ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSTITUTE OF TECHNOLOGY
ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

Studies on Power Distribution System Reliability Assessment and Improvement (Case Study: Jimma Town Distribution System)

By
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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Electrical and Computer 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 any other university, and all sources of materials used for the thesis have been fully acknowledged.

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

Dr.-Ing. Getachew Biru ______________

Thesis advisor's Name **Signature**

Abstract

A reliable electric power supply system is a predictable pre-requisite for the technological, political and economic growth of any nation. This is a reaction of an increasingly electricity dependent society, which demands electricity supplies at acceptable quality levels and at reasonable tariffs. Power interruption becomes a serious problem in Ethiopia. This is because of the very high outage frequency and very long time service restoration. Due to this problem, day to day activities of the society are highly affected and hence they are strongly complaining the electric utility. Power interruption significantly costs both sides, the utility and the customer.

This research has been conducted a studies on powers system reliability assessment and improvement with a case study in Jimma town distribution system. Customers has complained soundly about power interruptions in the city. The reliability assessment has been done on 15kV city feeder to assess the performance of the present system and also predictive reliability analysis for the future. The interruption data of years 2010-2015 has been used as a base year. The study has evaluated different mitigation alternatives to improve the system reliability at reasonable cost. Many alternatives has been assessed using heuristic method and the alternative with low SAIDI, SAIFI and EENS at a reasonable cost has been selected.

In general, this thesis work reveals that the reliability of the system has been improved significantly by implementing reliability improvement solutions that are justified economically. Even if the uncertainty of the input data is taken into account, SAIFI has been reduced by 84.75 % as compared with the average reliability indices values of the system in the base years. In the same case SAIDI and EENS have been decreased by 85 % and 88.651 % respectively.

The proposed solution has been saved 579523.96 ETB per year from the unsold energy of one feeder only with 2.03 years payback period investment. Satisfaction of the society has been considered as a priceless advantage.

Acknowledgment

This thesis work would not be possible without the help of my advisor Dr. ING. Getachew Biru, who has supported me by giving his invaluable guidance, encouragement, advice and suggestions throughout my MSc Education and thesis work.

My appreciation goes to Ethiopian electric utility Western region workers for providing important data and materials needed for this work, specifically, I would like to acknowledge Wondimu Astatike, Mezgebu Befikadu, Lemlem Aklilu and Getu Gebre Kidan.

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Acronyms

A	Ampere
AAC	All Aluminum Conductors
AENS	Average Energy Not Supplied Index
ALIDI	Average Load Interruption Duration Index
ASAI	Average Service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
DUR	Duration of Interruptions
EEA	Ethiopia Eclectic Agency
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
EEPCo	Ethiopian Electric Power Corporation
EENS	Expected Energy Not Supplied
ETB	Ethiopian Birr
ICS	Interconnected System
IEC	International Electro technical Commission
IEEE	Institute of Electrical and Electronics Engineers
Km	kilometer
KV	Kilo Volt
KVA	Kilo Volt Ampere
KWh	Kilo Watt hour
L	Load
LV	Low Voltage
m	meter
MVA	Mega Volt Ampere
MW	Mega Watt
OH	Overhead Line
P	Active Power
Pf	power factor
Q	Reactive Power
Rec	Recloser
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
TCC	Time Current Curve
USD	US Dollar
V	Volt
W	Watt

CHAPTER ONE

1 Introduction

1.1 Background

Institutionally, Ethiopia has moved from a vertically integrated monopoly towards an autonomous entity that ensures transport and distribution and allows for private generation. The Ministry of Water and Energy (MWE) is the federal institution responsible for development, planning, and management of energy resources as well as for creation of policies, strategies, and programs. The MWE develops and implements laws and regulations for the energy sector, provides technical support to regional energy bureaus and offices, and signs international agreements (http://www.reegle.info/policy-and-regulatory-overviews/ET).

According to the Ethiopian FEDERAL NEGARIT GAZETA, which is the official federal government law Gazette for the publication of all Federal laws, proclamation NO. 86/1997 The Ethiopian Electricity Agency is established as an autonomous federal agency having its own legal personality and the agency is accountable to the ministry, MWE. The budget of the Agency shall be drawn from the budget allocated by the government, license fees and moneys from other sources. As shown in practice, Ethiopian government forced Ethiopian electric utility to work self financially, rehabilitation works, preventive maintenance works are worked by the budget found from fees of electricity used [1].

Ethiopian Electric Power Corporation worked for many years to provide adequate and quality electricity transmission, distribution, and sales services, through continuous improvement of utility management practices, responsive to the socio-economic development and environmental protection.

For economic growth to take place sufficient supply of electricity is an important prerequisite and the mandate of the power sectors is to provide a direct link to achieving the national goal of Gross National Happiness.

The Ethiopian Electric Light and Power Authority (EELPA), which was established in 1956, after having undergone restructuring had been reorganized as Ethiopian Electric Power Corporation (EEPCo). The Ethiopian Electric Power Corporation (EEPCo) as public electric utility enterprise is named in 1997 for indefinite duration by regulation No. 18/1997.

Now as per the new restructuring of Ethiopian Electric Power Corporation the corporation is split in to two companies namely Ethiopian Electric Utility (EEU) and Ethiopian Electric Power (EEP). The EEP is formed by Council of Minister's Regulation No. 302/2013 dated 27th of December, 2013. EEP is responsible for design and development of electric generation, transmission, and substations and all operational and maintenance tasks. And EEU is established by Councils of Minister's Regulation No. 303/2013 dated 27th of December 2013 is responsible for administration of electric power distribution networks, purchase bulk electric power and sell energy to customer.

The company installed generation capacities is around 4620 MW from hydro, wind, geothermal and diesel power plants. It uses a transmitting lines operating at 400kV, 232kV, 132kV 66kV, 45kv, 33kv and 15kv spread across the country.

The vision in the sector is to improve access, increase power efficiency and reliability to world standard. The sector aims at a five-fold increase in hydroelectric power generating capacity, and doubling the number of consumers with access to electricity. (National Indicative Program for Ethiopia 2014 to 2020, p15-17)

The electric energy supply systems are the interconnected system (ICS) and the self-contained system (SCS).The main energy source of the interconnected system (ICS) is hydro power plant and wind farms and for SCS its main source are mini- hydro plants and diesel power Generators allocated in various areas of the country [2].

1.2 Statement of the Problem

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

Over the past years, distribution systems have received considerably less attention devoted to reliability modeling and evaluation than the power generating and transmission systems. The reasons for this are that the generating stations and the transmission systems are capital intensive and the generation and the transmission inadequacy can have widespread catastrophic consequences for both society and the environment. A distribution system, however, is relatively cheap as compared to the other two as its effects are localized. Therefore, less effort has been devoted to quantitative assessment of the adequacy of various alternatives and reinforcements. On the other hand, analysis of the customer failure statistics of most utilities shows that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer. The distribution systems account for up to 90% of all customer reliability problems, improving distribution reliability is the key to improving customer reliability. Since the primary purpose of the system is to satisfy customer requirements and the proper functioning and longevity of the system are essential requisites for continued satisfaction, it is necessary that both demand and supply considerations are appropriately viewed and included in the systems. Therefore, the distribution reliability is one of the most important in the electric power industry due to its high impact on the cost of electricity and its high correlation with customer satisfaction [3].

Power interruption becomes a serious problem in Ethiopia specifically, in the case study area of this thesis work. The outage frequency is as high as 435 and service restoration duration is as long as 272 hours per year per the selected feeder. The data clearly indicates that power interruption per day is a common phenomenon in the area and due to this problem day to day activities of the society are highly affected and hence they are strongly complaining the electric utility.

The project conducted in this thesis is to assess the reliability performance, identify the main causes of power interruptions and uses auto recloser and tie switches that should be placed at a potentially selected places using heuristic technique to achieve a maximum improvement in Jimma town distribution system reliability.

1.3 Objectives

General Objective

The main objective of this thesis work is to assess and study power distribution system reliability in Jimma town. It seeks to achieve a more thorough understanding of the root causes for the distribution system reliability problems, and to come with proper mitigation techniques for betterment of the system.

Specific Objective

The specific objectives of this research are as follow:

- To assess Jimma power distribution system
- Identify the major causes of power interruptions in the existing system
- Evaluate system reliability and compute its indices based on selected base years interruption data of the city feeder using available reliability analysis tool (ETAP12.6.0)
- Propose proper power outage mitigation techniques and draw relevant conclusions

1.4 Methodology

The following activities are performed in this paper:

- **Literature review**: A number of journals, article and papers on power distribution system reliability assessment and study, feeder reconfiguration and other related works have been reviewed.
- **Assessment of the existing network**: assessment of the physical system in the case study area, understanding and adopting the system as a whole.
- **Data collection**:
  - Six years(2010-2015) interruption data has been collected from Jima substation
  - The feeder length, number of poles, number and ratings of transformers has been collected from the existing system and the districts.
  - Load of the system has been gathered from districts and western region wire office
  - Questioner was prepared to identify causes of interruptions and discussions with concerned workers and close mangers was made regarding the system configuration, loading, number of customers, reliability status, and interruption costs.
  - The collected data has been used to clearly analyze the problems of the feeder under study.
- **System design and analysis**:
  - The distribution system is represented using single line diagram
  - Improved network topology reconfiguration with protection system has been developed.
  - Short circuit currents have been calculated for protection coordination analysis
  - Reliability indices have been calculated for the existing selected feeder and the modified systems
  - Based on the result of this analysis and assessment, reconfigured network with additional recloses have been evaluated for potential reliability improvement

The system has been designed and simulated using a latest Electrical software, ETAP 12.6.0.

1.5 Thesis Layout

The thesis work has been done in such a way that it gives a clear flow and understanding regarding the thesis work. Chapter one presents introduction, objectives and problem explanation. Chapter two discusses the theoretical fundamentals of reliability, protection and it includes review of literatures focusing on reliability, distribution systems and related works. Chapter three presents the methodology and approaches in more detail staring from site description and data gathering; cost and worth of reliability and causes of interruptions has been also presented in this chapter. Simulation studies and analysis of different mitigation alternatives has been done in Chapter four; and the results are presented with reasonable explanations in this chapter. Finally, conclusion has been given followed by points of recommendation in Chapter five.

CHAPTER TWO

2 Theoretical Background and Review of Literatures

2.1 Introduction

Power quality and reliability are the two most important terms in power system and they are interrelated to each other in many ways.

Perfect power quality is characterized by a perfect sinusoidal voltage source without waveform distortion, variation in amplitude or variation in frequency. To attain near perfect quality, a utility could spend vast amounts of money and accommodate equipment with higher power quality needs. On the other hand a utility could spend little and require customer s to compensate for the resulting power quality problems. Neither of extreme is desirable, utilities must find a balance between cost and power quality provided to the customer. Power quality concerns are becoming more frequent with the proliferation of sensitive electronic equipment and automated process. Power quality problems are basically divided into many categories such as interruptions, sags, swells, transients, noise, flicker, harmonic distortion and frequency variations.

Reliability may be defined in many ways for electric power systems. These include continuity of service, meeting customer demands, and the vulnerability of the power system. Reliability concerns are often split into different categories: adequacy, or the capacity and energy to meet demand; and security, or the ability to withstand disturbances.

Reliability cannot be discussed apart from the objectives of the system. The goals of the distribution system may be identified as (1) covering the territory (an aspect of adequacy), (2) having sufficient capacity for peak demand (another aspect of adequacy), (3) being able to operate under adverse conditions (security), and (4) providing a stable voltage (quality).

Thus, the goals of the distribution system are congruent with reliability concerns (Power Distribution Planning Reference Book).

The North American Reliability Council provides a Glossary of Terms. Reliability and the concepts of adequacy and security are defined there as follows (NERC Glossary of Terms):

Reliability: The degree of performance of the elements of the bulk electric system that results in electricity being delivered to customers within accepted standards and in the amount desired.

Reliability may be measured by the frequency, duration, and magnitude of adverse effects on the electric supply. Electric system reliability can be addressed by considering two basic and functional aspects of the electric system: adequacy and security.

Adequacy: the ability of the electric system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.

Security: the ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements.

