, it is observed that a SAIDI value of 396.529 interruptions/customer/year occurred on average during 2013. Whereas analytically obtained value of SAIDI was 395 interruptions per customer per year. Similarly, the percent error in between the two results is only 0.386%. Thus, the analytically evaluated indices are almost the same as those simulated values.

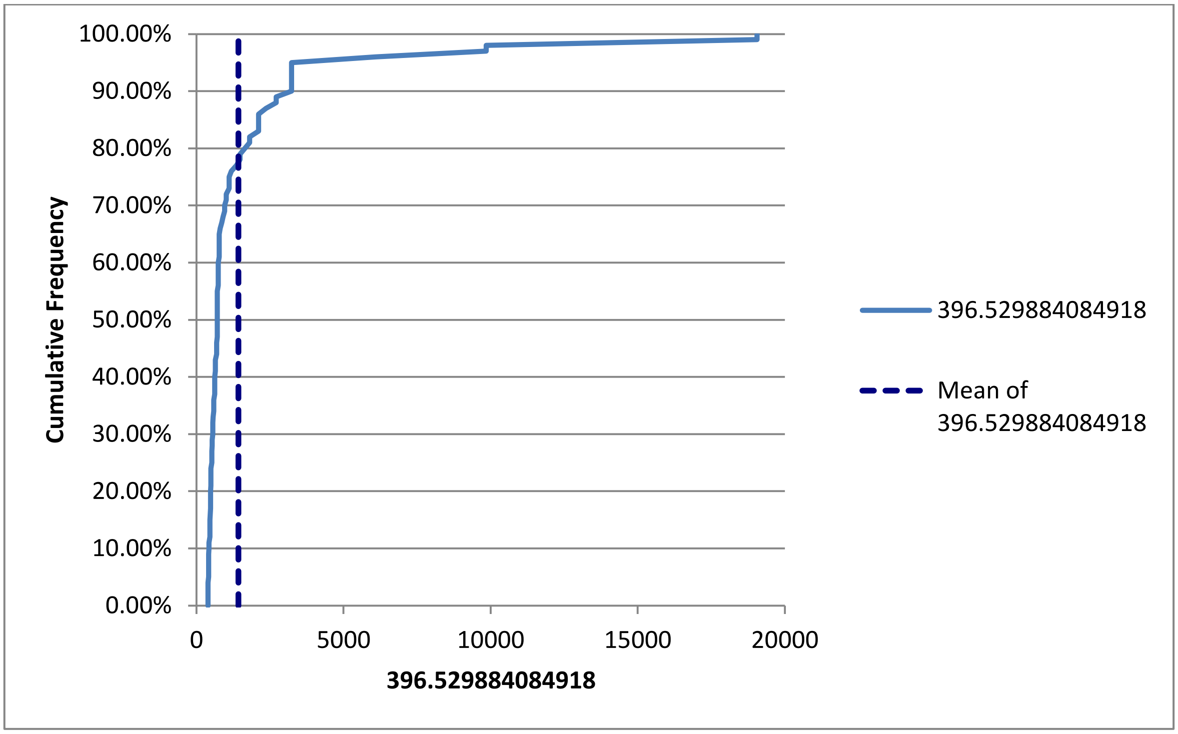

Figure4. 2 Cumulative Distribution of SAIDI value for the year 2013

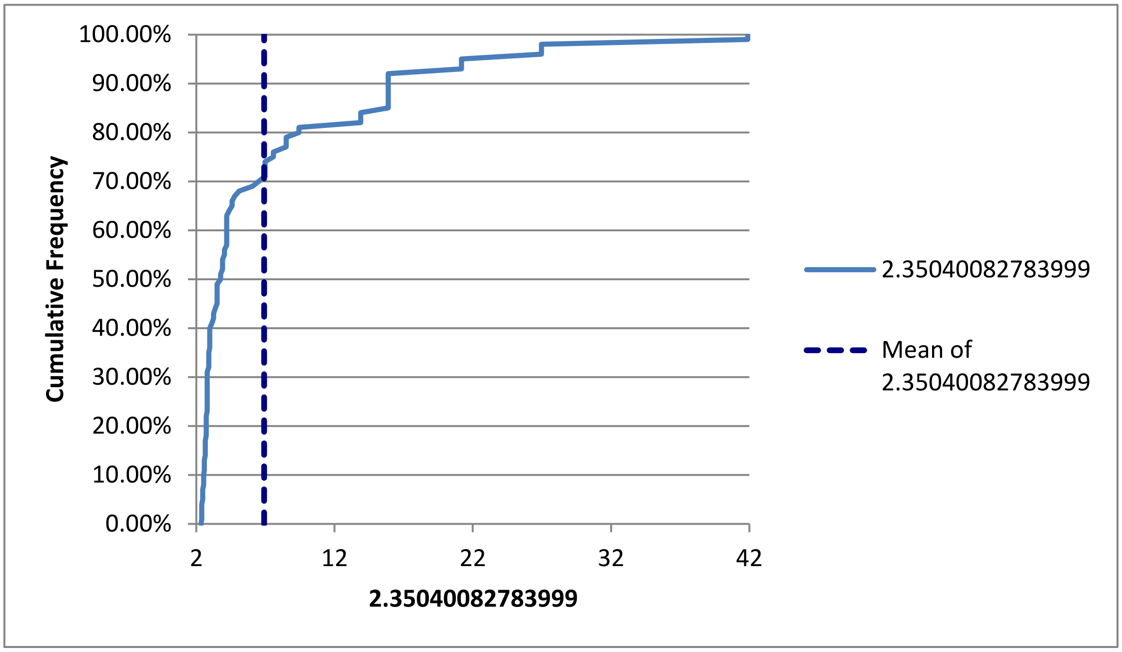

Figure4. 3 Cumulative Distribution of CAIDI value for the year 2013

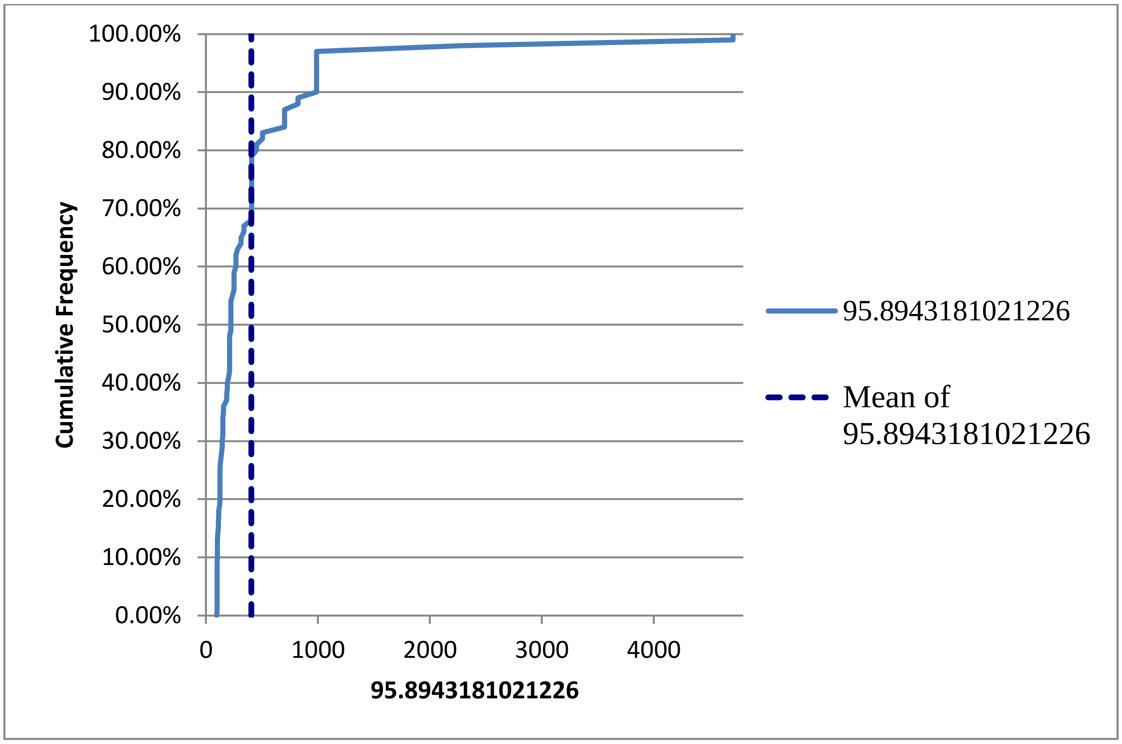

Figure4. 4 Cumulative Distribution of ASAI value for the year 2013

4.1.2. Comparison between Analytical results And Monte Carlo Simulation

Table 4. 1 Comparison between analytical and Simulation results

Indices	Analytical result			Simulation Result		
	2013	2014	2015	2013	2014	2015
SAIFI	168	176	195	168.405	179.85	193.73
SAIDI	395.84	412.23	403.8	396.529	409.884	403.288
CAIDI	2.36	2.34	2.07	2.350	2.346	2.058
ASAI	95.48	95.29	95.39	95.894	95.265	95.388

As it can be observed from table 4.1, the analytical and simulated values of the indices are almost the same because the |% error| between respective indices is less than 5%.

4.1.3. Design improvement of Hossana Power distribution system Reliability

It has been analyzed that the Hossana city feeder of Hossana distribution system, which has serving 8613 customers, was highly unreliable. At the beginning of feeder line, the main feeder line is divided into three primary feeder lines. There are no automatic re-closers and only have 5 sectionalizing switches for the entire line feeder of the city. Fuses are connected after distribution transformers which are near to customers. The insufficiency of protective devices in the feeder line is one of the causes for the unreliability of the feeder. Having such unreliability problem in the city, redesigning of the network by feeder reconfiguration is one solution in this thesis work to improve reliability of the specified feeder (GMF).

4.1.3.1. Feeder Reconfiguration using ETAP Software

Poor availability and reliability are key factors which force the utilities and distribution companies to implement some initiatives such as FR to improve the system performance. Hossana city, Goffer Meda outgoing feeder 16-bus system is modeled using ETAP 12.6. Transmission lines are modeled as Nominal Pi model. Loads are assumed as lumped power loads. Distribution system is Radial in Nature and hence current/power flow is unidirectional from source to load. Failure/loss of any component results in power outage for downstream. Voltage profile degrades from source towards load centers. Current increases from load to source towards source.