Distribution reliability primarily relates to equipment outages and customer interruptions. In normal operating conditions, all equipment (except stand by) is energized and all customers are energized. Schedule and unscheduled events disrupt normal operating conditions and can lead to outages and interruptions. The unscheduled events are caused either due to human error or due to equipment failures. The schedule events are meant for periodic maintenance of the equipment and shall be notified in advance to the customers. Several indicators are used to evaluate reliability in the transmission and distribution system. The Regulation can aim to compensate customers for very long interruptions, keep restoration times under control and create incentives to reduce the total number and duration of interruptions (disincentives to increase them).

2.2 Reliability Indices

There are various reliability indices that can be employed in measuring reliability of a given system and / or comparing the reliability of different electric utility companies.
Reliability indices are statistical aggregations of reliability data for a set of loads, components or customers. The reliability of the power supply is assessed using the known reliability indices.

Most reliability indices are average values of a particular reliability characteristic for an entire system, operating region, or feeder. The indices for distribution system analysis include customer-oriented indices and energy-oriented indices as defined in IEEE Standard 1366™-2012 [4].

A. Customer Oriented Indices

System Average Interruption Frequency Index (SAIFI): It is the average frequency of sustained interruptions per customers over a predefined area. Total number of customer interruptions per year divided by the total number of customers served.

$$SAIFI = \frac{\text{Total Number of interruptions}}{\text{Total number of customers served}} = \frac{\sum N_i}{N_t} \qquad \left(\frac{\text{events/customer}}{\text{yr}}\right) \qquad (2.1)$$

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

System Average Interruption Duration Index (SAIDI): It is commonly referred to as customer minutes of interruption or customer hours and provides information as to the average time the customers are interrupted.

$$\text{SAIDI} = \frac{\text{Total Durations of all interruptions}}{\text{Total number of customers served}} = \frac{\sum r_i N_i}{N_t} \qquad \left(\frac{\text{hrs /customer}}{\text{yr}}\right) \qquad (2.2)$$

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

Customer Average Interruption Frequency Index (CAIFI): This index gives the average frequency of sustained interruptions for those customers experiencing sustained interruptions. It is the value of total number of customer interruptions divided by total number of customers affected.

Customer Average Interruption Duration Index (CAIDI): It is the average time needed to restore service to the average customer per sustained interruption. It is the sum of customer interruption durations divided by the total number of customer interruptions.

$$\text{CAIDI}= \frac{\text{Total Durations of all interruptions}}{\text{Total number of customer interruptions}} = \frac{\text{SAIDI}}{\text{SAIFI}} \quad (2.3)$$

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

B. Load or Energy Oriented Indices

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

$$EENS = (\textit{Average load during outage})\ x\ (\textit{The Outage duration}) = \sum_i L_i r_i \quad (Watt - Hours) \quad (2.4)$$

Where, L_i is the average load connected to load point *i* and r_i is outage duration for event *i*.

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

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

Average Load Interruption Frequency Index (ALIFI): This factor is analogous to the System Average Interruption Frequency Index (SAIFI) and describes the interruptions on the basis of connected load (kVA) served during the year by the distribution system.

SAIFI, SAIDI and EENS are the most commonly used and known indices to measure reliability performance of utilities [5].

2.3 Protection System

Protection coordination is performed among protection devices to prevent unwanted operation of the equipment for a fault occurred on the system.

The main objectives of distribution system protection and coordination are:

- To detect and isolate the faulted area from the system
- To minimize the duration of the outage or problem
- Minimize the actual problem on the system so the damage is minimal
- Provide alternate circuits or supply in short time where applicable

A time-overcurrent relay characteristic is generally plotted as a single-line curve. Curves for specific relays are provided by the manufacturer on log-log paper and include the available range of time-delay (or time-dial) settings. The term time dial originates from the electromechanical time-overcurrent relays that have a dial with continuous adjustment from typically 0.5 to 10. Indentations on the dial correspond to the characteristic curve numbers provided by the manufacturer. Selection of any other position requires curve extrapolation and testing of the relay to ensure proper settings.

The term time dial has carried over to static relays where adjustment of the time delay is also provided. The major difference is that static technology provides a greater degree of curve selectivity and accuracy.

For a given current, the time delay selection indicates the time required for the relay to close its output contacts, The higher the time-dial setting, the greater the time to contact closure.

On the coordination plot (On the logo-logo paper Figure 2.1,) the characteristic curve (the curve which relates peak current and time) is moved as required to achieve coordination. The pickup current of the relay is determined by the current transformer ratio and the tap setting of the relay.

The pickup current selection provides the flexibility to move the characteristic left and right on the coordination plot, and the time dial provides adjustment up and down.

Characteristics of time-current relays have historically been defined as either inverse or definite time. The definite-time relay operates within a given time regardless of the magnitude of the current, as long as the current is generally several multiples of minimum pickup and below the saturation limit of the current transformers.

The inverse time-delay relay has an operating time that is inversely proportional to the current magnitude. In other words, the higher the fault current magnitude, the faster the relay operates. Manufacturers may also offer other types of relay characteristics, such as a fixed-time curve, I^2t curve (i.e., a form of inverse-time curve), and curves corresponding to different international standards.

Within the inverse characteristic, several families of curves exist with different degrees of inverse. When exposed to a given input current above the minimum pickup value and with identical time-dial settings, an extremely inverse relay operates faster than a very inverse relay, which in turn operates faster than a standard inverse relay. Figure 2.1 below shows the relative invers shape and of the characteristics.

The relay having an inverse or very inverse characteristic is most commonly used, and ideally the same inverse characteristic is used throughout the system. Selection of relay curve characteristics is often based upon preferences or standardization. In other words, the application is more of an art than a science [6].

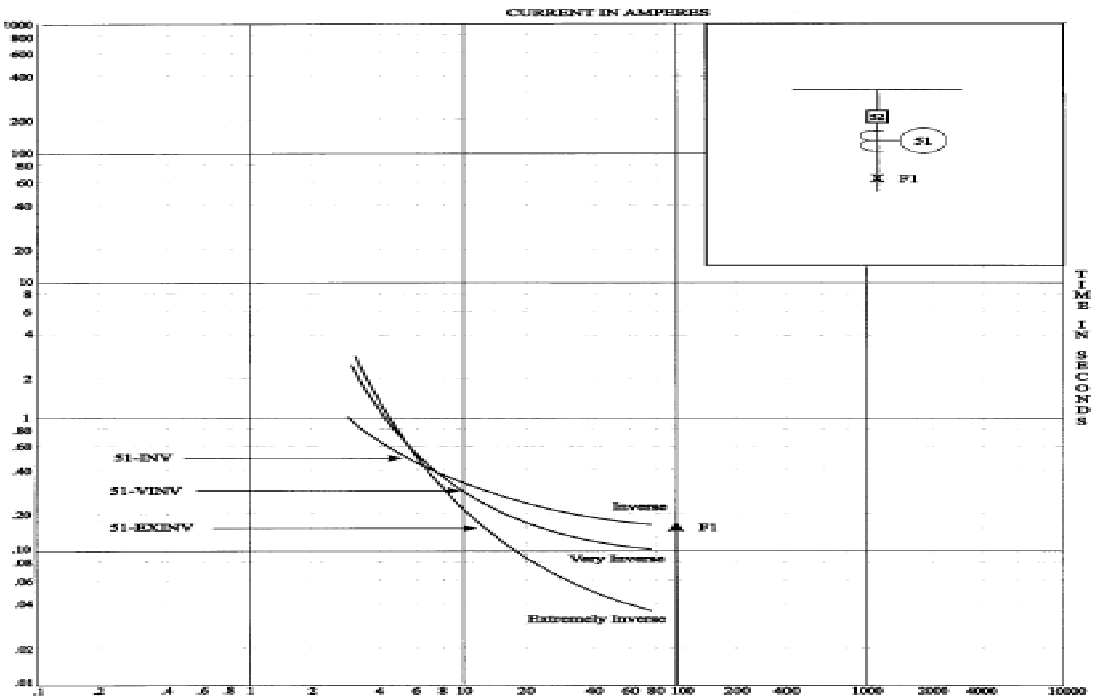


Figure 2.1: Different Time-Current Curves Of a typical relay

Circuit breakers, Re-closers and fuses are the most used protection devices in power distribution system. In the case of medium-voltage circuit breakers, the sensing devices are separate current transformers and protective relays or combinations of relays. A fuse is both a sensing and interrupting device, but not a switching device. It is connected in series with the circuit and responds to thermal effects produced by the current flowing through it.

A re-closer is a device with the ability to detect phase and phase-to-ground overcurrent conditions, to interrupt the circuit if the overcurrent persists after a predetermined time, and then to automatically reclose to re-energize the line. If the fault that originated the operation still exists, then the re-closer will stay open after a preset number of operations, thus isolating the faulted section from the rest of the system. In an overhead distribution system between 75 to 95 per cent of the faults are of a temporary nature and last, at the most, for a few cycles or seconds.

Thus, the re-closer, with its opening/closing characteristic, prevents a distribution circuit being left out of service for temporary faults.

Typically, re-closers are designed to have up to three open-close operations and, after these, a final open operation to lock out the sequence. One further closing operation by manual means is usually allowed. The counting mechanisms register operations of the phase or ground-fault units which can also be initiated by externally controlled devices when appropriate communication means are available. The operating time/current characteristic curves of re-closers normally incorporate three curves, one fast and two delayed.

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

Re-closers are used at the following points on a distribution network:

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

When installing re-closers it is necessary to take into account the following factors:

- System voltage
- Maximum load current
- Minimum short-circuit current within the zone to be protected by the re-closer
- Coordination with other mechanisms located upstream towards the source, and downstream towards the load
- Sensitivity of operation for ground faults

The voltage rating and the short-circuit capacity of the re-closer should be equal to, or greater than, the values that exist at the point of installation. The same criteria should be applied to the current capability of the re-closer in respect of the maximum load current to be carried by the circuit.

2.3.1 COORDINATION

Protection in a system uses to detect and isolate the affected portion of the system whenever a short circuit or other abnormality occurs that might cause damage to, or adversely affect the operation of any portion of the system or the load that it supplies.

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

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

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

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

If the power system is automated or semi-automated a separate zone of protection is normally established around each system element. This practice logically divides the system into protective zones. Any failure occurring within a protection zone sends a trip signal to circuit breakers serving that zone to isolate the faulted equipment from the rest of the system.

Protection zones are classified as primary and/or backup. The primary protective relays are the first line of defense against system faults and operate first to isolate the fault. When a fault is not isolated after some time delay, backup protection clears the faulted equipment by re-tripping the primary circuit breakers or by tripping circuit breakers in adjacent zones. When adjacent zones are tripped by backup protective relays, more of the power system is removed from service.

The protection zones generally overlap to ensure no portion of the power system is left unprotected. Also, primary and backup protection systems should be selectively coordinated by current magnitude, time, fault type, direction, temperature, etc.

On designing protection system coordination it may differ from system to system because of economic considerations, equipment availability, system topology and others.

The time-overcurrent relay has an operating characteristic such that its operating time varies inversely as the current flowing in the relay. The three most commonly used time-overcurrent characteristics are inverse, very inverse, and extremely inverse. These curves differ by the rate at which relay operating time decreases as the current increases. In practice, selectivity between overcurrent relays protecting different system elements can be obtained on the basis of sensitivity (pickup) or operating time or a combination of both, depending on the relative time-current characteristics of the particular relays involved.

The main protection should clear a permanent or temporary fault before the backup protection operates, or continue to operate until the circuit is disconnected. Loss of supply caused by permanent faults should be restricted to the smallest part of the system for the shortest time possible.

The economic costs and the benefits of a protection device should also be considered to arrive at a suitable balance between the requirements of the scheme and the available financial resources.

In most modern relays the time dial settings can start from values as low as 0.1s, and goes to as high as 20s. In distribution systems where it is possible to increase the loading on feeders under emergency conditions, the minimum pickup current setting is usually two times the nominal circuit current. And in order to make sure that the relay is able to trip under fault condition, the maximum pick up current is usually chosen to be half of the smallest single phase to ground fault current [7].

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

$$T_{i,j} = \left(\frac{A_k}{(I_{ij}/I_{Pi})^{c_k - 1}} + B_k\right) x TDS_i \qquad (2.5)$$

Where $T_{i,j}$ is the operation time of relay i for a fault at location j, TDS_i is the time dial setting for rely i, I_{Pi} is the pickup current of relay i, I_{ij} is the fault current passing through the relay *i* for a fault at place *j*, and *A*, *B* and *C* are constant values to provide selected curve characteristics. It can be seen from the equation that the non-linearity comes from the pickup current term.

By adjusting the physical design parameters different time current characteristic can be implemented. The time current characteristics are classified according to the steepness of the curves and the overall time delay as:

- Short time
- Long time
- Definite Minimum
- Time Moderately Inverse
- Inverse
- Very Inverse, and
- Extremely Inverse

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

TABLE 2.1: CONSTANTS AND EXPONENTS FOR STANDARD CHARACTERISTICS OF OVERCURRENT RELAYS

Characteristic	A	B	C
Moderately Inverse	0.0515	0.114	0.02
Very Inverse	19.61	0.491	2
Extremely Inverse	28.2	0.1217	2

Recloser-Relay Coordination

Two factors should be taken into account for the coordination of these devices; the interrupter opens the circuit some cycles after the associated relay trips, and the relay has to integrate the clearance time of the recloser. The reset time of the relay is normally long and, if the fault current is re-applied before the relay has completely reset, the relay will move towards its operating point from this partially reset position [8].

Recloser - Recloser Coordination

The downstream re-closer must be faster than the upstream re-closer, and the clearance time of the downstream re-closer plus its tolerance should be lower than the upstream re-closer clearance time less its tolerance. Normally, the setting of the re-closer at the substation is used to achieve at least one fast re-closure, in order to clear temporary faults on the line between the substation and the load re-closer. The same procedure and science is followed for relay-relay and relay - recloser coordination [8].

All protection settings and the reclosing pattern shall be configurable by both operator panel and a computer which is connected remotely or locally. A minimum of four (04) tripping operations to lockout shall be provided and the number and sequence of operations to lockout shall be adjustable in the field.

The applicable over current tripping shall be of the instantaneous, standard inverse, very inverse and extreme inverse types as per IEC 60255-149 and the tripping current/time delay setting range shall be 25% - 150% of rated current for over current and 5% to 50 % of the rated current for earth fault. Inrush restraint facilities shall be also provided. The tripping current/time delay setting range for earth fault and sensitive earth fault tripping shall be 5 second to 180 seconds. If the fault is cleared by any one of the auto recloser trip operations and the auto recloser remains closed, it shall reset itself for another complete sequence of operations. The reset time shall be adjustable from 5-180sec [9].

2.4 Literature Reviews

The research publications which are related to power distribution system reliability enhancements are discussed in this section. Power interruption becomes a serious problem in the country, Ethiopia, and the entire nation always complains about it. Distribution system automation is a must-do work by utilities to improve their system reliability and to satisfy their customers. The distribution systems need to be automated to improve their reliability, efficiency, and service quality.

In 2006, D. O. Koval and A. A. Chowdhury [10] presented a basic new restoration methodology for distribution system configurations that maximizes the amount of load that can be restored after a grid blackout, substation outage and distribution feeder line section outages and evaluates the cost of load point interruptions considering feeder islanding and substation capacity constraints. Several case studies with restoration procedures are presented and discussed to clearly reveal the impact of distribution system capacity constraints on load point reliability indices and the cost of load point interruptions.

In 1975, Merlin and Back [11] proposed a branch and bound type heuristic method to determine the network configuration to enhance distribution system reliability and for minimum line losses. Its solution scheme starts with a meshed network by initially closing all switches in the network. The switches are then opened one at a time until a new radial configuration is reached. In this process the switch to be opened at each stage is selected in order to enhance distribution system reliability and to minimize line losses of the resulting network.

Sung-Yul Kim, Student Member of IEEE and Jin-O Kim, Senior Member of IEEE [12], have proposed an evaluation technique for distribution reliability that uses the improved failure rate of all protective devices in a network, depending on location of the superconducting fault current limiter. As a result, it is expected that the SFCL makes the reliability of adjacent equipment on an existing network improve, and these changes are analyzed. In addition, in order to apply the effect of the intermittent output of renewable-energy sources, distribution reliability indices were redefined in this paper. Case studies verify that the SFCL is effective in reducing fault currents and improving distribution reliability. These effects are analyzed with respect to the location of the SFCL in a case study system.

A fuzzy knowledge based approach for reliability evaluation of a distribution network presented by M.R Emjedi, K.Awodele, S.Chowdhury, and S.P.Chowdhury together [13]. This approach makes a direct assessment of the network configuration, distribution substation, the maintenance policy and the weather and assigns to the network under consideration a reliability index by expressing those variables mathematically using fuzzy logic. Results obtained using the fuzzy model on actual utility data are presented and compared to historical reliability indices.

CHAPTER THREE

3 Evaluation and Analysis of the Existing System

3.1 Introduction

This chapter deals with the methodologies used for data collection and the design procedures for the existing system.

3.2 Site Description

Jimma is located at the geographical coordinates of 7^0 40'22.1" N and 36^0 50'32.9"E and is 354 km away from Addis Ababa, capital of Ethiopia. It covers an area of about 50.52 sq. km with an elevation of 1780 meters above sea level. Based on the figures from the central statistical agency in 2005, this town has an estimated total population of 159,009.

Figure 3.1: Geographical Map of Jimma Town

Jimma is one of the oldest towns in south-western part of Ethiopia. It is one of the three largest zones in Oromia region along with Illuababor and Wollega. Western region, Jimma, is one region according to the Ethiopian electric utility hierarchies, which has a total of 14 regions country wise. Western region consists of 26 districts (Customer service centers) of which two of them are located in Jimma town.

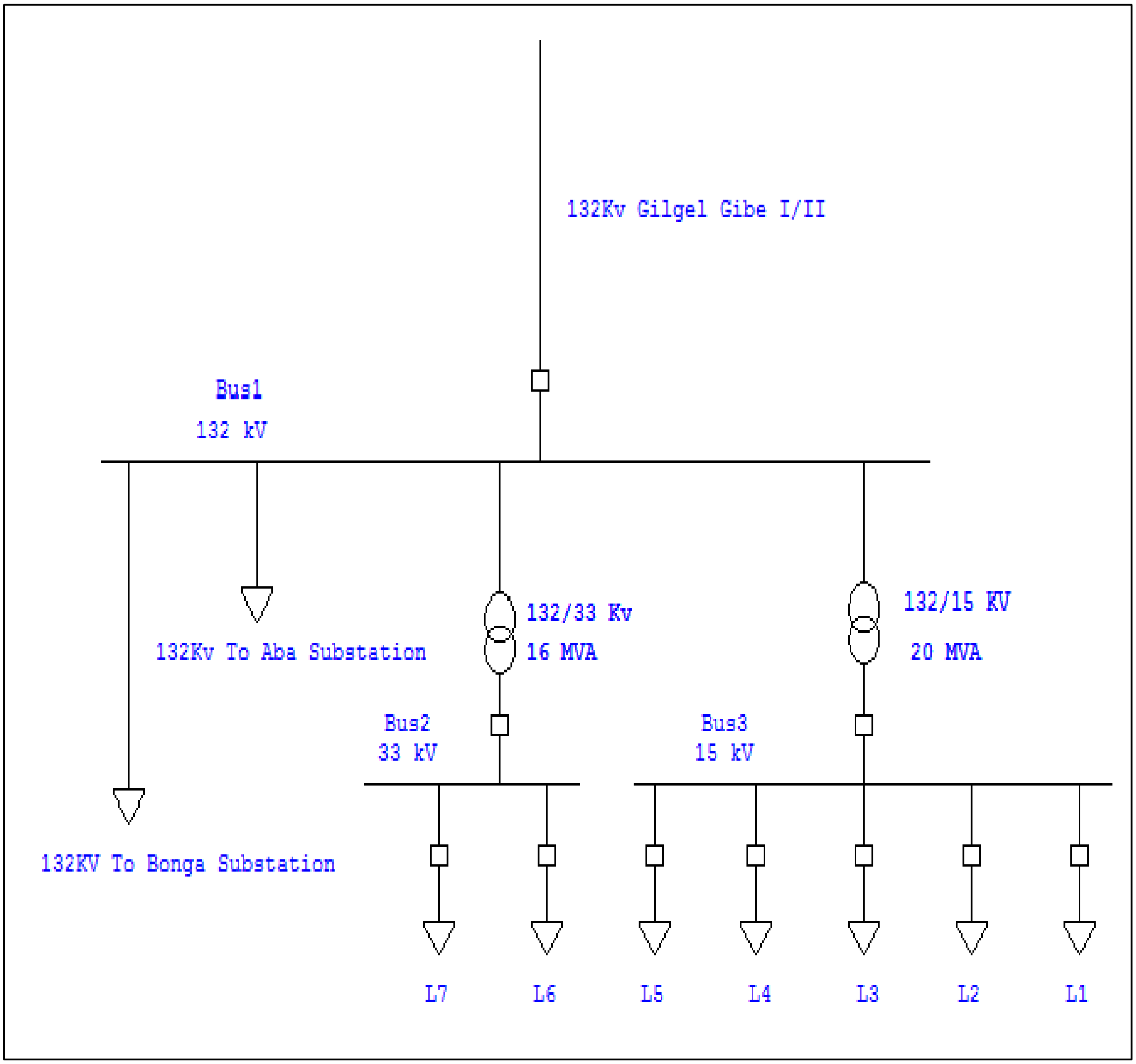
Jimma Distribution System

Jimma od substation supplies electric power to Jimma town and the nearby areas and it receives power via 132kv power lines from power plants Gilgel Gibe I & II in synchronized mode. The 132kv is stepped down and distributed by 15 and 33kv feeders.

The Substation consists of 7 outgoing feeders. The nominal voltage of the five feeders is 15 kV and the remaining two feeders is 33kV. As per the data found from western region billing office, western region has a total of 138,665 customers and from theses the two districts in Jima town have approximately 28000 customers served.

Jimma substation was installed at the end of 1979 E.C (1987) with a power transformer capacity of 6.5 MVA by a company from Finland. At around 1997 E.C the power transformer upgraded to 20MVA, 132/15kv and another 16MVA, 132/33kv was added in the substation by Company from china. The 15kv medium voltage feeders were renamed by the local names of the area they distributed in the town. These are: Kochi line, City line, Agri Line (Agriculture Campus and nearby customers), Jimma University Line (Main campus) and Kitto Furdesa Line (Engineering Campus). 33kV lines are used for far flung rural areas which has to be extended further in order to cover all the rural electrification activities (Shebe Sembo and Limu Genet) whereas the town and nearby rural areas are served by 15kV medium voltage (MV) lines. Figure 3.3 shows distribution feeders' schematic diagram of Jimma old Substation.

FIGURE 3.2: Jimma old substation



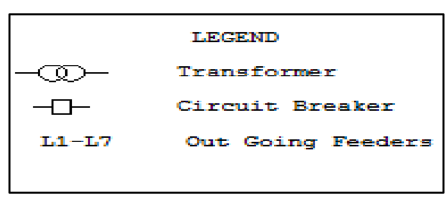


FIGURE 3.3: Schematic diagram of Jimma old Substation outgoing feeders

From the five 15KV feeders, City line is serving customers found in the center of the city and is extended to Dedo and Miteso, which are around 40km away from Jimma town. Commercial centers like Bishishe, Merkato, Mentina and other major areas are served by this feeder. Big hotels, Small and micro industries, banks, most administrative offices, telecommunication BTSs, schools and large number of residential customers get electricity from this feeder. City line is represented by L3 as depicted in figure 3.3 according to the breakers arrangement in the control room (figure 3.4). Current Transformer (CT) rating of city feeder is 400/5 A. This primary distribution feeder delivers power from the old substation to distribution transformers. It begins with the feeder breaker at the distribution substation and exits the substation in a concrete duct bank (feeder get-away) and routed to a nearby pole.

The main primary feeder branches into various primary laterals which in turn separates into several sub laterals to serve all the distribution transformers. The main feeder and sub feeders before the transformer are three phase three wire circuits and the laterals are three phase four wire or single phase two wire circuits

FIGURE 3.4: JIMMA OLD SUBSTATION CONTROL ROOM

A new substation is under construction in Jiren about 8 kilometers away from the center of Jimma town. The 230KV incoming lines are from Gilgal Gibe I & II and also planned to get power from Fincha power plant via Nekemt - Bedele -Agaro HV power line during an outages of Gilgal Gibe I & II. There are 40MVA, 230/132 KV and 40MVA, 230/15KV large power transformers in the substation. The breakers are vacuum and SF6. The new substation is located on the other end of the town almost in the opposite side of the old substation, which makes reconfiguration of the existing distribution system simple.