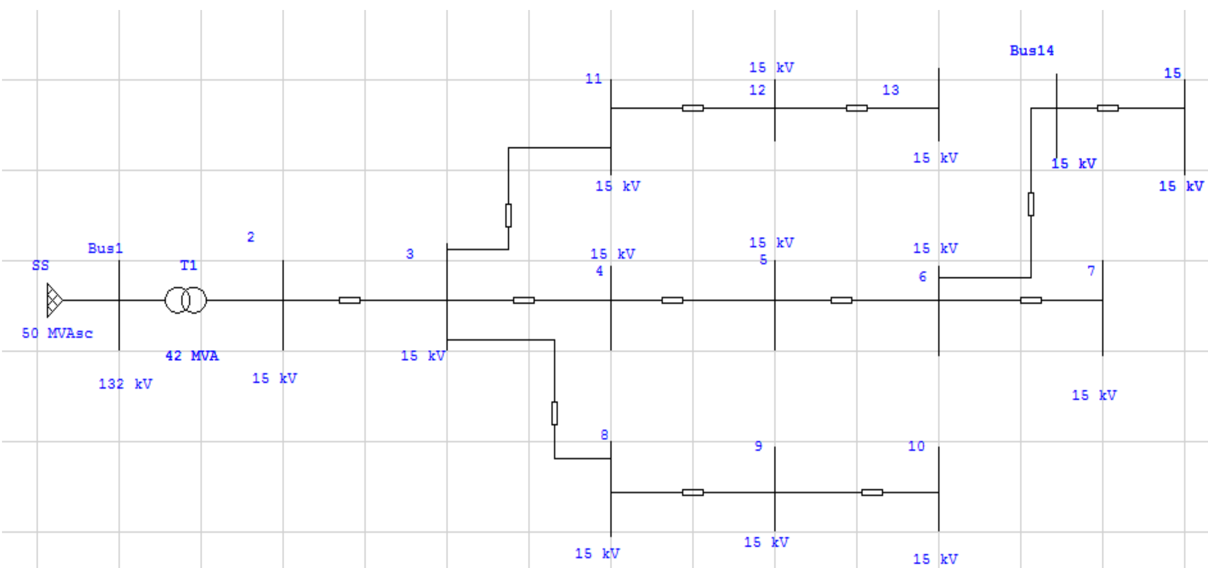

Figure4. 5 Single Line Diagram of existing GMF-16 bus system configuration

The ETAP load flow analysis Module calculates the bus voltages, branch power factors, currents and power flows throughout the electrical system. ETAP allows for swing, voltage regulated and unregulated power sources with multiple power grids and generator connections. It is capable of performing analysis on both radial and loop systems. The data for the equipment loading of each branch for the base case (of Hossana, Goffer Meda outgoing feeder 16-bus system) is given in table 4.2 below.

Table 4. 2 Bus and load data of GMF16-bus system for simulation calculated by ETAP

Bus ID	V (kV)	Load (kVA)
1	15	0
2	15	0
3	15	0
4	15	25
5	15	20
6	15	11
7	15	18
8	15	18
Bus ID	V (kV)	Load (kVA)
9	15	10
10	15	30
11	15	30
12	15	12
13	15	20
14	15	18
15	15	11
16	15	20

Table 4. 3 Branch data of GMF16-bus system for simulation calculated using ETAP software.

CKT/Branch		Connected bus ID		% impedance, pos. seq. , 100MVA base			
ID	Type	From bus	To bus	R	X	Z	Y
T	2wxFMR	1	2	1.93	35.95	36	0
L1	Line	3	2	40.83	31.03	51.28	0.0014402
L2	Line	4	3	40.83	31.03	51.29	0.0014402

CKT/Branch		Connected bus ID		% impedance, pos. seq. , 100MVA base			
ID	Type	From bus	To bus	R	X	Z	Y
L3	Line	5	4	40.83	32.58	52.24	0.0013654
L4	Line	6	5	40.83	32.58	52.24	0.0013654
L5	Line	6	7	40.83	32.58	52.24	0.0013654
L6	Line	3	8	40.83	31.03	51.28	0.0014402
CKT/Branch		Connected bus ID		% impedance, pos. seq. , 100MVA base			
ID	Type	From bus	To bus	R	X	Z	Y
L7	Line	9	8	40.83	32.58	52.24	0.0013654
L8	Line	10	9	40.83	31.03	51.28	0.0014402
L9	Line	11	3	40.83	31.03	51.28	0.0014402
L10	Line	12	11	40.83	32.58	52.24	0.0013654
L11	Line	13	12	40.83	32.58	52.24	0.0013654
L12	Line	14	6	40.83	31.03	51.28	0.0014402
L13	Line	15	14	40.83	32.58	52.24	0.0013654
L14	Line	16	15	40.83	31.03	51.28	0.0014402

The single line diagram for the base case (radial configuration) is given below

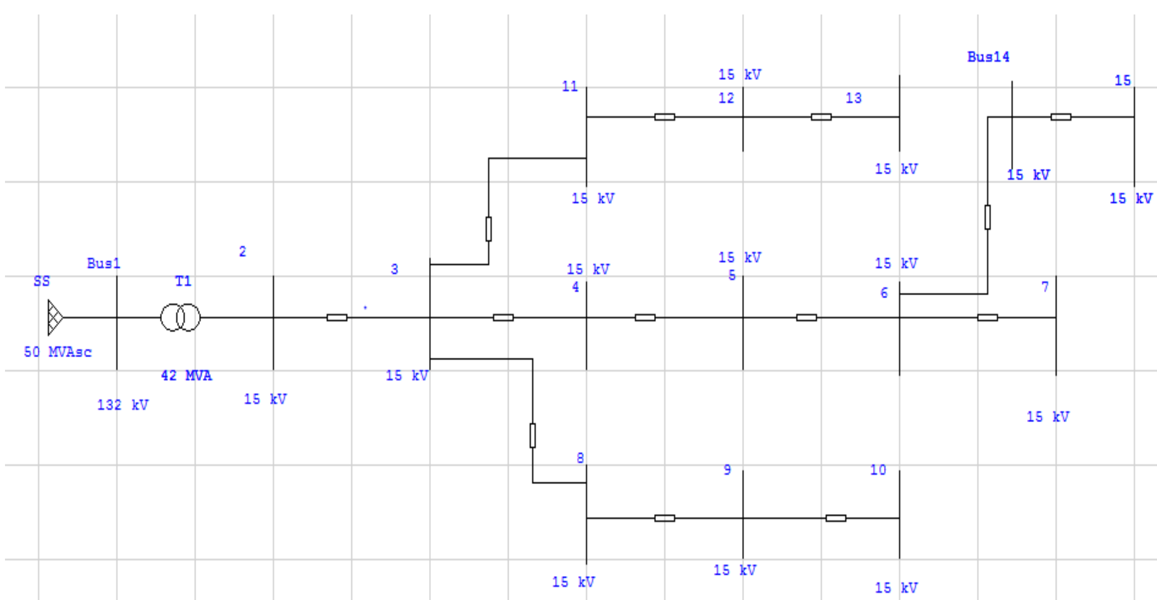

Figure4. 6 Single line diagram of GMF-16 bus radial configuration (base case)

4.1.3.2. Simulation result: Load Flow Report

Table 4.4 General information after LF by ETAP

Element	Value after LF
Buses	15
Branches	14
Generators	0
Power Grids	1
Loads	12
Load-MW	0.189
Load-Mvar	0.102
Generation-MW	0.189
Generation-Mvar	0.102
Loss-MW	0
Loss-Mvar	-0.015
Mismatch-MW	0
Mismatch-Mvar	0

Table 4. 5 Source information

ID	Rating	Rated kV	MW	Mvar	Amp	%PF
SS	50 MVA	132	0.189	0.102	0.942	88.01

Table 4. 6 Bus information

Bus ID	Nominal kV	MW Loading
2	15	0.189
3	15	0.189
4	15	0.087
5	15	0.066
6	15	0.049
7	15	0.015
8	15	0.049
9	15	0.034
10	15	0.025
11	15	0.053
12	15	0.027
13	15	0.017
14	15	0.025
15	15	0.009

Table 4. 7 Branch information

ID	Type	MW Flow	Mvar Flow	Amp Flow
Line1	Line	0.189	0.103	8.309
Line2	Line	0.087	0.048	3.852
Line3	Line	0.066	0.036	2.913
Line4	Line	0.049	0.027	2.166
Line5	Line	0.015	0.009	0.693
Line6	Line	0.049	0.028	2.181
Line7	Line	0.034	0.02	1.512
Line8	Line	0.025	0.016	1.155
Line9	Line	0.053	0.03	2.345
Line10	Line	0.027	0.016	1.21
Line11	Line	0.017	0.011	0.771
Line12	Line	0.025	0.014	1.094
Line13	Line	0.009	0.006	0.423
T1	Transf. 2W	0.189	0.102	0.942

Table 4. 8 Load information

ID	Rating kVA	Rated kV	kW	Kvar	Amp	% PF	% Loading	V termal	
								in kV	in %
Lo1	30	15	25.486	15.795	1.156	85	100.1	14.979	99.86
Lo2	12	15	10.193	6.317	0.462	85	100.1	14.975	99.83
Lo3	20	15	16.988	10.528	0.771	85	100.1	14.973	99.82
Lo4	25	15	21.218	13.15	0.962	85	100	14.978	99.85
Lo5	20	15	16.97	10.517	0.77	85	100	14.973	99.82
Lo6	11	15	9.331	5.783	0.423	85	100	14.97	99.8
Lo7	18	15	15.267	9.461	0.693	85	100	14.967	99.78
Lo9	18	15	15.279	9.469	0.693	85	100	14.979	99.86
Lo10	10	15	8.495	5.265	0.385	85	100.1	14.978	99.85
Lo11	30	15	25.461	15.779	1.155	85	100	14.977	99.85
Lo12	18	15	15.266	9.461	0.693	85	100	14.967	99.78
Lo13	11	15	9.329	5.782	0.423	85	100		99.78

As discussed in chapter two above, most distribution systems (low voltage distribution systems) are radial in nature because of their low cost and simple design. They are configured radially with manual or automatic switching operations so that all of the loads are supplied. A radial system consists of a series of components between the substation and the load points. Although the configuration is expected to reduce power loss, increase system security and enhance power quality and reliability, failure of any of the series component in the radial configuration may result in outage at the load point(s). The duration of the outage depends on the protection and sectionalizing schemes used in the distribution system.