FIGURE 3.5: JIMMA NEW SUBSTATION

3.3 Data Collection

Primary data has been collected by the direct involvement of the researcher and workers of EEU from Jima for the purpose that is intended to be done.

During the site survey, the primary data necessary for this study were the length of the feeder, rating and type of each transformer, topology and layout of the system, conductor type, topography and others.

TABLE 3.1: NAME AND VOLTAGE LEVELS OF JIMMA SUBSTATION OUTGOING FEEDERS

Feeder Name	**Voltage Level in KV**	**Circuit Breaker Type**	**CT Ratio and Maximum Load**	**Peak Load in MW, 2015**
Kochi Line =L1	15	*Oil Circuit Breaker*	*300-600/5/5 A, (4MW)*	5.2
Jimma University =L2	15	*Oil Circuit Breaker*	*75-150/5/5A, (3.3 MW)*	1.2
City Line = L3	15	*Oil Circuit Breaker*	*200-400/5/5A, (4 MW)*	*5.4*
Kitto Furdisa = L4	15	*Oil Circuit Breaker*	*75-150/5/5A, (3.3 MW)*	1
Agri Line = L5	15	*Oil Circuit Breaker*	*150-300/5/5 A (2 MW)*	3.2
Limmu Line= L1	33	*Vacuum Circuit Breaker*	*75-150/1/1A (3.5MW)*	0.8
Shebe Sembo Line= L2	33	*Vacuum Circuit Breaker*	*75-150/1/1A (3.5MW)*	0.8

TABLE 3.2: LINE DATA FOR THE SELECTED FEEDER

Line Name	Length of Line			Line Name	Length of Line		
	From	To	Km		From	To	Km
Ln1	B1	B2	0.6	**Ln46**	B76	B77	0.4
Ln2	B2	B3	0.25	**Ln47**	B76	B79	0.4
Ln3	B3	B5	0.25	**Ln48**	B79	B80	0.35
Ln4	B2	B7	0.2	**Ln49**	B80	B82	0.5
Ln5	B7	B8	0.15	**Ln50**	B82	B84	0.3
Ln6	B7	B10	0.4	**Ln51**	B84	B86	0.3
Ln7	**B10**	**B12**	**0.4**	**Ln52**	**B86**	**B88**	**0.15**
Ln8	B12	B14	0.1	**Ln53**	B79	B90	0.15
Ln9	B14	B15	0.2	**Ln54**	B90	B91	1.35
Ln10	B15	B17	0.2	**Ln55**	B90	B94	0.4
Ln11	B17	B19	0.15	**Ln56**	B94	B96	0.25
Ln12	B14	B21	0.4	**Ln57**	B96	B98	0.9
Ln13	B21	B22	0.15	**Ln58**	B98	B100	0.55
Ln14	B21	B24	0.45	**Lin59**	B65	B102	0.2
Ln15	B24	B26	0.3	**Ln60**	B102	B103	0.2
Ln16	B26	B28	0.05	**Ln61**	B103	B104	0.25
Ln17	B28	B29	0.05	**Ln62**	B103	B106	0.25
Ln18	B29	B31	0.1	**Ln63**	B106	B108	0.4
Ln19	B28	B33	0.1	**Ln64**	B108	B110	0.05
Ln20	B33	B34	0.1	**Ln65**	B110	B111	0.15
Ln21	B33	B36	0.15	**Ln66**	B110	B113	0.25
Ln22	B36	B37	0.15	**Ln67**	B113	B115	0.05
Ln23	B37	B39	0.6	**Ln68**	B115	B116	0.4
Ln24	B39	B41	0.4	**Ln69**	B116	B117	0.25
Ln25	B36	B43	0.05	**Ln70**	B116	B119	0.4
Ln26	B43	B44	0.35	**Ln71**	B115	B121	0.2
Ln27	B43	B46	0.35	**Ln72**	B121	B123	1.15
Ln28	B46	B47	0.2	**Ln73**	B123	B125	0.2
Ln29	B46	B49	0.25	**Ln74**	B125	B127	0.35
Ln30	B49	B51	0.15	**Ln75**	B127	B128	5.4
Ln31	B51	B53	0.15	**Ln76**	B128	B130	2.4
Ln32	B53	B54	0.65	**Ln77**	B127	B132	0.12
Ln33	B54	B56	0.3	**Ln78**	B132	B134	0.54
Ln34	B53	B58	0.4	**Ln79**	B134	B136	1.8

Ln35	B58	B60	0.25	**Ln80**	B136	B138	3.6
Ln36	B60	B61	0.1	**Ln81**	B138	B140	2.16
Ln37	B60	B63	0.3	**Ln82**	B140	B142	3
Ln38	B63	B65	0.25	**Ln83**	B142	B144	2.52
Ln39	B65	B66	0.025	**Ln84**	B144	B146	2.52
Ln40	B66	B67	0.025	**Ln85**	B146	B148	0.72
Ln41	B67	B68	0.05	**Ln86**	B148	B150	0.54
Ln42	B67	B70	0.2	**Ln87**	B150	B152	0.6
Ln43	B70	B72	0.2	**Ln88**	B152	B154	0.42
Ln44	B72	B74	0.6	**Ln89**	B154	B156	1.38
Ln45	B74	B76	0.1	**Ln90**	B156	B158	5.4
Total			**10.85**		**+**		**43.87**

One basic parameter for design of the existing system using the software (ETAP 12.6.0) is length of the line. The total length of the feeder has been segmented based on the location of tap points and transformers. The segments were represented as Ln1, Ln2, Ln3… Ln90. All successive lines were connected by nodes: B1 to B158. The total length of the feeder was summed up 54.72km.

TABLE 3.3: TRANSFORMER AND CUSTOMER DATA OF CITY LINE

City Line Transformer Data				
No.	**Specific area/ Location**	**Transformer size in KVA**	**#Estimated Customers served**	**Manufacturer and year**
1	Jima Agriculture College Telecom network	25	1	India 2009
2	Ethiopian Electric utility – W/Region office	25	1	India 2007
3	Medhani Alem	315	325	China 2003
4	Museum	250	215	Maribor/cubical
5	Photo Park	200	187	China 2003
6	National Hotel (Beherawi Hotel)	200	243	
7	Hermata kebele 05	200	267	India 2009
8	Gumruk office, Telecom network	25	1	India 2007
9	Kebede Hotel	200	223	2009
10	Tana area, Tana sefer	300	230	1968
11	Merkato telecom network	50	1	India 2007
12	Aba Mecha Grain mill Trafo	200	220	India 2007
13	Merkato Near tele ntk	315	207	
14	Mentina, Hermata	315	278	1971
15	Mentina, Alebachew Grain mill	315	315	Italy 2002
16	Hamle School telecom network	25	1	INDIA 2007
17	Abajihad grain mill	200	287	
18	Ababadeg area,ababadeg sefer	200	255	
19	Bishishe Market center	315	267	INDIA 2007
20	Bishishe Leghar	200	223	INDIA 2007
21	Geenu Hotel	315	332	
22	Jimma Central Hotel	315	123	
23	Studium Telecom Network	25	1	INDIA 2007
24	Kulober (Kebede Wakene area)	100	65	INDIA
25	Abegaz Hotel	200	221	ZENNARO
26	PEPSI	200	214	ZENNARO
27	Sojat bakery	100	1	
28	Around Adugna Garage Telecom network	25	1	INDIA 2007
29	Mesfin Garage	315	169	METEC 2000
30	Rikardo garage	315	231	Italy 1996
31	Hasen garage (around Thehay Abebe's home)	200	180	CROATA 2001
32	Addisu Gebeya ECX Condominium	315	167	METEC 2004
33	Mars bakery	200	1	METEC 2005
34	Marse no.4 (near Grima Gezahegn Home)	315	298	china 2003
35	behind Agip School Telecom Network	50	1	India 2007
36	Mars no.4 (near Somarya Salon)	200	1	METEC 2005

37	Woreda Court Condominium	200	188	METEC 2005
38	Ambayee wood Work(garage)	200	89	INDIA 2009
39	Eldan School Main gate	315	237	METEC 2007
40	Technique Amede Grain mill	315	343	METEC 2006
41	Technique Pottery Telecom network	25	1	INDIA 2009
42	Trade and Trusim	315	323	India 2007
43	Kulober behind Gidey Grain MIll	280	101	PAUWELS 1988
44	Near old Soap factory	315	152	ZENNARO 1995
45	Slaughterhouse(Arogie Qera)	200	166	China 2006
46	Shenen Gibe Hospital (Zone Drug Store)	50	1	China 2003
47	Slaughterhouse(Qera) Telecom Network	25	1	INDIA 2009
48	Berkume	100	144	China 2004
49	Behind Shenen Gibe Hospital	100	131	China 2004
50	Slaughterhouse(Qera) SOS School	315	240	METEC 2004
51	Bechobere, Bore Trafo	200	260	Italy 1995
52	Yifredew and his families floor mill	100	47	
53	Rishad floor mill- Kolobo	100	50	Ethiopia2008
54	Waro kolobo	100	80	
55	Buchena floor mill	100	39	Ethiopia2007
56	Dilbi Tele Network Transformer	50	1	India2013
57	Berata	100	113	Lepper dominit1974
58	Berata (Dingay kesel)	50	1	Ethiopia2007
59	Dedo Tele Network near to cattle market	25	1	Ethiopia2008
60	Dedo marketing area	200	187	WSWujiang2007/8
61	Dedo Administration	200	199	China2003
62	Sheger	200	161	Ethiopia2005
63	Dedo Tele Network Transformer	50	1	Croatio2000
64	Keta Town center	200	184	China2006
65	Dedo TVET	100	15	Italy2002
66	Gerima Tele Network Transformer	25	1	Ethiopia2001
67	Near She Siraj floor mill -Meteso	50	41	India2009
68	Around Meteso health center	50	38	India2009
Total		**11720**	**9289**	

Each transformer ratings, local name of their specific locations and number of customers connected on each transformer are clearly shown in Table 3.3.

TABLE 3.4: SUMMARY OF RELIABILITY INDICES OF CITY FEEDER FOR YEARS 2010-2015

Reliability indices	Unit	2010	2011	2012	2013	2014	2015	Average of Six Years
SAIDI	Hrs./customer/yr.	237	181	238	203	302	471	272
SAIFI	Int./customer/yr.	241	302	480	424	461	705	435.5
CAIDI	Hrs./Interruptions	0.9	0.6	0.49	0.48	0.66	0.67	0.62
EENS	MWH	311	335	441	721	851	1458	686.2

The summary of interruption data from the years 2010 to 2015 was selected as a base year for the system to predict its future reliability performance. As it is bulky to put the detailed interruption data of each year as part of this document, only interruptions data of year 2010 was selected as a sample and placed in the Appendix A.

3.4 Causes of Power Interruptions

In Jimma each interruption, interruption duration and loads of each feeder per hour is recorded but the causes of interruptions are not described. But to put an appropriate mitigation technique for the reliability problem in the case study area; it is critical knowing the causes of interruptions. To know the causes of interruptions discussions and questioners were prepared to the employees and longtime daily workers (they are working techniques for longtime as employees of the utility). The questioner was prepared to describe the common causes of interruptions in the selected feeder for the last six years. After selected the causes of interruptions the experienced employees have been requested in order to categorize the causes according to the degree of contribution. It was very difficult to categorize the causes, at the end of the discussion respondents decided to put their agreement level. For the purpose of determining the degree of contribution of each factor the point is assigned for the agreement level from one up to five points. The allocation of the point is 5 for strongly agree, 4 for agree, 3 for neutral, 2 for disagree and 1 for strongly disagree. Accordingly table was prepared and 43 employees (i.e. emergency operators, distribution technicians, Jimma-2 customer center technicians, some distribution managers and managers have worked for long time in the distribution but now working in another task of the utility) and seven experienced daily laborers have given their response. The questioner was prepared in Amharic and the agreement levels with their translated English meaning were: ‘Betam Esmamaloh’ /strongly agree/, ‘Esmamaloh’ /Agree/, ‘Enie Enja’ / Neutral/, Alsmama’ /disagree/ and ‘Fetsimo Alsmamam’ / strongly disagree/.

Based on their response as depicted in Table 3.5, feeder overloading ranked in the first place followed by tree contact and windy rain with scheduled interruptions and unknown causes ranked fourth and fifth place respectively. The factors ranked at the top have a high degree of contribution for the electric power interruptions.

From the questioner and discussion with the senior technicians, substation and emergency operators, top managers and experienced laborers, the most common causes of interruptions are: trees, overload, windy rain, lightning, accidents, Animals, scheduled interruptions, human error, generation outage, equipment malfunction, unknown causes of interruptions and others.

Tree

Per the discussion with line technicians trees are identified as cause of power interruption. Tree trimming, periodically pruning vegetation adjacent to power lines to ensure safe and reliable clearances, is a critical utility activity. Many customers have extremely negative responses to tree trimming.

In Ethiopian Electric utility Western Region, Jimma, tree trimming is held occasionally once in one, two or three. Tree trimming should always be performed by a trained crew to ensure safety, maintain tree health and direct re-growth away from conductor location. But in Jimma area trimming is performed by the community and it is not done as per standard.

Over Load

Based on the questionnaire and the discussion conducted with line technicians overload is ranked first as a cause of power interruption. Transformers, lines and equipments are overloaded above their capacity, as more and more customers are connected to already existing distribution system.

Scheduled Interruptions

It is sometimes necessary to interrupt customer service when performing work on radial distribution systems. Since this work is scheduled in advance, customers can be notified as to the time and expected duration of the interruption. Advance knowledge greatly reduces the economic impact and negative perception that interruptions have on customers. Certain types of distribution maintenance require equipment to be de-energized and grounded. During maintenance, all customers downstream of the maintenance location will experience interruptions unless they can be fed from an alternate path. Even if the system can be reconfigured to restore certain customers, short interruptions may be necessary since many switches can only be switched while de-energized. Even if all switches are capable of making and breaking load, operating the system as a temporary network may be unacceptable and customer interruptions may be required.

Feeder expansions also require scheduled interruptions. Since the expansion location must be de-energized before a feeder extension can be connected, all customers downstream of this point (on the original feeder) may need to be interrupted. The use of live-line construction techniques can avoid these types of interruptions.

Human Errors

Mistakes, carelessness and improper works (Daily labors and junior technicians) by utility workers often result in customer interruptions. The utility Workers who have informal relationship with contraband traders interrupt the line when they need. Carelessly cut down of trees and dropping heavy branch over power distribution lines causes long time power interruptions. People from small towns, in between Jimma town and Dedo woreda, with no electricity access frequently throws conductors over the power lines and causes interruption.

Vehicle Accidents

Speeding automobile, illegal drivers (Getting the license in formally or with no license or not good in driving), drunk drivers and others accidentally striking a wooden distribution pole and usually causes the pole to lean, causing unsafe line clearances and requiring repair. These collisions may also result in a fault by causing conductors to swing together, sagging lines into the ground or damaging the pole entirely. Vehicles loaded with height above the line clearance also causes conductors to damage, to swing together and poles to knock over.

TABLE 3.5: SUMMARY OF QUESTIONNAIRES ABOUT CAUSES OF POWER INTERRUPTION

No.	Causes of interruptions	Contributing factor agreement levels					Total points	Rank
		Strongly Agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**		
1	Feeder Overloaded	30	9	6			204	1
2	Tree contact	16	23	4	2		188	2
3	Wear out and Failure of distribution Materials	5	17	8	9		135	7
4	Windy rain	10	30	5			185	3
5	Vehicle accidents on distribution equipment	5	7	15	10	8	126	9
6	Scheduled Interruptions	15	20	5	5		108	4
7	Human errors	5	14	16	5	5	144	6
8	Supply outage/Gibe I &II/	1	6	13	19	6	112	11
9	Employees skill gaps or errors	3	7	11	15	14	120	10
10	Natural phenomenon		3	22	13	7	111	12
11	Animals and birds		3	30	12		126	9
12	Unknown	7	25	10	3		171	5
13	Others		5	34	6		134	8

Furthermore, many reasons for prolongation of the outage durations were identified. Some of them are: lack of automatic fault detectors, shortage of maintenance tools, shortage of man power, communication gap between substation operators and distribution workers, unnecessary scheduled outages.

3.5 Reliability Cost And Worth

Overview

Power systems exist in order to provide, as economically and as reliably as possible, electrical energy to the customer. It is known truth that the reliability of a system can be increased by increased investment. At the same time, the outage costs of the system will decrease and this leads to the concept of an optimum reliability. The essential problem in applying the concept of optimum reliability is lack of knowledge of true outage costs and the features that should be included.

The outage costs have seen by the utility' and the customer. The utility outage costs include: loss of revenue from customers not served; loss of customer goodwill; increased expenditure due to maintenance and repair. Costs seen by the customer and most of these are extremely difficult, if not impossible, to quantify. They include: costs imposed on industry due to lost manufacture, spoiled products, damaged equipment, extra maintenance and costs imposed on residential customers due to spoiled deep frozen foods, alternative heating and lighting costs, etc. [14].

Outage Cost Evaluation

Access to electricity supplies at reasonable cost and quality levels has become a basic condition for development, economic growth and welfare. The more developed societies are, the more vulnerable they are to electricity supply interruptions. This dependence on reliable electricity supplies implies that costs are associated with power interruptions.

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

For small industries, electricity supply interruption costs are strongly related to production losses and to costs involved in restoring production. In addition, interruptions also cause property damages and revenue loses for industries, commercial customers and for private individuals.

Wide-spread long-lasting blackouts put the vulnerable society to the test and involve extra expenses required to maintain tolerable living conditions. It is difficult to estimate the exact value interruption costs and economical loses, since the properties of each customer are different.

On the utility side power interruption cost is estimated based on customer data, interruption data and cost per outage data.

The number of customers considered in estimating the cost of power interruptions will have a significant impact on the magnitude of the estimate. Substantial uncertainty can result from differences in how customers are defined. It is better to differentiate the type of the customers interrupted whether they are residential, commercial or industrial.

Electricity utilities recorded many data and use different reliability indices for measuring their system performance. In the case study area, Jimma city, power interruptions data are usually recording in the form of interruption duration, interruption frequency and load (MW) reading of each feeder on each hour. From these data it is easy to know the reliability indices, System Average interruption Frequency index (SAIFI), System Average interruption Duration index (SAIDI) and Expected Energy Not Supplied (EENS) of sustained interruptions experienced by customers of each feeder in a year. According to the Institute of Electrical and Electronics Engineers (IEEE), a "sustained interruption" is any interruption that lasts at least five minutes and is not classified as "momentary" [15]. SAIDI represents the average duration of customers' power interruptions, while SAIFI represents the average number of interruptions per customer per year for a specified electricity supply system. By using the recording Mega Watt (MW) load before interruption on each hour, SAIDI and SAIFI data unsold energy (MWH) will be calculated. Energy is a very important term to estimate the interruption cost of the system for a typical year.

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

TABLE 3.6: ETHIOPIAN ELECTRICITY TARIFF SINCE JULY 8, 2006 (1998 E.C)

No.	Tariff Category & Block Identification	Monthly Consumption(kWh)	Birr/kWh)
1	**Domestic**		
	Equivalent Flat Rate		0.4735
	1stBlock	0-50	0.273
	2nd Block	51-100	0.3564
	3rd Block	101-200	0.4993
	4th Block	201-300	0.55
	5th Block	301-400	0.5666
	6th Block	401-500	0.588
	7th Block	Above 500	0.6943
2	**General / Commercial**		
	Equivalent Flat Rate		0.6723
	1stBlock	0 – 50	0.6088
	2nd Block	Above 50	0.6943
3	**Low Voltage Time of Day Industry**		
	Equivalent Flat Rate		0.5778
	Peak		0.7426
	Off - Peak		0.5453
4	**High Voltage Time of Day Industry @ 15KV**		
	Equivalent Flat Rate		0.4086
	Peak		0.5085
	Off - Peak		0.3933
5	**High Voltage Industry @ 132KV**		
	Equivalent Flat Rate		0.3805
	Peak		0.4736
	Off – Peak		0.3664
6	**Street Lighting Tariff**		
	Equivalent Flat Rate		0.4843

Based on the Ethiopian Electric Power Corporate Marketing and sales process Estimation manual, which is currently applicable, interruption cost or unsold electricity is calculated as:

$$\text{Interruption Cost} = \frac{1}{4} \text{x} \left(\text{Total capacity of interrupted transformers(KVA)}\right) \text{x} \left(\text{Total interrupted Hours}\right) \text{x } 0.8 \text{ x } 0.4407) \text{ ETB} \quad (3.1)$$

As shown in the equation above to calculate the interruption cost: summing up the Kilo Volt Ampere (KVA) of the interrupted transformers and multiplying by power factor (0.8) and then divided by one fourth (1/4) gives the average interruption power (Kilo Watt). One fourth indicates the average load used from the capacity of the transformer during the interruption period. Multiplying the load (KW) by total interruption duration (Hr.) and then multiplying by the price per KWh (0.4407 Ethiopian Birr) gives unsold energy or interruption cost. The tariff 0.4407 is taken from the average of the first block tariffs of domestic and commercial customers, which most Ethiopian electricity customers are assumed to be grouped [16].

For example if a driver by accident cut an electrical 15KV power line, and 5 with 200KVA and 2 with 100KVA rating transformers are interrupted for 4 hours by that reason.

$$Interruption\ Cost = \frac{1}{4} x\ 1200(KVA) x\ 0.8\ x\ 4x\ 0.4407 = 423.072\ ETB$$

The driver will pay the sum of material cost for replacement if damaged and the interruption cost 423.072 ETB for Ethiopian Electric Utility (EEU).

For city line, Energy not supplied (MWH) is calculated for the last six years from interruption frequencies, interruption Durations (Hr.) and the Load (MW) before interruptions from the substation recorded data. The cost of energy not supplied is calculated and summarized in Table 3.7 based on exchange rate of the Commercial Bank of Ethiopia on 21 November, 2016 which equates One US Dollar (USD) to22.23 Ethiopian Birr (ETB).

Interruption Cost

$$= Sum\ of\ (Load\ before\ interruption\ (MW) x1000x\ Interruption\ Duration\ \ (Hr))\ \ x\ 0.0198245614\ USD \quad (3.2a)$$

$$\text{Interruption Cost} = \sum_{i=1}^{n} L_i x ID_i \text{ x 1000 x 0.0198245614 USD} \quad (3.2b)$$

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

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

ID_i = Interruption Duration (hr.) for event i

For year 2010:

The unsupplied Energy from Appendix 4 is 311 MW then, 311x1000 = 311000KWH

Interruption Cost = 311x 1000 x 0.0198245614 USD = 6165.439 USD or 137057.7 ETB

By the same procedure the interruption cost for years 2011 to 2015 is calculated and summarized in Table 3.7.

TABLE 3.7: SUMMARY OF ESTIMATED INTERRUPTION COSTS OF YEARS 2010 TO 2015

Year	**Unit**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Average of Six Years**
EENS	MWH	311	335	441	721	851	1458	686.167
Interruption Costs	ETB	137057.7	147635	194349	317745	375036	642540.6	302393.799
Interruption Costs	USD	6165.439	6641.2	8742.63	14293.5	16870.7	28904.211	13602.96

3.6 Data analysis

The primary as well as secondary data obtained are directly or indirectly used to design the existing system of the selected feeder in this research. All the parameters necessary for the system design are calculated and filled accordingly.

As indicated in Table 3.4, the values of SAIFI is the total sum of interruptions in a desired year. SAIDI is equal to the sum of interruption durations in each year and EENS is the product of interruption duration (in hour) and the load (in MW) during that period. CAIDI is calculated by Equation 2.3.