Case 1: Before FR of the Radial configuration

i. Active and Reactive Power flow

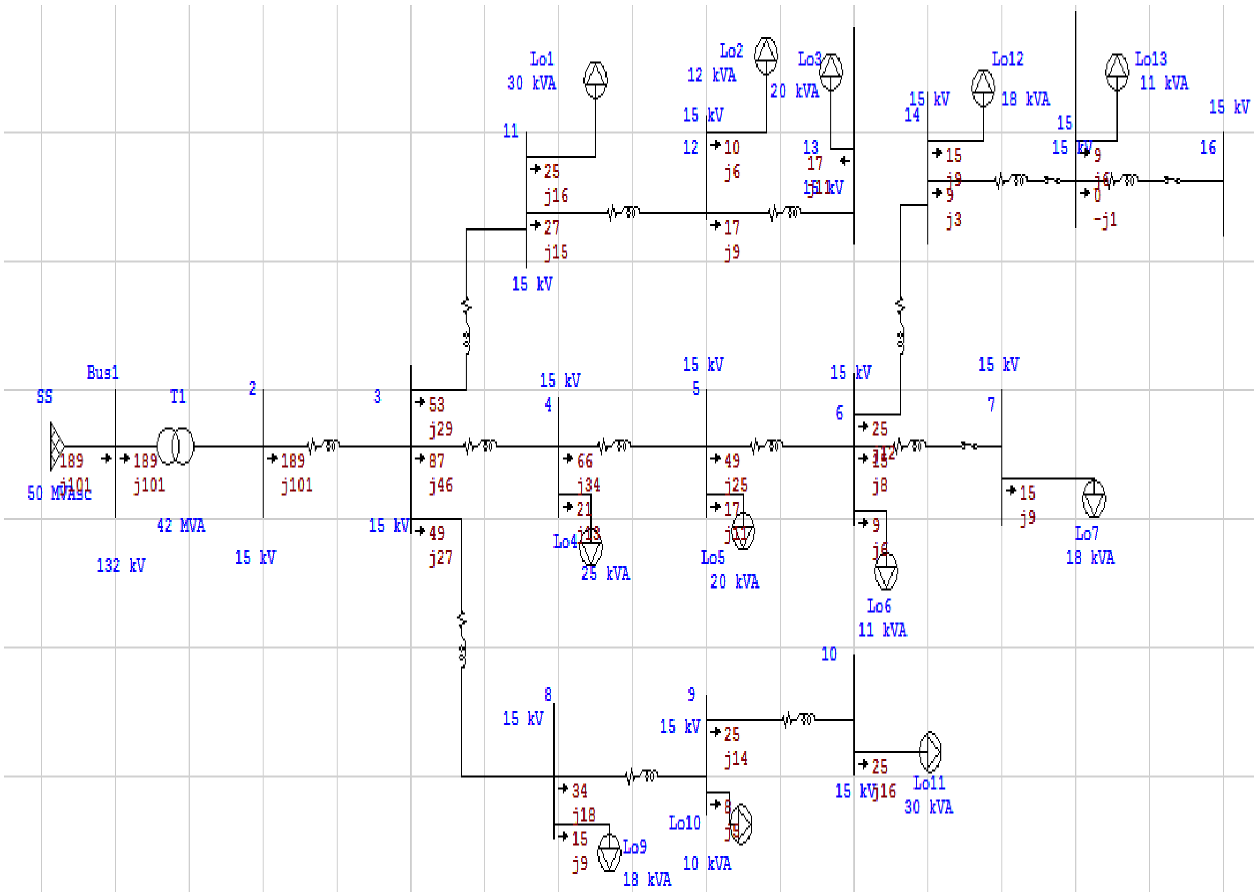

Figure4. 7 Power flow for base case (redial configuration)

ii. Current through each branch

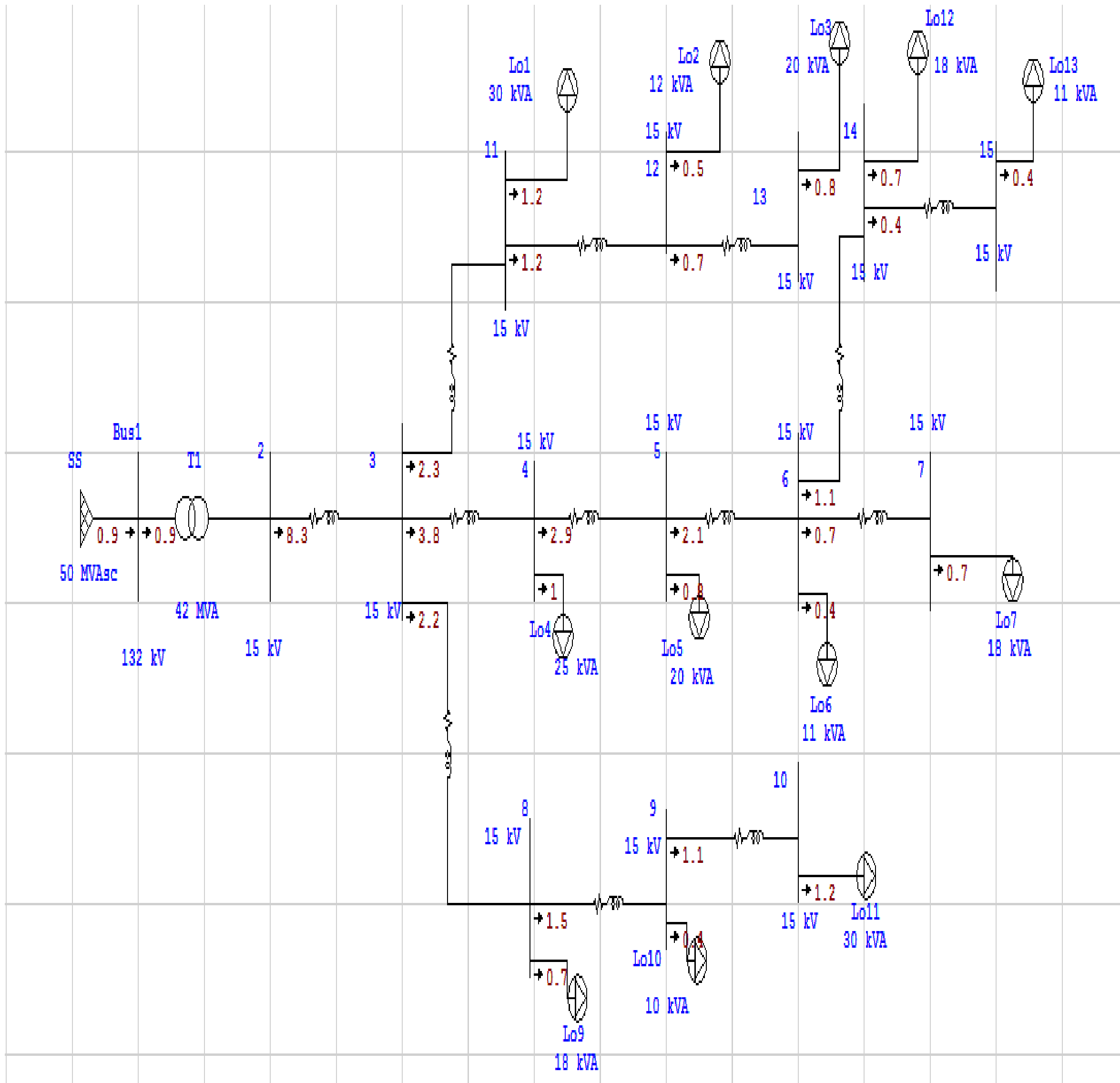

Figure4. 8 current through each branch for base case

iii. Magnitude of Voltage of each bus and active power flowing to each branch

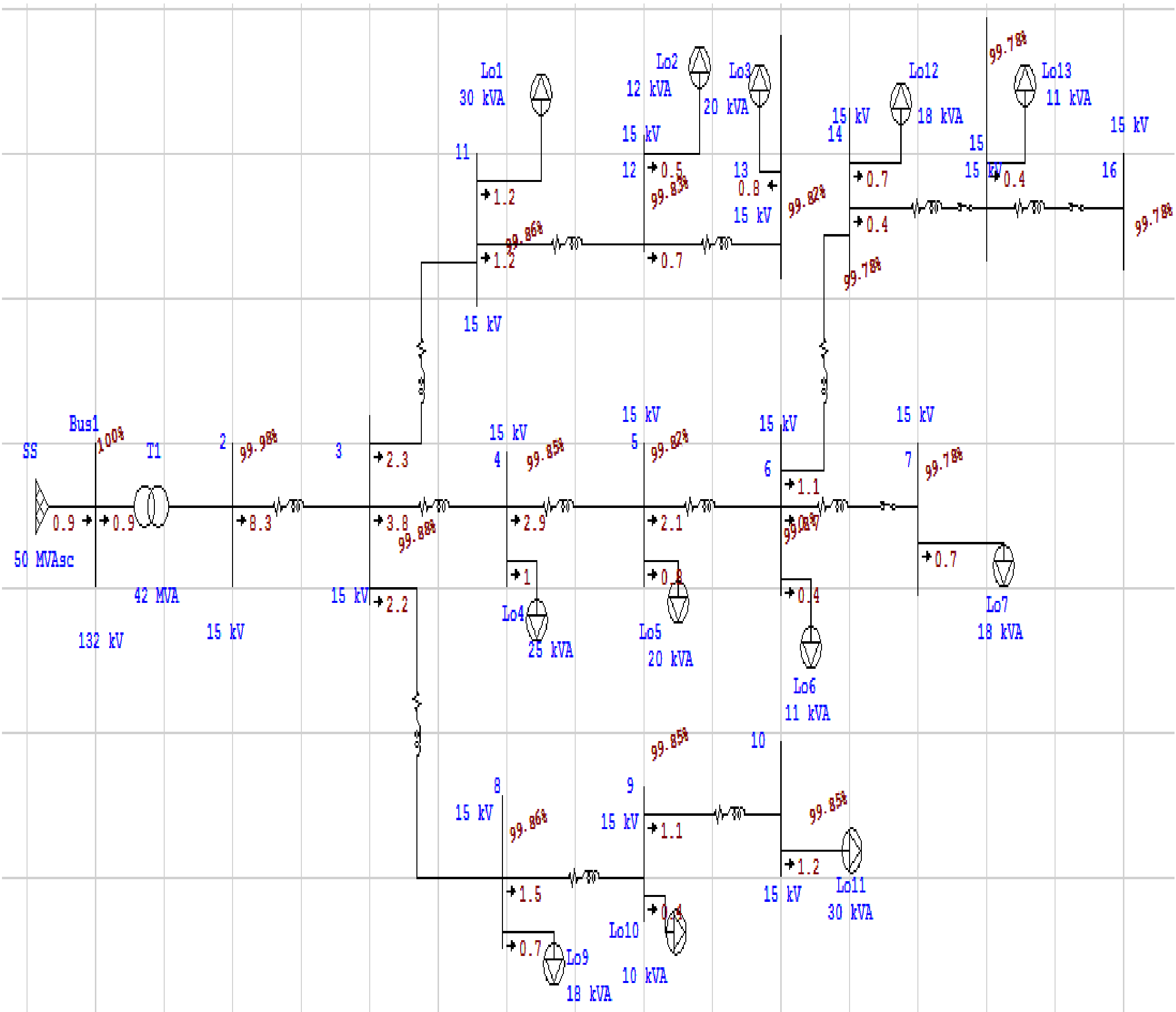

Figure4. 9 Voltage magnitude of each bus

Case 2: Meshed configuration

This meshed configuration is important to obtain the sectionalizing switch having minimum current value after running load flow so as to open it. Optimization techniques so called exhaustive search techniques are needed to search the optimal switching scheme. Current flowing through each branch for Meshed configuration so as to obtain optimum point for placing Tie Switches is shown in figure below.