To predict the reliability indices of a distribution system, values of failure rates and mean time to repair for each component are necessary. To estimate the failure rate of the line per kilometer, the total number of outages should be divided by the feeder length (Kilo meters) as indicated in equation (3.3).The average mean time to repair of each failure is computed using equation (3.4). The calculated average failure rate of the line and repair times per km of the existing feeder are 7.96 $(\text{Interruptions/km. year})$and 0.62 *(Hrs. /interruption)* respectively.

$$\mu_A = \frac{\text{Total Number of interruptions}}{(\text{Total feeder length(km))x (Number of years)}} \qquad (\text{Interruptions/km. year}) \qquad (3.3)$$

$$\text{MTTR} = \frac{\textbf{Total Repair Time}}{\textbf{Total number of interruptionss}} \qquad \textit{(Hrs. /interruption)} \qquad \textit{(3.4)}$$

Where,μ_A *= active failure rate of any component*

$MTTR$ *= Mean Time to Repair*

By using the above two equations the basic reliabilities parameters used in ETAP software for reliability analysis are calculated as follow:

$$\mu_A = \frac{(\text{Sum of all the interruptions of the base years})}{\text{Length of the feeder x 6}}$$

$$= \frac{(241+302+480+424+461+705)}{54.72 \ \text{x}\ 6} = \frac{435.5}{54.72} = 7.96 \quad \text{interruptions/km. year}$$

$$\text{MTTR} = \frac{(\text{Sum of all the interruption durations of the base years})}{\text{Length of the feeder x 6}}$$

$$= \frac{((237+181+238+203+302+471)/6)}{((241+302+480+424+461+705)/6)} = \frac{272}{435.5} = 0.62 \ \textit{(Hrs. /interruption)}$$

To estimate the failure rate of a component ETAP 12.6.0 uses combination of active μ_A and passive μ_p failure rates together. μ_A , the active failure rate in number of failures per year per unit length. The active failure rate is associated with the component failure mode that causes the operation of the primary protection zone around the failed component and can therefore cause the removal of the other healthy components and branches from service, after the actively failed component is isolated, and the protection breakers are reclosed. This leads to service being restored to some or all of the load points. It should be noted, however, that the failed component itself (and those components that are directly connected to this failed component) could be restored to service only after repair or replacement. While μ_p is the passive failure rate in number of failures per year per unit length. The passive failure rate is associated with the component failure mode that does not cause the operation of protection breakers and therefore does not have an impact on the remaining healthy components. Repairing or replacing the failed component will restore service [Software Library]. As there is no means of isolating a specific faulty areas in the system, μ_p is assumed as zero in the model.

The feeder has been constructed by 50mm^2, 7stranded, All Aluminum Conductor (AAC). This almost matches with Pirelli Libra Code AAC 49.5mm^2 which is available in ETAP Library. The overhead three phase line mounted on wooden pole of height 12m with triangular configuration. All the distribution transformers are pole mounted, liquid fill type and Oil Natural Air Natural (ONAN) classes.

3.7 System Modeling

As explained in the software help index, Electrical Transient Analysis Program (ETAP) is a fully graphical Enterprise package that runs on different Microsoft Windows operating systems. ETAP is the most comprehensive analysis tool for the design and testing of power systems available. Using its standard offline simulation modules, ETAP can utilize real-time operating data for advanced monitoring, real-time simulation, optimization, energy management systems, and high-speed intelligent load shedding. ETAP allows you to easily create and edit graphical one-line diagrams, underground cable raceway systems, three-dimensional cable systems, advanced time-current coordination and selectivity plots, geographic information system schematics, as well as three-dimensional ground grid systems. The program operation emulates real electrical system operation as closely as possible. For example, when you open or close a circuit breaker, place an element out of service, or change the operating status of motors, the de-energized elements and sub-systems are indicated on the one-line diagram in gray. ETAP incorporates innovative concepts for determining protective device coordination directly from the one-line diagram. ETAP combines the electrical, logical, mechanical, and physical attributes of system elements in the same database. ETAP is one of the foremost-integrated database for electrical systems, allowing engineers to have multiple presentations of a system for different analysis or design purposes. The software uses to analyze different electrical analysis, like reliability, short circuit, load flow, arc flash, protection coordination and others.

In this thesis ETAP 12.6.0 has been used as a design, simulation and reliability assessment analysis tool. Load flow and short circuit analysis used for the study has been calculated. Figure 3.6 shows the project editor view, with the reliability page open. Parameters used in designing and assessment analysis for reliability of any system are those shown on this page.

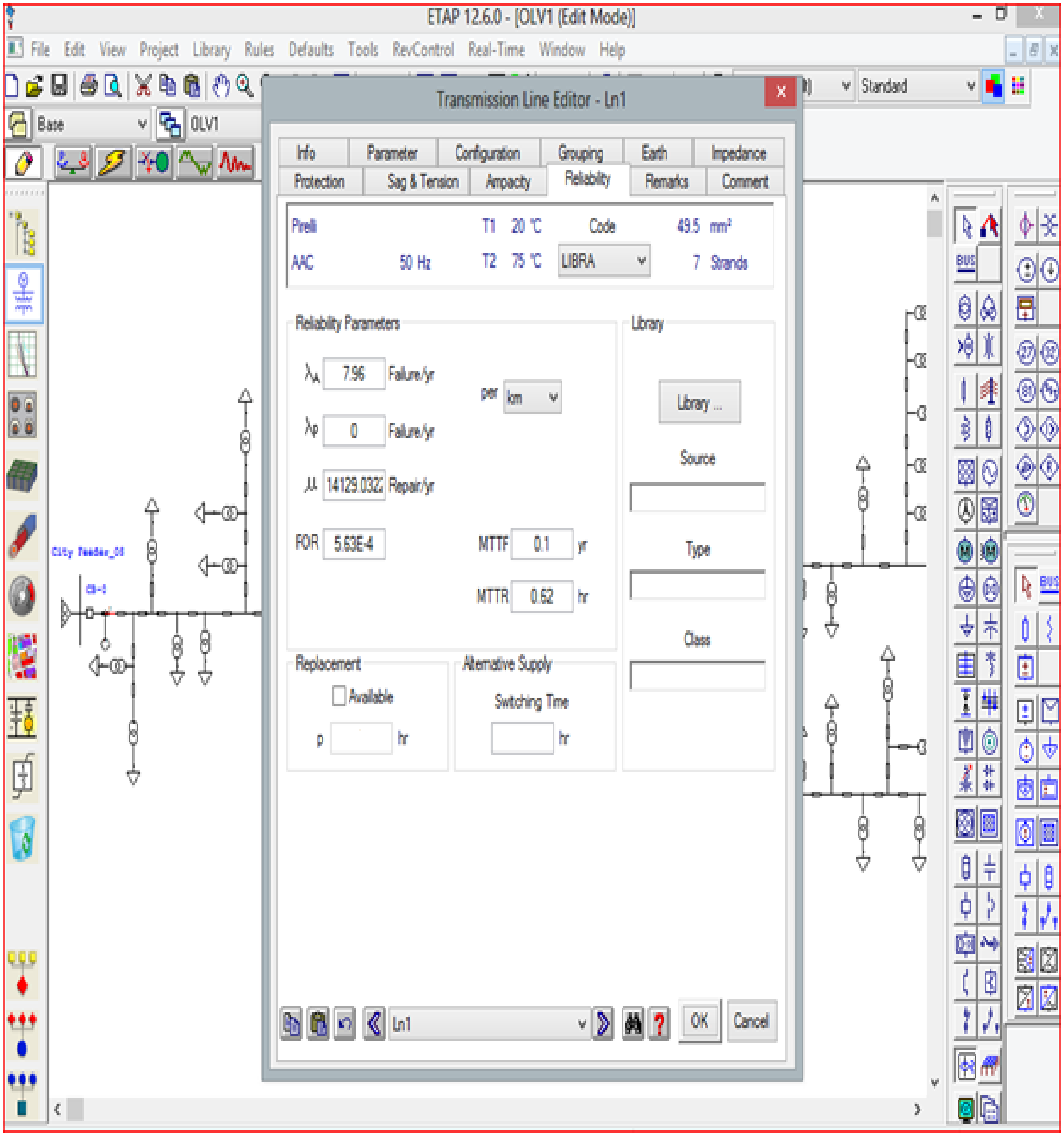
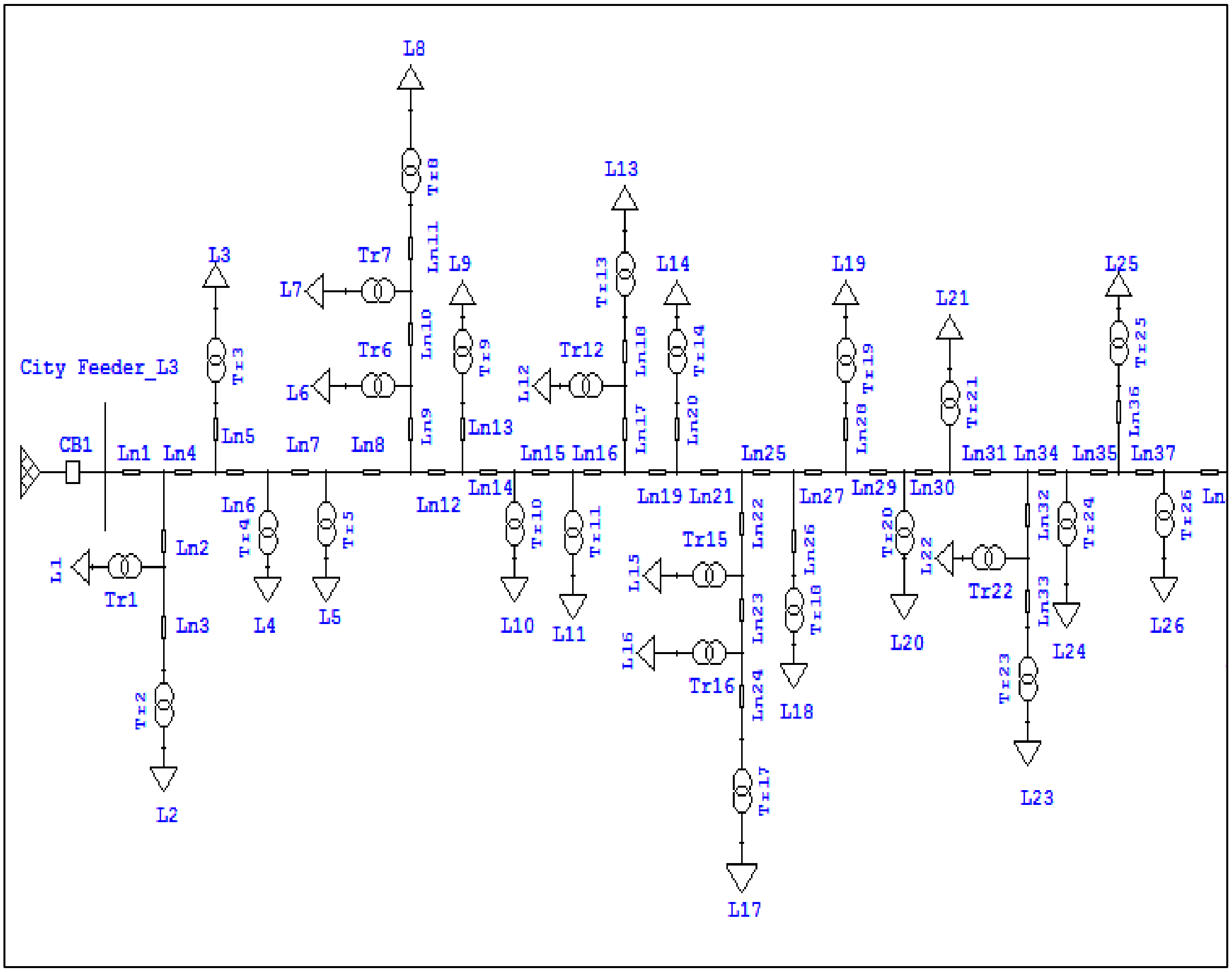


Figure 3.6: Window of ETAP12.6.0 software as reliability page opened

Figures 3.8 shows the complete single line diagram of the existing feeder, whereas figure 3.7 shows part of the system for clarity.



<u>**Legends**</u>

L1-L68 = Load Points on each transformers
Tr1-Tr68 = Transformers
Ln1-Ln90 = Segmented Lines of the Feeder
CB1 = Circuit Breaker

Figure 3.7: Single Line Diagram of the Existing System Partially

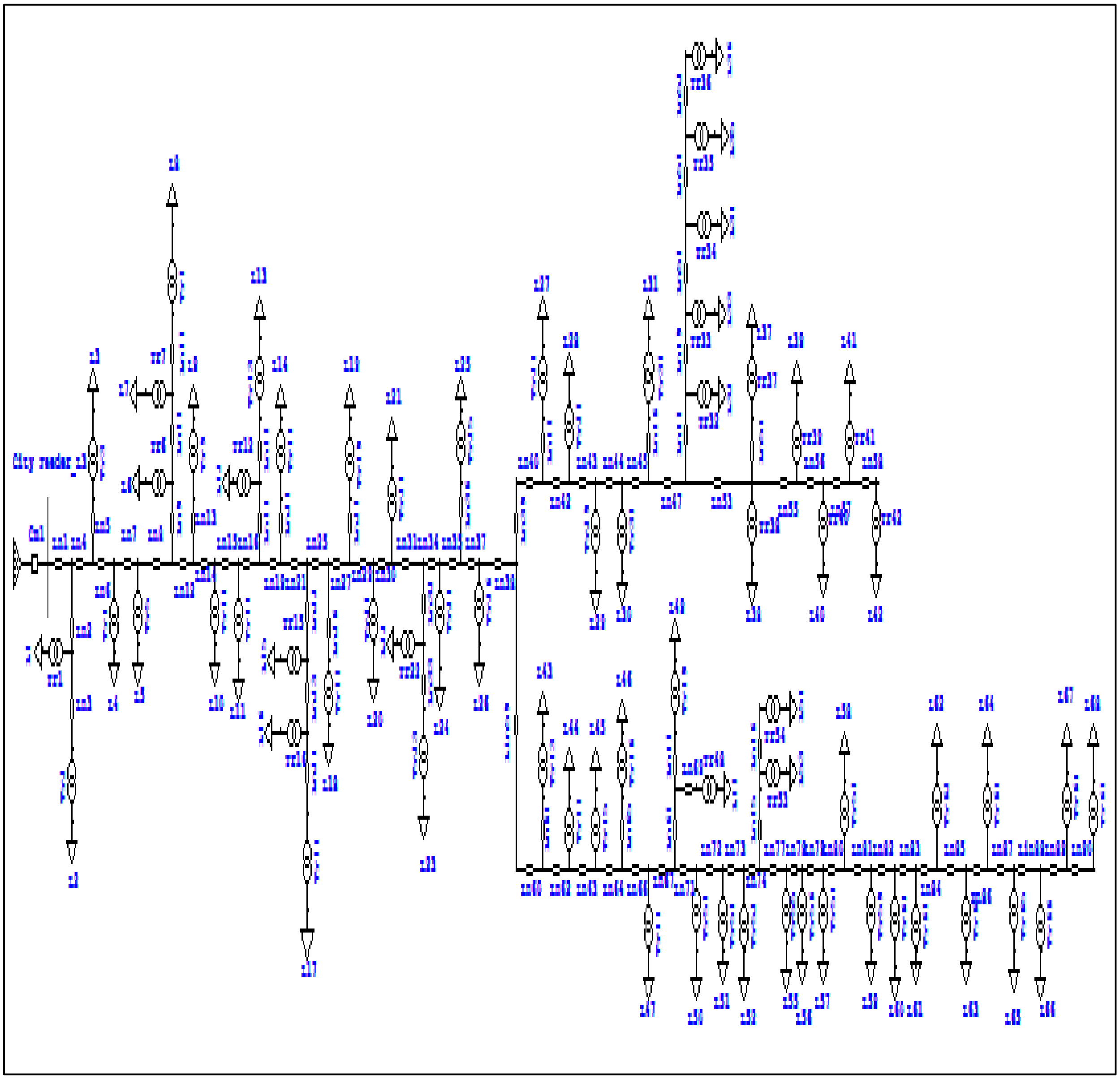
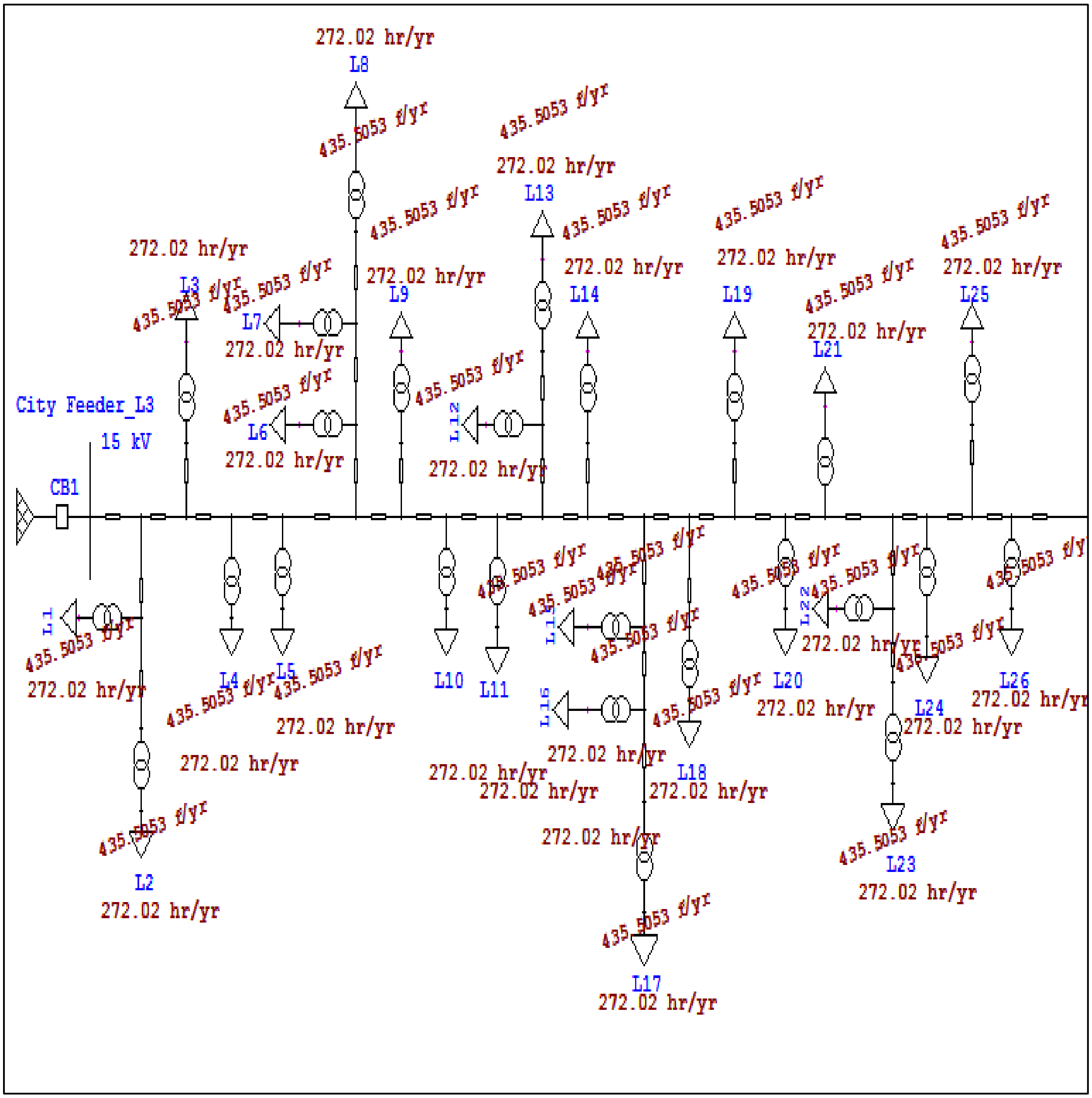


Figure 3.8: Single Line Diagram of the existing System

Figures 3.10 shows the complete single line diagram of the existing feeder with reliability indices values of SAIFI and SAIDI as indicated on the calculated points, whereas Figure 3.9 shows part of the system for clarity.



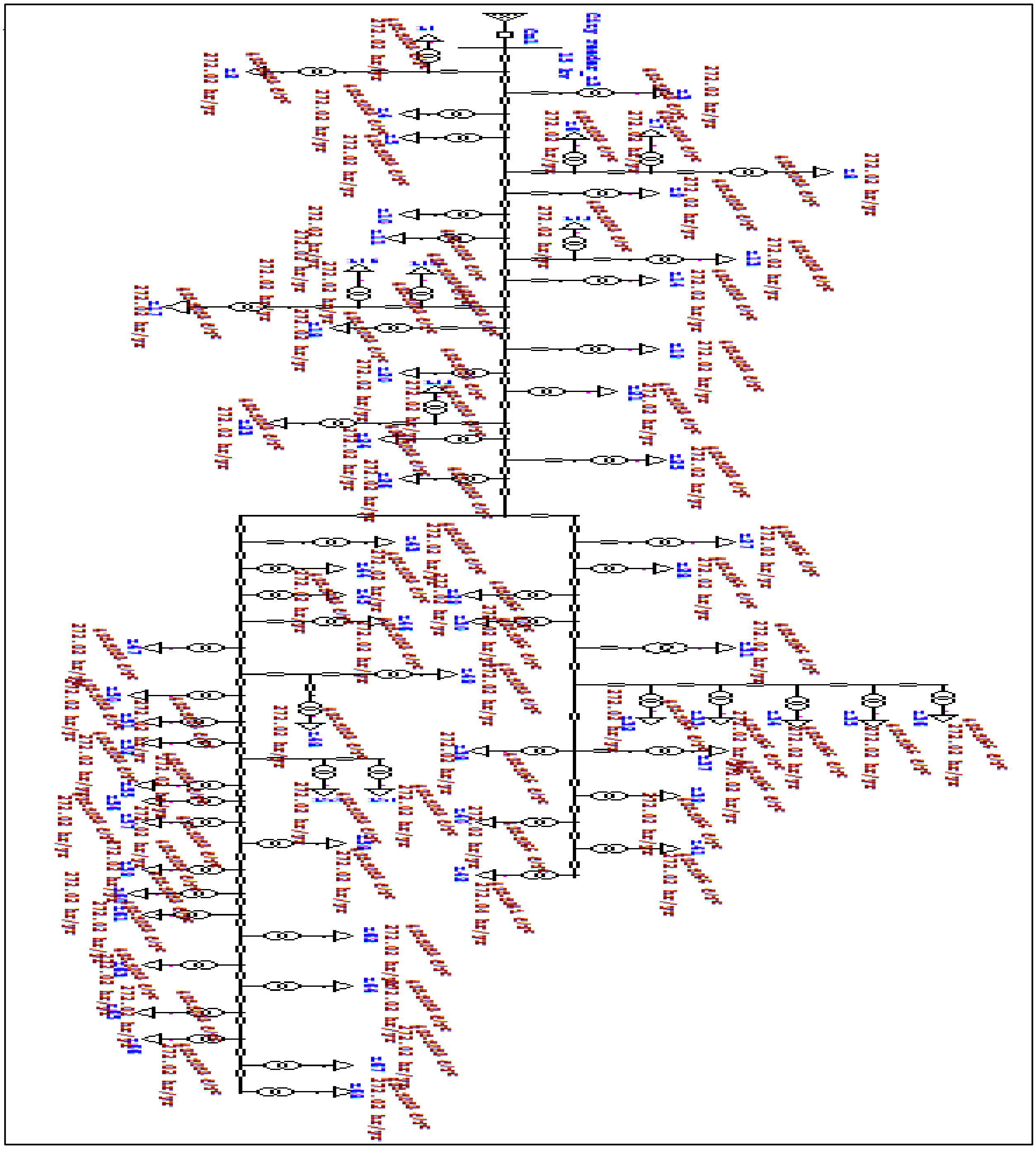


Figure 3.10: Complete diagram of the existing system with SAIFI and SAIDI

Table 3.8 reveals that the designed system has given the same reliability indices output values as found from the average of six years interruption data. The two basic reliability indices, system average yearly interruption duration and system average yearly interruption frequency are 272.02 and 435.5 respectively.

Table 3.8: Results of reliability indices for the existing system

Project:	Reliability on Distribution	ETAP	Page:	1
Location:	Jimma, Oromia	12.6.0H	Date:	11-05-2016
Contract:			SN:	
Engineer:	Eyasu Berhanu	Study Existing System: RA	Revision:	Base
Filename:	Main city		Config.:	Normal

SUMMARY

System Indexes

SAIFI	435.5062 f / customer.yr
SAIDI	272.0240 hr / customer.yr
CAIDI	0.625 hr / customer interruption
ASAI	0.9689 pu
ASUI	0.03105 pu
EENS	1483.348 MW hr / yr

CHAPTER FOUR

4 Simulation of Power Reliability with Feeder Reconfiguration

4.1 Introduction

Starting from the existing system design and the reliability indices of the base years, the study has evaluated different mitigation alternatives to improve the system reliability at reasonable cost. Different cases have been analyzed by computer simulation. The simulation focuses on evaluating the impact of using reclosers and reconfiguration of the feeder on reliability of the system.