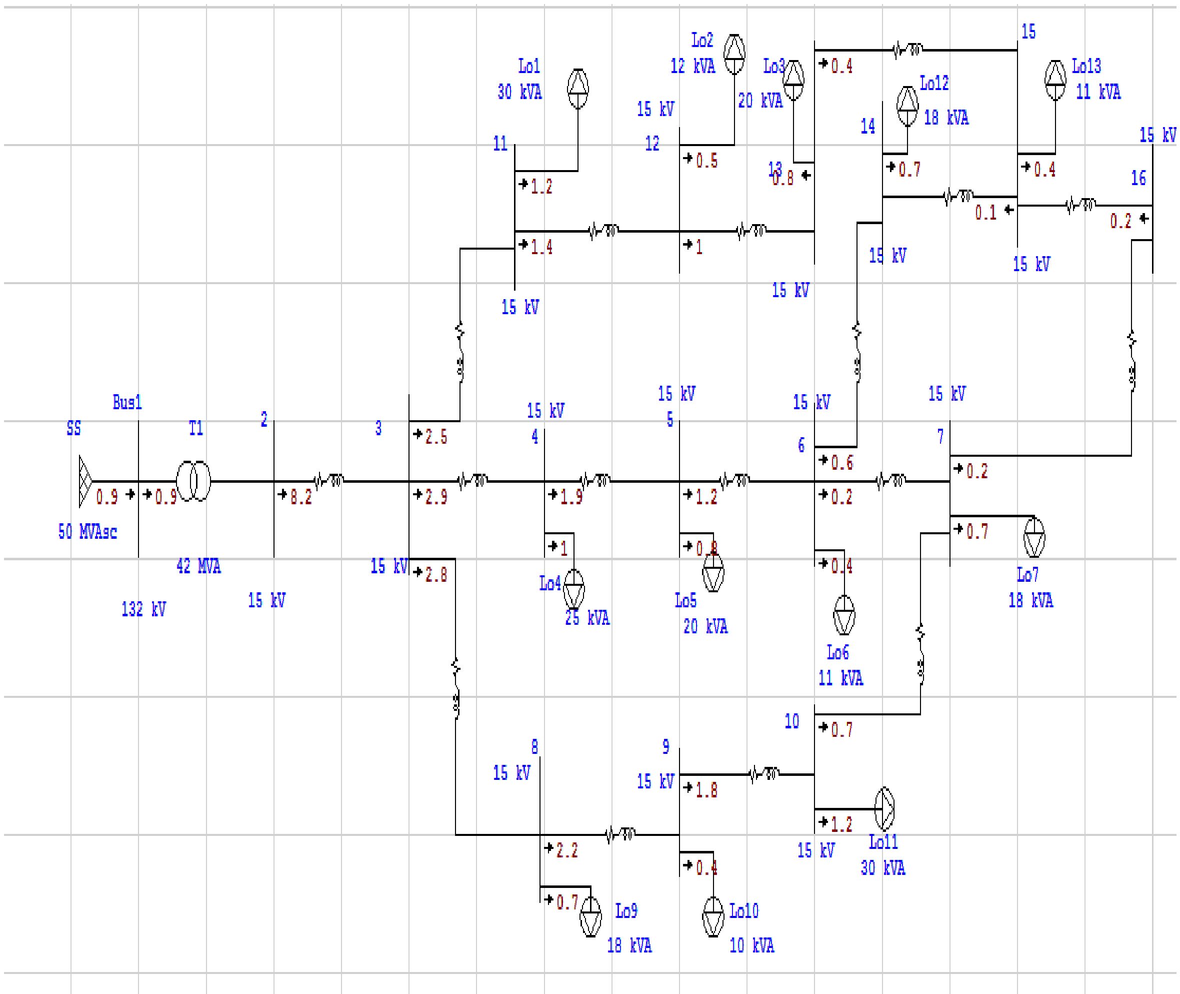

Figure4. 10 Load flow for GMF-16 bus meshed configuration

Based on the proposed method/algorithms (number 3 and 4) given in chapter two, number of Sectionalizing Switches that will be opened must be equal to the number of loops in the network. Thus, there are three loops in the given meshed network above. As it can be seen from the table below, branches with minimum current at meshed configuration are: 6-7, 14-15 and 15-16. When the above three Sectionalizing Switches are opened due to some fault/operation, the Tie switches, 13-15, 7-10 and 7-16, respectively are get closed.

Case 3: After FR

After FR the network was radial and all the loads have been energized as shown below. And the average current of the network was less that of before reconfiguration.

i. Active and Reactive Power flow

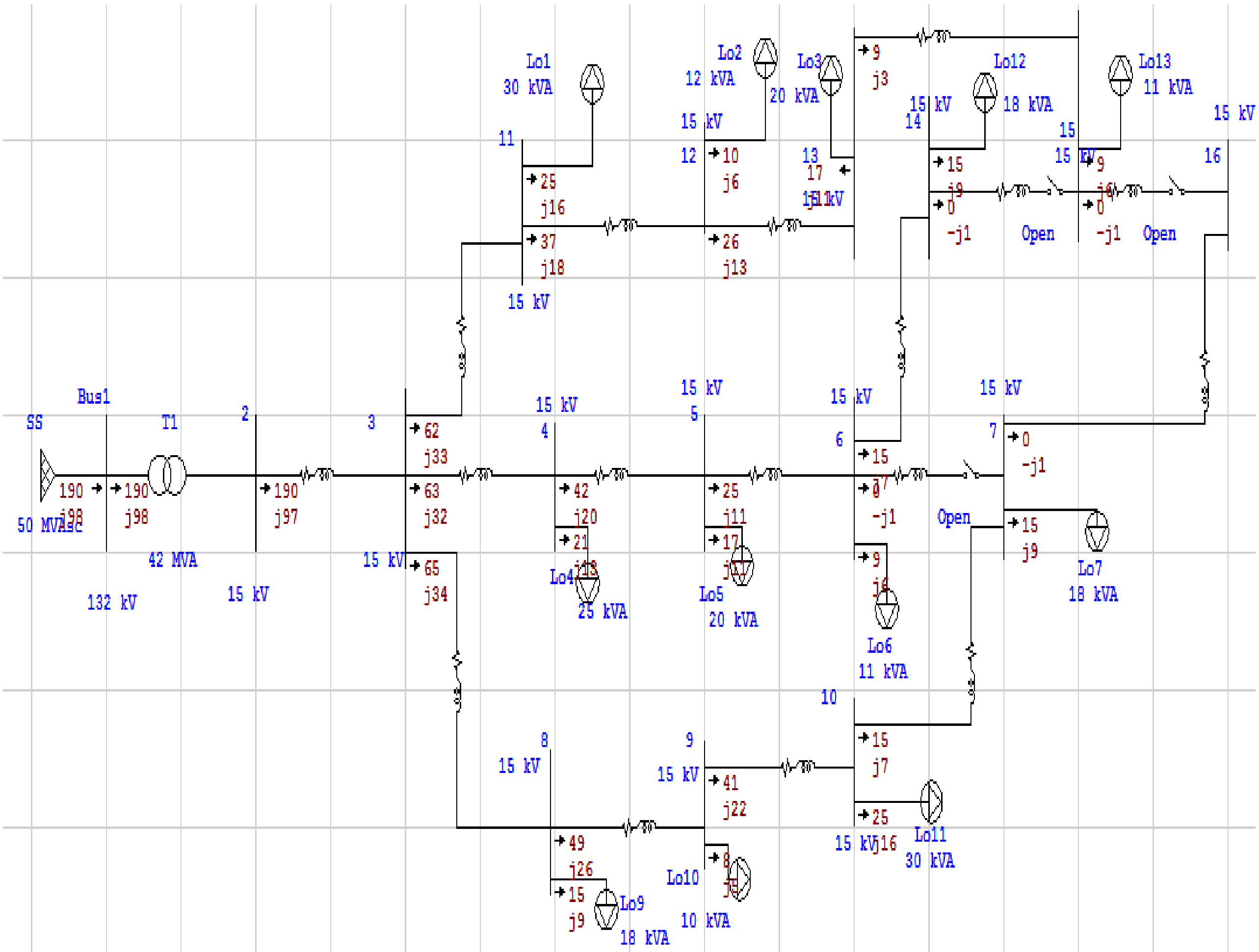

Figure4. 11 Active and Reactive Power flow

i. Current through each branch

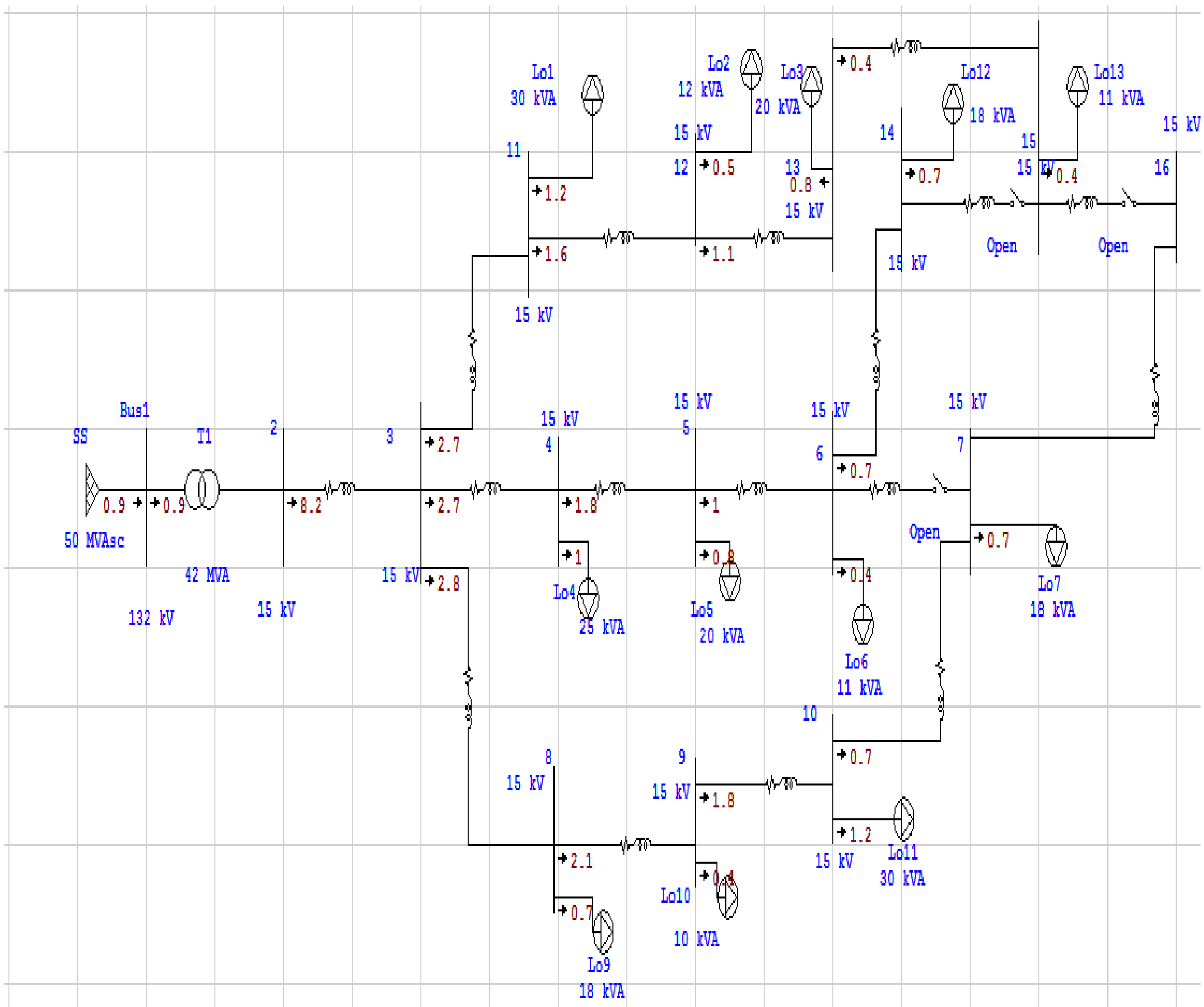

Figure4. 12 Current through each branch

ii. Voltage drop

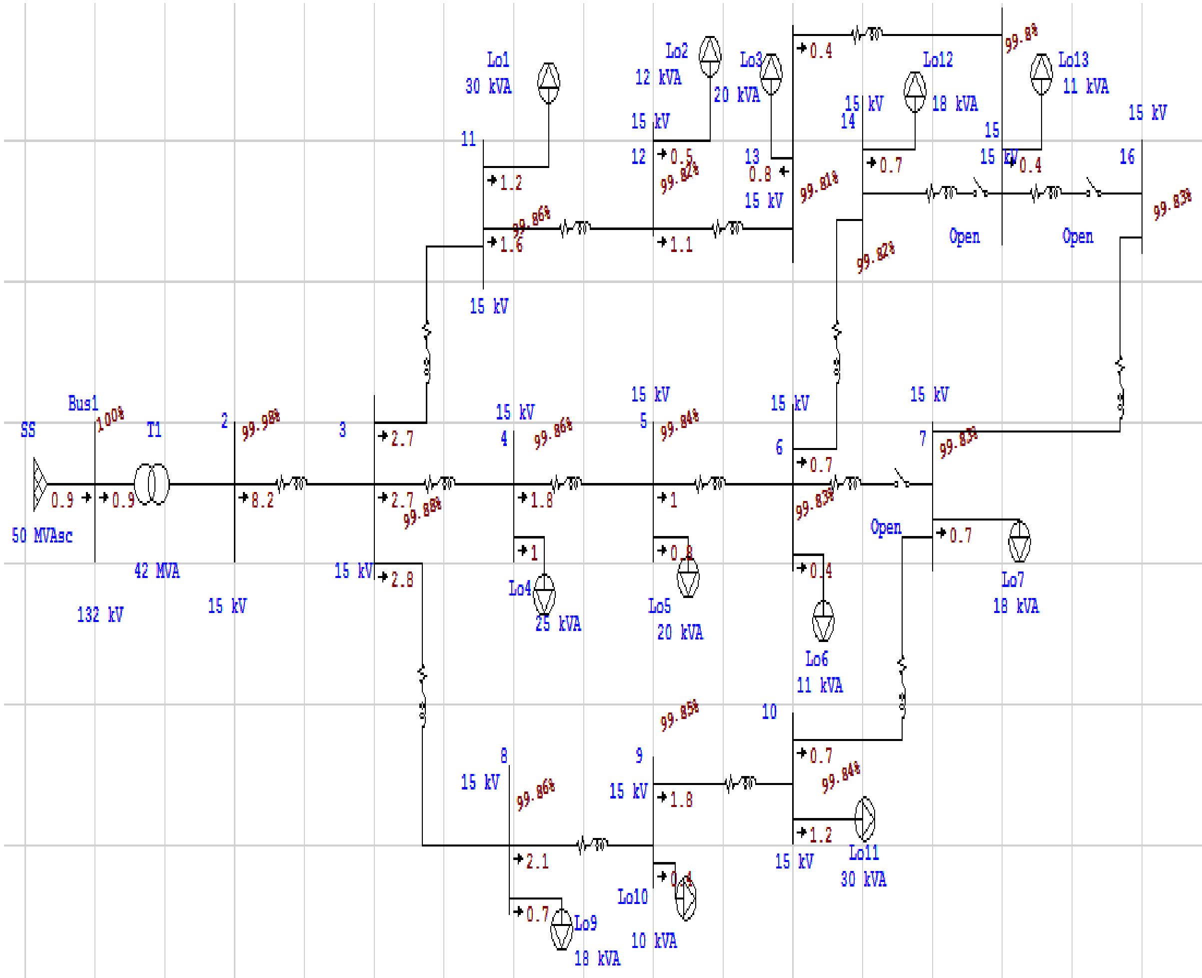

Figure4. 13 Voltage drop

As it can be seen from the table 5.9 below, the total current for the case before FR was 29.6A whereas it was 26.0 after FR. The difference of the current magnitude is 3.6A (12.16%). Assuming line/feeder resistance is constant, Power loss in overhead distribution system (copper loss) is a function of current through the lines (feeders). That means power loss in the line (Feeder) is directly proportional to the square of the line (Feeder) current. Thus, in this FR the amount of power loss minimized after FR will be about **22.85%**.

The system after redesigning was more reliable than the existing radial configuration. By placing the required Tie switches at the selected point the reliability of selected feeder increases.

Table 4. 9 Comparison of the current through each branch before and after FR

Branch (i-j)	Before FR		After FR
	I radial base case (A)	I mesh (A)	I FR (A)
1-2	0.9	0.9	0.9
2-3	8.3	8.2	8.1
3-4	3.8	2.9	2.5
3-8	2.2	2.8	2.1
3-11	2.3	2.5	2.2
4-5	2.9	1.9	1.3
5-6	2.1	1.2	1.0
6-7	0.7	0.2	0
6-14	1.1	0.6	0.7
8-9	1.5	2.2	2.1
9-10	1.1	1.8	1.5
10-7	0	0.7	0.7
11-12	1.2	1.4	1.4
12-13	0.7	1.0	1.1
14-15	0.4	0.1	0
13-15	0	0.4	0.4
15-16	0.4	0.2	0
Total	29.6	28.1	26.0

4.2. Result and Discussion

In this thesis serious reliability problem of Hossana Distribution system has been thoroughly analyzed and possible ways of solutions for the problems identified have been recommended. The thesis work carried out through carefully collected and analyzed data obtained from the Hossana distribution substation. In addition to this, the causes for power interruptions have been identified and solutions were suggested for the same.

The reliability indices for the Hossana city feeder was calculated analytically and summarized in table 3.11 of chapter four above whereas the simulation of the indices for the feeder for the years 2013, 2014 and 2015 were done and results were shown from figures 4.1 to 4.12. Both simulated and analytical values have been compared and the deviation was very small as seen in chapter four above.

As stated in chapter two above, the importance of using time sequential Monte Carlo simulation is to get the probability distribution of reliability indices. It is used to evaluate both expected and probability distribution of the reliability indices. It is also used to obtain accurate frequency and duration indices, and to synthesize annual reliability index probability distribution. The basic parameters needed to evaluate the indices are TTF and TTR from a generated uniform random number (U). To have the nearest indices to that of exact values, 1000 iterations have been done in this thesis work.

As it can be seen in table 4.1, the simulation and the analytical values of SAIFI, SAIDI, CAIDI and ASAI are almost the same. For example analytically calculated value of SAIFI for 2013 is 168 interruptions per customer whereas simulated result is 168.405 interruptions per customer. The error (%) between analytical and simulation value is about 0.241%. And analytical value of SAIDI for 2013 is 395.84 minute per year while its simulated result is 396.529 minute per year for the same year. The error (%) between analytical and simulation value is about 0.174%.

The reliability indices of the study area should be compared with the reliability benchmarks so as to be in conformity with standard-driven reliability values regardless of the expectations and perceptions of the customers.

Though a typical customer expects to have power at all time (100% availability), in reality, a utility is able to make power available between 99.9 and 99.999% of the time. For instance, in America average customers may be dissatisfied if he/she is without electricity for more than 53 minutes per year [7]. However, the Average System Availability Index (ASAI) was 95.48%, 95.29% and 95.31%, for years 2013, 2014 and 2015, respectively for Hossana distribution system. The deviation from the standard range for American power distribution system (in 2012) is 99.999-95.290= 4.709%, for 2014. Thus, the customers lost electricity for 412.5084 hours per year or 24768.504 minutes per year.

The main objective of modern electric power system is to provide an adequate electrical supply to its customers as economically as possible at a reasonable level of reliability. It is important to recognize that reliability and economy must be treated together in-order to perform objective cost benefit studies. On the other hand, determination of outage cost is to understand the nature of faults and variety of customer impacts that would be resulted due to electric service interruption.

The customers in the study area have lost Expected Energy (in MWh) 14883.58, 18576.47 and 23750.58, respectively in the years 2013, 2014 and 2015 due to interruptions. And they have been paying cost of lost Energy (in Birr) 8930150.40, 11,145,882 and 14,250,348, respectively in the three consecutive years.

As discussed in chapter three above, the impact of interruption or outage costs can be broadly classified into direct and indirect costs. Direct costs are those arising directly from the electrical interruption and related to such impacts as lost industrial production, spoiled food or raw materials, personnel leisure time, injury or loss of life. Indirect costs are related to impacts arising from response to the interruption, such as crime during blackouts, business relocation and civil disobedience and looting during an extended blackout.

According to discussion in chapter two of this thesis the customers connected at the far end of this pure radial feeder were experiencing voltage fluctuations and power loss which led them power interruption. Therefore, the reliability of the Hossana distribution system was less. Thus, to alleviate such problems of less reliability some measures that minimize the interruption frequencies and durations have been taken. As a mitigation measure in this thesis work feeder reconfiguration has been done using ETAP simulation software. After reconfiguration, the appropriate locations for placing Tie-switches were obtained by running power flow to use them during fault in any of the outgoing line of feeder by opening the sectionalizing switches. Thus, the unreliability due to interruption for long time, to clear the fault, was minimized by using Tie-switches to reconnect the line out due to some fault. Thus, the system after redesigning was more reliable than the existing radial configuration. By placing the required Tie switches at the selected point the reliability of selected feeder increased by minimizing the duration of outage.

As it can be seen from table 4.9 above, the total current for the case before FR was 29.6A whereas it was 26.0 after FR. The difference of the current magnitude is 3.6A (12.16%). Assuming feeder line resistance is constant, Power loss in overhead distribution system (copper loss) is a function of current through the lines (feeders). That means power loss in the line (Feeder) is directly proportional to the square of the line (Feeder) current. Thus, in this work the amount of power loss minimized after FR by about **22.85%**.

In addition to the feeder reconfiguration (redesign), others solutions for improving the reliability of the Hossana Distribution system have been suggested and stated. The improvement strategies like replacing the old distribution network equipment with new equivalent ones, tree trimming were discussed in the thesis work.

Chapter 5

Conclusion and Recommendation

5.1. Conclusion

The aim of this thesis is to evaluate the reliability of Hossana power distribution system. And also the thesis aimed to suggest possible solutions for identified causes of power interruption for the Hossana distribution system. Different fault types were identified. From the distribution fault records, it is concluded that most of the fault in the distribution system are short circuit, earth fault, overload and operational.

In this thesis work, the evaluation of the distribution reliability for Hossana distribution system using analytical and time sequential Monte Carlo simulation excel add in software approaches were done. The data collected from the Hossana Distribution substation was analyzed to evaluate the reliability indices. Using the data the distribution reliability indices such as SAIF, SAIDI, CAIDI, ASAI and EENS were calculated for three consecutive years, 2013 to 2015 and reported in this thesis. The results of the indices were also compared with the benchmark values. From the comparison, it is concluded that the Hossana distribution system is less reliable.

Lastly, some of the solutions for improving the reliability of the Hossana Distribution system have been suggested and stated. The proposed solutions are redesign (Feeder reconfiguration) solution and improvement strategies like replacing the old distribution network equipment with new equivalent ones, tree trimming were discussed in the thesis.

5.2. Recommendation

The Reliable distribution supply is a determinant factor for the development of a country. This is because every aspect of customer life today is dependent on electricity. To supply reliable and efficient power for the customers the power system network should be planned and redesigned well by evaluating the past performance and predicting future expansion. This goal will be achieved by distribution system network reliability assessment based on reliability cost and worth assessment approach.

The following recommendations are given for further work to improve the Hossana distribution system reliability based on this thesis work:

- In this thesis work only one feeder was reconfigured as a solution to improve feeder reliability. To have reliable distribution network it is recommended that the whole three feeders with 15kV and two feeders with 33kV to be reconfigured by any interested researchers to solve the reliability problems of the study area.
- The improvement techniques such as distribution system network reconfiguration using Artificial intelligence software, like GA, PSO, for the HDS to identify the weakest points that needs replacement and replacing old components are economical alternatives for further improvement using additional re-closer, Tie switches, sectionalizing switches and load break switches in cost effective locations.
- Some Reliability Improvement mechanisms for Radial Distribution System, like Hossana Distribution system network, such as using Smart Grid Technology are suggested to be used.
- It is recommended to convert radial networks to ring network for improving reliability after identifying the locations which put the Hossana distribution reliability at rescue.
- Outages on customer premises highly affect reliability of distribution system because most of the reliability problems arise on customers side thus it is recommended that the utility to have some devices that are used to read/ record data of customer side.

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Appendix A

Fault Data for the years 2013-2015

Table A- 1 Fault Data for the years 2013-2015

Feeder	Peak Load		Min. Load		Permanent Fault				Temporary Fault							
					E. F		S. Circuit		Earth Fault		Short Circuit		SOS		Operational	
Name	P	I	P	I	F	D	F	D	F	D	F	D	F	D	F	D
January-13																
Gim	2.8	135	1	45	2	0.66	8	17.15	1	0.07	1	0.13	-	-	-	2
Ang	1.9	90	0.4	18	1	0.33	3	1.58	-	-	5	0.39	-	-	-	5
Hos	1.7	80	0.08	4	-	-	12	22.54	-	-	5	0.42	-	-	-	8
Feb-13																
Gim	2.8	135	1	45	1	0.58	4	10.38	-	-	2	0.18	-	-	-	7
Ang	2.1	100	0.4	20			6	15.92			5	0.41	-	-	-	13
Hos	1	96	0.2	6	2	19.0	24	84.01	1	0.05	10	0.86	-	-	-	13
Mar-13																
Hos	2.8	135	1	45	-	-	1	5.58	1	0.17	-	-	-	-	-	6
Ang	2	94	0.4	20	3	14.59	8	34.89	-	-	1	0.08	-	-	-	8
Gim	1.6	80	0.08	4	1	1	16	29.45	-	-	5	0.56	-	-	-	4
Apr-13																
Gim	3.5	175	1	45	-	-	2	2.32	2	0.21	-	-			11	20.4
Ang	2.4	120	0.3	16	-	-	5	19.28	-	-	-	-			17	34.3
Hos	2.3	115	0.1	6	-	-	6	48.98	-	-	3	0.39			14	14.1

May-13

Gim	3.5	175	1	45	2	1.75	2	1.08	-	-	-	-	-	-	5	11.9
Ang	2.4	120	0.1	6	4	3.95	8	33.29	-	-	1	0.1	-	-	10	26.8
Hoss	2.1	105	0.2	8	1	12.75	10	6.06	3	0.33	3	0.33	-	-	12	24.1

Jun-13

Gim	2.8	140	1	45	2	-	-	-	-	-	-	-	-	-	9	2.29
Ang	2.2	110	0.1	6	1	0.83	14	37.51	1	0.17	2	0.22	2	3.17	9	4.61
Hos	1.5	74	0.2	8	4	22.4	10	28.8	1	0.13	2	0.25	2	3.8	13	5.82

Jul-13

Hos	2.8	140	1	45	-	-	4	3.38	-	-	-	-	-	1	2.3	5
Ang	2.1	105	0.2	8	1	0.25	13	10.07	-	-	4	0.23		2	2.9	8
Gim	1.8	84	0.3	12	1	0.5	10	26.5	1	0.08	2	0.16		1	1.3	13

Aug-13

Hoss	3	150	0.9	42	2				1	0				4		
Ang	2.4	120	0.2	10	-	-			1					6		
Gim	1.8	90	0.08	4	5				2	0				1		

Sep

Hos	3.4	170	0.8	40	1	0.88	2	1.6	-	-	-	-	0.34	2	14	4
Ang	2.4	120	0.1	6	1	0.2	6	67.37	1	0.08	4	0.39	5.12	3	14	2
Gim	1.9	92	0.1	4	-	-	6	10.69	-	-	3	0.39	-	5	9.9	1

Oct

Hos	3.4	170	0.6	30	-	-	3	3.55	-	-	1	0.17	0.58	2	2.3	14
Ang	2.4	120	0.4	20	1	0.5	7	19.75	-	-	-	-	-	3	7	6
Gim	1.6	80	0.2	10	-	-	13	9.65	-	-	6	0.75	-	3	4.7	8

Nov

Hos	3.4	170	1.3	60	2	1.42	1	0.47	1	0.17	1	0.08	0.03	4	7.7	34
Ang	2.4	120	0.2	10	-	-	7	4.96	-	-	4	0.35	0.08	8	15	15
Gim	2.4	120	0.1	6	-	-	13	33.16	6	0.85	12	0.82	-	5	9.3	26

Dec

Hos	3.4	170	1.2	58	1	0.34	1	13.25	-	-	2	0.11	0.53	4	11	11
Ang	2.4	120	0.2	10	2	4	6	20.33	-	-	-	-	1	7	20	11
Gim	2.4	120	0.2	10	1	0.17	5	12.13	-	-	3	0.19	-	10	42	3

Interruption Data for 2014

Jan-14

Feeder Name	Peak Load		Min. Load		Permanent Fault				Temporary Fault SOS					
					Earth Fault		Short Circuit		Earth Fault		Short circuit			
	P	I	P	I	F	D	F	D	F	D	D	F	D	
Hos	3.4	170	1.3	60	-	-	-	-	2	0.13	3.05	1	1.58	20
Ang	2.4	120	0.1	6	1	1.75	6	7.17	-	-	-	3	13.53	6
Gim	2.4	120	0.4	20	1	0.38	7	11.5	1	0.07	0.2	3	12.5	12

Feb

Hos	3.4	170	1.3	60	3	16.09	8	47.99	4	0.5	0.78	1	1.67	23
Ang	2.1	105	0.2	10	3	22.01	12	66.44	-	-	-	3	5.83	8
Gim	2.1	105	0.2	12	-	-	19	62.53	1	0.17	-	2	4.08	21

Mar-14

Hos	3	150	1.3	60	-	-	5	9.54	-	-	-	2	5.22	17
Ang	2.4	120	0.2	10	-	-	14	54.81	1	0.12	-	3	7.38	14
Gim	2.4	120	0.2	10	2	3.34	13	24.97	-	-	-	1	2.5	23

Apr-14

Hos	3.4	170	0.9	45	1	5	-	-	1	0.08	2.16	1	5.83	19
Ang	2.4	120	0.2	8	6	10.41	4	14.83	-	-	1	3	17.21	11

Gim	2.4	120	0.3	12	-	-	6	13.82	-	-	0.36	3	19.61	13

May-14

Hos	3.4	170	60	1.2	1	1.27	7	9.82	2	0.15	1.32	1	4.75	17
Ang	2.4	120	0.3	16	3	2.2	15	93.01	-	-	-	6	34.49	6
Gimb	2.4	120	0.2	10	2	8.67	14	43.41	-	-	1.77	4	21.77	11

Jun-14

Hos	3.6	180	1.5	70	-	-	5	3.05	-	-	0.98	-	-	-
Ang	2	90	0.1	6	3	8.71	8	40.79	-	-	-	5	17.82	11
Gimb	2.1	105	0.1	5	3	15.86	5	14.7	2	0.2	-	5	17.69	11

Jul-14

Hoss	3.4	170	1.6	75	-	-	-	-	-	-	1.01	1	3.03	7
Ang	2.2	110	0.4	20	2	1.83	6	12.55	-	-	-	1	18.89	7
Gim	2.1	105	0.3	12	-	-	4	10.02	-	-	-	8	17.11	7

Aug-14

Hos	3.6	180	1.3	60	4	6.29	3	4.3	-	-	-	-	-	9
Ang	1.8	86	0.5	26	1	0.7	6	29.05	-	-	-	3	5.51	9
Gimb	2	100	0.2	10	2	3.39	18	26.5	-	-	-	1	2	13

Sep-14

Hos	3.4	175	1.3	60	1	3	2	1.2	-	-	-	-	-	1
Ang	2.1	105	0.3	12	2	8	1	1.34	-	-	-	1	1	6
Gim	2.1	105	0.4	20	1	4.62	4	5.59	-	-	-	-	-	3

Oct-14

Hos	3.9	195	1.3	60	-	-	3	7.28	-	-	-	5	14.47	16
Ang	2	100	0.2	6	10	42.28	9	23.76	2	0.13	-	9	22.36	9
Gim	2	100	0.2	10	1	0.34	7	10.43	-	-	-	8	27.95	13

Nov-14

Hos	5.1	255	1.8	90	6	2.16	6	6.87	2	0.11	-	-	-	11
Ang	1.9	95	0.2	8	9	27.19	10	22.07	8	0.92	-	1	3.16	13
Gim	1.8	85	0.1	7	19	27.67	29	109.8	8	0.85	-	3	17.68	40

Dec-14

Hos	5.4	270	1.3	60	12	27.85	8	28.05	2	0.27	-	1	1.53	24
Ang	2	100	0.1	6	1	0.56	11	37.87	4	0.5	-	1	2.97	22
Gim	2.1	105	0.2	8	15	8.28	4	6.43	20	2.34	-	-	-	29

Interruption Data for 2015

Jan-15

Feeder Name	Peak Load		Min. Load		Permanent Fault							
	P	I	P	I	Earth Fault		Short Circuit		Earth Fault		SOS	
					F	D	F	D	F	D	D	F
Hos.	4.3	215	1.8	90	1	0.3	-	-	-	-	-	1
Ang.	2	100	0.2	20	4	7.33	4	3.33	1	0.17	-	8
Gim.	2.4	120	0.2	20	3	3.06	5	2.63	2	0.21	-	7

Feb-15

Hos	4.3	215	1.8	90	1	0	4	3.33	1	0.17	-	1
Ang	2	100	0.2	20	4	7.33	5	2.63	2	0.21	-	8
Gim	2.4	120	0.2	20	3	3.06	1	3.83	-		-	7

Mar-15

Hos	4.8	240	0.2	10	8	7.36	3	26.91	1	0.16	-	2
Ang	2	100	0.1	5	4	16.07	4	13.6	2	0.24	-	5
Gim	2.1	105	0.2	10	8	18.61	2	7.41	4	0.67	-	3

Apr-15

Hos	4.8	240	0.6	30	3	4.2	2	1.33	2	0.16	-	9
Ang	2.4	120	0.2	10	8	19.94	6	19.13	-	-	-	11
Gim	2	100	0.1	5	6	11.02	-	-	3	0.32	-	13

May-15

Hoss	4.8	240	1.2	60	3	1.64	4	12.19	-	-	-	4
Ange	1.8	90	0.2	10	3	8.3	8	45.46	-	-	-	5
Gim	2	200	0.2	10	9	5.05	7	29.11	-	-	-	6

Jun-15

Hoss	4.2	210	1.2	60	3	4.52	3	4.52	5	12.47	-	1
Ange	1.8	88	0.2	10	4	24.19	4	24.19	6	18.83	-	1
Gim	2.2	212	0.2	10	11	23.45	11	23.45	2	4.96	-	2

Jul-15

Hos	5.2	260	0.7	36	7	17.42	3	1.12	1	0.11	-	6
Ang	2	100	0.2	10	1	1	8	8.95	-	-	-	7
Gim	2.2	110	0.1	5	9	9.91	4	25.04	-	-	-	8

Aug-15

Hoss	4.8	240	1.5	75	3	2.16	2	1.41	1	0.17	-	4
Ange	2.4	120	0.3	15	6	14.5	7	6.86	1	0.16	-	3
Gim	2.2	108	0.1	5	8	13.34	15	15.22	-	-	-	3

Sep-15

Hoss	5.4	270	1.4	68	4	2.68	5	4.88	-	-	-	5
Ange	2.5	125	0.2	8	7	5.25	7	53.89	2	0.25	-	7
Gim	2.5	125	0.1	7	7	6.27	10	23.19	3	0.53	-	6

Oct-15

Hoss	5.1	255	1.8	90	6	2.16	6	6.87	2	0.11	-	-
Ange	1.9	95	0.2	8	9	27.19	10	22.07	8	0.92	-	1
Gim	1.8	85	0.1	7	19	27.67	29	109.8	8	0.85	-	3

Nov-15

Hoss	5.4	270	1.3	60	12	27.85	8	28.05	2	0.27	-	1
Ange	2	100	0.1	6	1	0.56	11	37.87	4	0.5	-	1
Gim	2.1	105	0.2	8	15	8.28	4	6.43	20	2.34	-	-

Dec-15

Hoss	4.8	240	1.8	90	1	0.63	3	2.48	2	0.24	-	-
Ange	2.4	120	0.1	4	5	2.76	5	29.03	1	0.16	-	2
Gim	2.4	120	0.2	9	4	23.66	5	4.31	1	0.08	-	4

Appendix B

Load Variations per month of the three years for Hossana Power Distribution Feeder

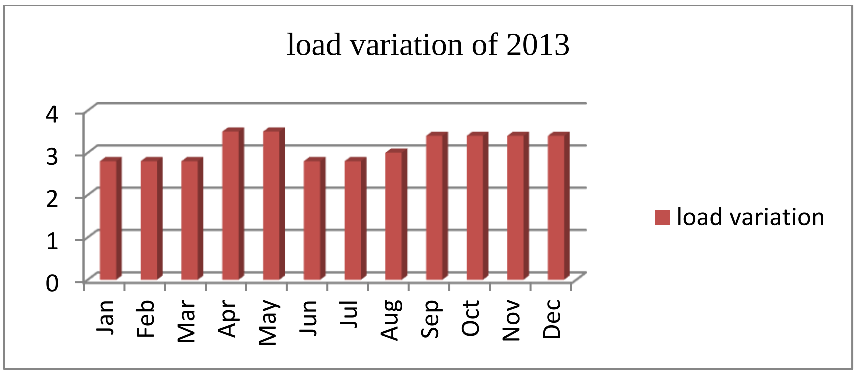

Figure B- 1 Load variation in 2013

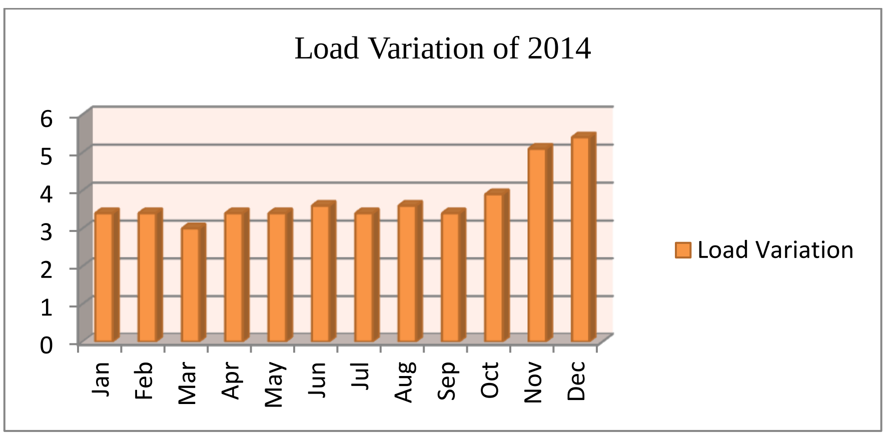

Figure B- 2 Load variation in 2014

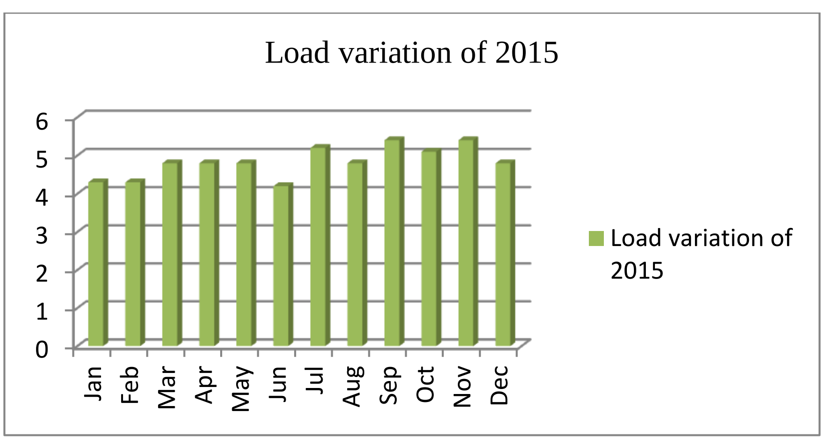

Figure B- 3 Load variation in 2015

Appendix C

Sequential Monte Carlo Simulation result of years 2014-2015

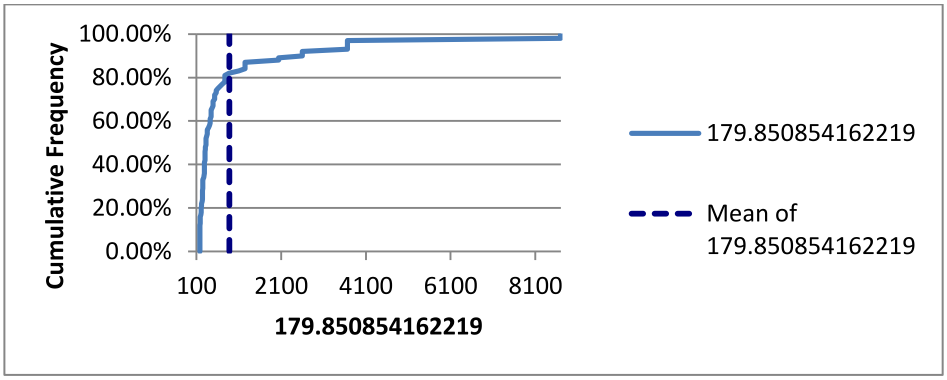

Figure C- 1 Cumulative Distribution of SAIFI value for the year 2014

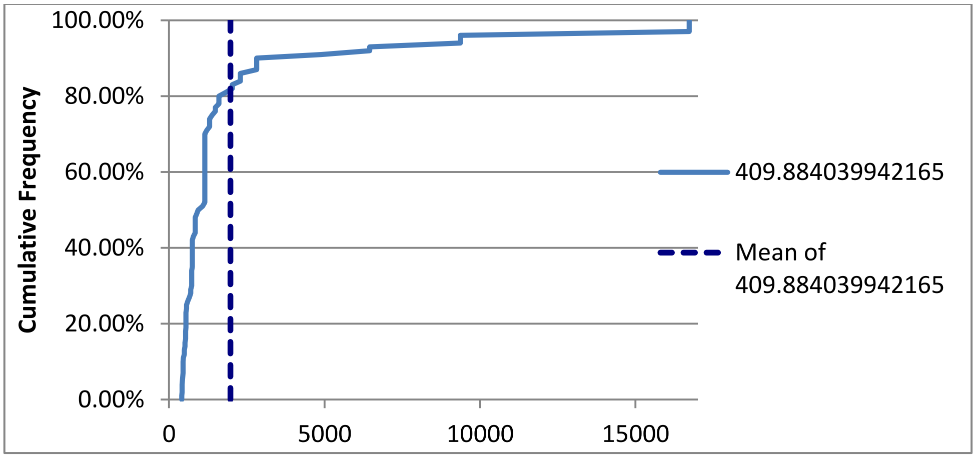

Figure C- 2 Cumulative Distribution of SAIDI value for the year 2014

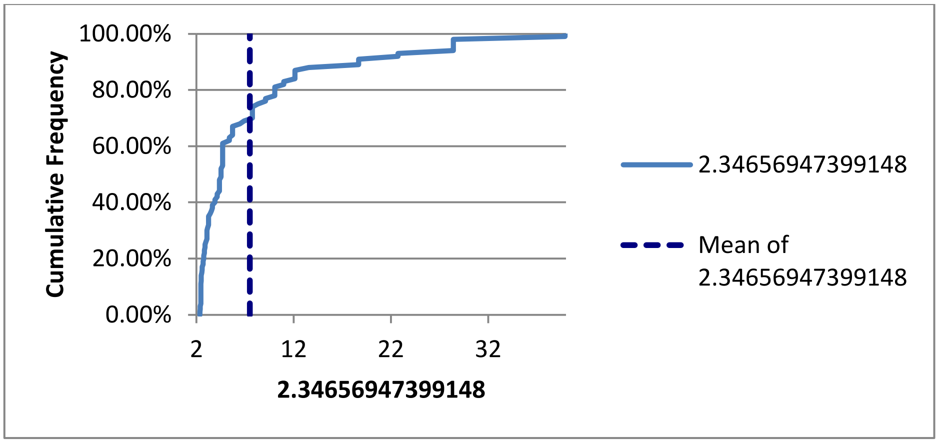

Figure C- 3 Cumulative Distribution of CAIDI value for the year 2014

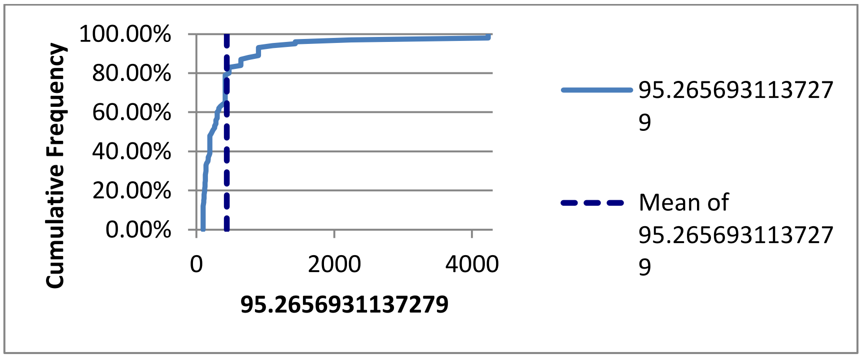

Figure C- 4 Cumulative Distribution of ASAI value for the year 2014

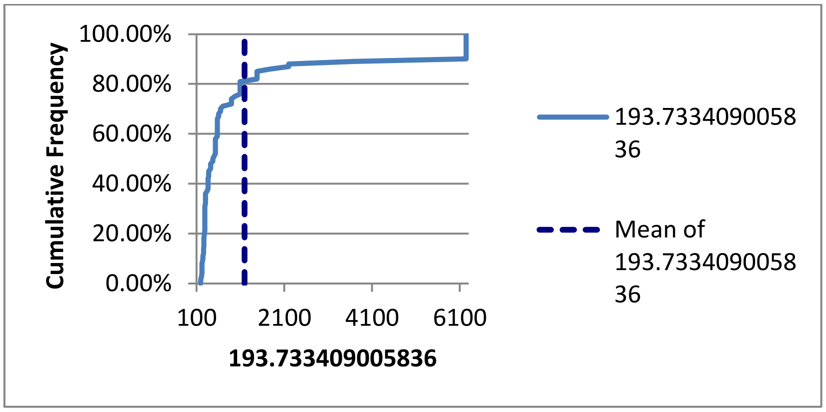

Figure C- 5 Cumulative Distribution of SAIFI value for the year 2015

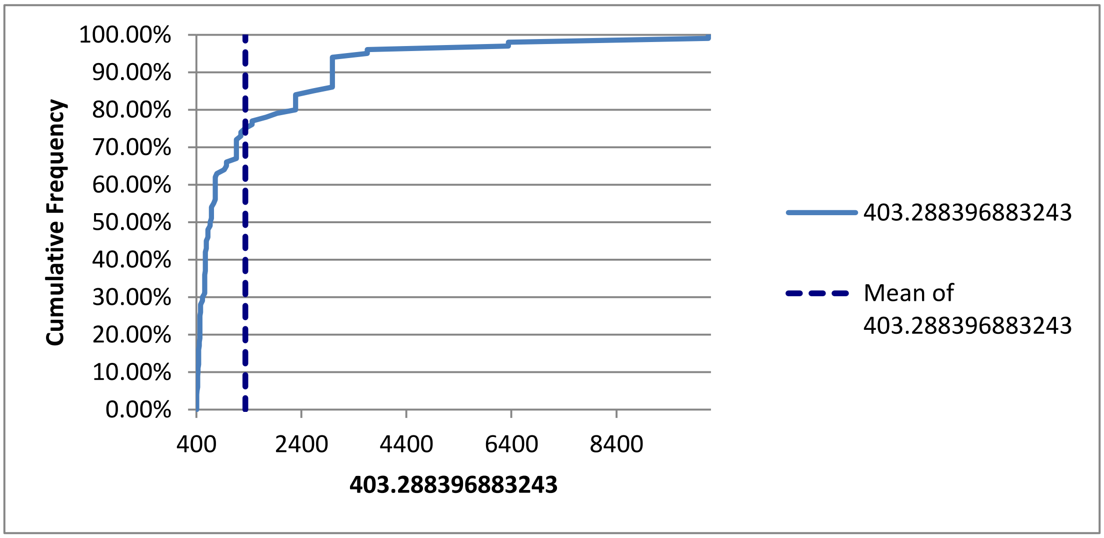

Figure C- 6 Cumulative Distribution of SAIDI value for the year 2015

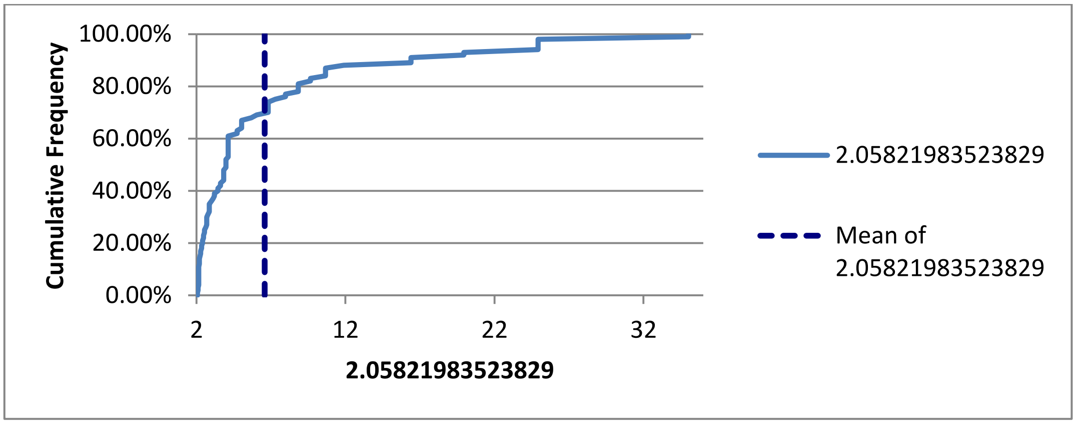

Figure C- 7 Cumulative Distribution of CAIDI value for the year 2015

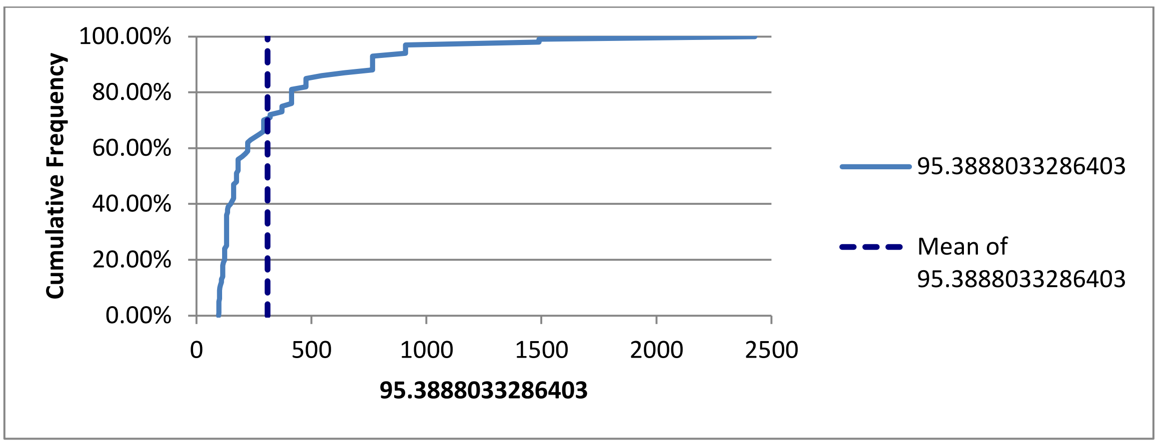

Figure C- 8 Cumulative Distribution of ASAI value for the year 2015

Appendix D

Questioner filled by the utility experts

The purpose of this document is to provide an outline of preliminary information such as to obtain the experience of fault tracing and clearing methods, causes of power outages and cost of customers due to power interruption that will be used by the thesis work done in the Department of Electrical and Computer Engineering, Electrical Power engineering Stream, Jimma Institute of Technology, Jimma University.

Therefore, respondents are kindly requested to give the required information as accurately as possible. Your feedback will be kept confidential and used only for academic purpose.

Thank you for your cooperation!

Table D- 1 Number of customers with their demand in the area

Type	Number	Demand in (MW)
Residential		
Commercial		
Industrial		
Street lighting		

1. What types of MV primary distribution network exist? (If possible put it in %)
   a) Overhead network
   b) Underground cable
   c) Mixed network
2. What types of MV primary distribution network topology exist?
   a. Radial system b. Closed ring system c. Open ring system
   d. Dual ring system e. Multi-radial system
   f. If other specify ___________________
3. Outgoing feeder profile
   a. Total feeder conductor length (km) ____________________________
   b. Feeder cross section area (mm) ____________________________

c. Load (MVA) ___________________________

d. Number of distribution transformers per feeder __________________

4. What types of LV secondary distribution network exist? (If possible put it in %)

a. Overhead network

b. Underground cable

c. Mixed network

5. What types of LV secondary distribution network topology exist?

a. Radial system

b. Open ring system

c. Closed ring system

d. Dual ring system

e. Multi-radial system

f. If other specify __________________________________

6. What is the standard LV level exists in Hossana's distribution system?

a) 400/230 V b) 380/220 V c) 208/120 V d) 416/240 V e) 110/190 V

7. How long will it take to trace the fault point?

a) 30 minutes b) 1 hour c) 2 hours d) 3 hours

e) If Any other ________________________

8. How long would it take to restore the feeder that is out due to fault?

a. 30 minutes

b. 1 hour

c. 2 hours

d. 3 hours

e. Any other ________________________

9. Rank the listed causes of power interruptions by their occurrence in the table below.

Table D- 2 Lists of causes of interruptions

Type of Source	**Distribution Outage Reason**	**Rate of outage (mark your choice with X)**		
		Low	High	Very high
Network Technical Problem	Medium voltage lines contact due to wind			
	Medium Voltage Cut			
	Breakdown of aged tower due to heavy rain			
	Medium Voltage Underground Cable Explosion			
	Breakdown of aged tower and contact of 'Ganch' and distribution line			
	Fire ignited due to transformer secondary side loose connection			
	Line outage due to oil leakage grounding of transformer			
	Feeder opens in switching station and time taken for fault locating			
	Short circuit and earth fault line outages			
	High voltage contact with street lighting			
	Medium voltage loose line fire ignition			
	Sudden opening of circuit breaker and fault clearing			
	Clamp loose and cut in tapping line			
	Disconnected lines due to sudden increase in load			
External Outage Source	Car accident on medium voltage line			
	Tree falling on medium voltage line			
	Explosion of arrestor due to lightening			
	Line short-circuit due to bird contacts			
	Interrupted lines due to stormy weather			

10. If you have any other comments please write them in the space below.