Recloser allows utilities to implement automatic back feed restoration (loop automation), fault finding and fault isolation. The device is also equipped with precise timing parameters allowing protection coordination time between devices to be minimized. Automatic circuit reclosers are designed for use on overhead distribution lines as well as distribution substation applications for different voltage classes like 15kV, 27kV and 38kV [17].

The recloser's incorporated protective relaying equipment can be set to trip at specific overcurrent conditions and reclose at specific time intervals. After a circuit trip and settled time delay, the recloser automatically reenergizes the circuit. Reclosers are typically set to trip and reclose two or three times before a lock-out condition occurs. Lock-out means that a person working on the line must manually reset the recloser for power to be restored. If the fault condition clears before the recloser locks-out, the protective relaying resets back to the start of the sequence. Reclosers can also be tripped manually. This allows the recloser to be used as a load-break switch [20].

The result of reliability analysis is obtained by performing the following procedures in ETAP12.6.0 software

- One line diagram of the existing system has been designed on the working plane of the software
- Useful parameters for load flow, short circuit and reliability calculations has been specified and entered
- Type and operation characteristics of switching and protection devices has been specified
- Protection coordination and switching sequence interlocking has been Worked, then
- Run Load flow, short circuit and the reliability assessment

Place and number of automatic re-closers are chosen by considering number of customers, feeder length, sensitivity of the area and economic benefits. The reliability indices SAIFI, SAIDI and cost benefits would be the main drivers for comparison of the alternatives using heuristic technique.

Nu-Lec 15kv outdoor pole mounted, automatic circuit recloser, is selected for this thesis work. The recloser is available on the software library, allows protection coordination with other devices and is applicable in the real world. Nu-Lec industries is Schneider electrics core business unit for recloser technology [18].

4.2 Simulation and Discussions of Feeder Reconfiguration

Case-1: Using One Auto Recloser

Every necessary parameters used for distribution system reliability analysis are entered in the ETAP software. The interruption data of years from 2010 to 2015 are used as a base year. As per the data found from the customer service center, total number of customers currently connected to the feeder is about 9223. Based on number of customers (4659 customers to source side of the recloser) and criticality of the point, the recloser has been placed at line (Ln65) as shown in the single line diagram, Figure 4.1.

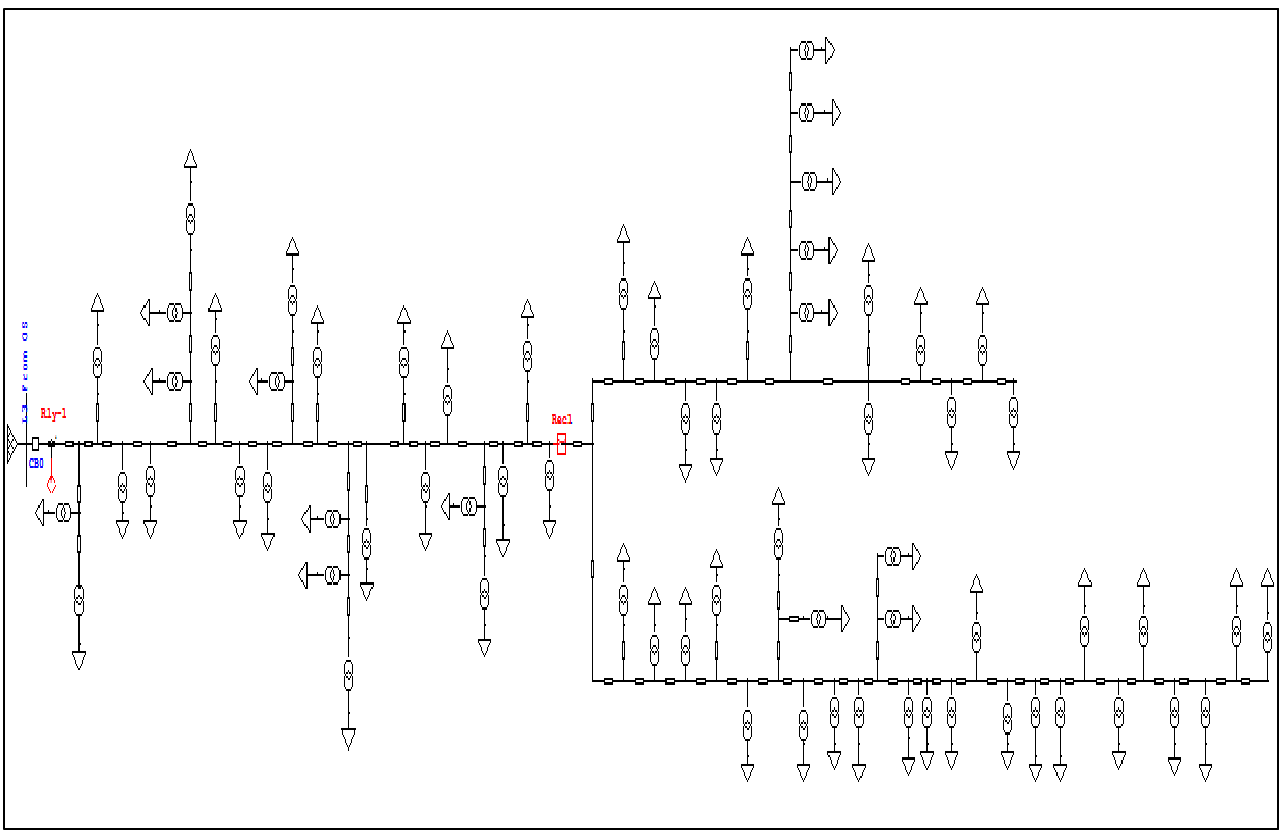


Figure 4.1: Single line diagram of the system for Case-1

Table 4.1 (Case 1), illustrates the effect of one recloser in the system, As can be seen from the table SAIFI is reduced from 435.5062 to 297.593 and SAIDI has been lowered from 272 to 185.2367 hours per customer per year and the interruption energy cost has been decreased from 29406.7 to 17112.3 US Dollars.

TABLE 4.1: RESULTS OF RELIABILITY INDICES FOR CASE-1

Project:	Reliability on Distribution	ETAP	Page:	1
Location:	Jimma, Oromia	12.6.0H	Date:	10-12-2016
Contract:			SN:	
Engineer:	Eyasu Berhanu	Study Case -1: RA	Revision:	Base
Filename:	Main city		Config.:	Normal

SUMMARY

System Indexes

SAIFI	297.5934 f / customer.yr
SAIDI	185.2367 hr / customer.yr
CAIDI	0.622 hr / customer interruption
ASAI	0.9789 pu
ASUI	0.02115 pu
EENS	863.186 MW hr / yr

Case -2: Using Two Auto reclosers

In this particular case the effect of two auto reclosers have been presented. One of the two reclosers has been placed at Line (Ln65) as revealed in Case- 1, and the second recloser has been placed at the exit of Jimma town to Dedo woreda.

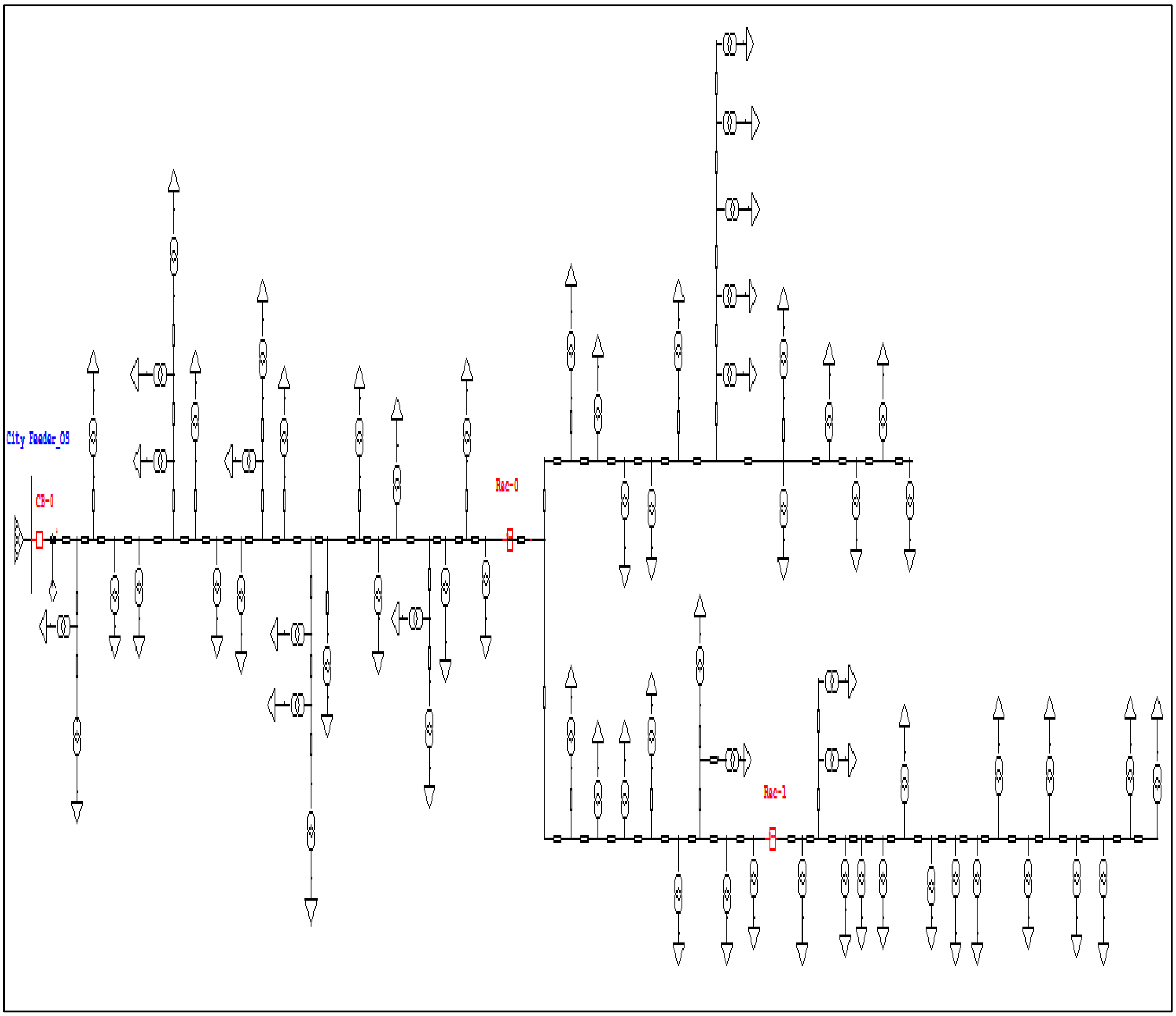


Figure 4.2: Single line diagram of the system for Case-2

Table 4.2 (Case -2), shown below, demonstrates the value of using the two reclosers in the feeder. As can be seen from the table, the two reclosers together with the substation breaker significantly improves the reliability of the system. The expected number of outages per year has been reduced from 435.5062 to 199.1338, and the annul outage duration has been reduced by 148.185 hours as compared to base years' average.

TABLE 4.2: RELIABILITY INDICES SIMULATION RESULTS FOR CASE-2

Project:	Reliability on Distribution	ETAP	Page:	1
Location:	Jimma, Oromia	12.6.0H	Date:	11-12-2016
Contract:			SN:	
Engineer:	Eyasu Berhanu	Study Case-2: RA	Revision:	Base
Filename:	Main city		Config.:	Normal

SUMMARY

System Indexes

SAIFI	199.1338 f / customer.yr
SAIDI	123.8389 hr / customer.yr
CAIDI	0.622 hr / customer interruption
ASAI	0.9859 pu
ASUI	0.01414 pu
EENS	529.540 MW hr / yr

Case -3: Reconfiguring the system using Tie switch

In this case reconfiguring of the feeder with the new substation using a normally open tie switch has been demonstrated. The normally open tie switch divides the feeder load (based on number of customers) almost in to two equal parts, and using the tie switch paves the way to transfer the load from one substation to the other in case of outages. This has solved the problems related with overloads. The recloser has been placed at the outgoing of Jima town to Dedo woreda as described in case two, and this has been played a great role in reducing temporary faults caused by tree contact.

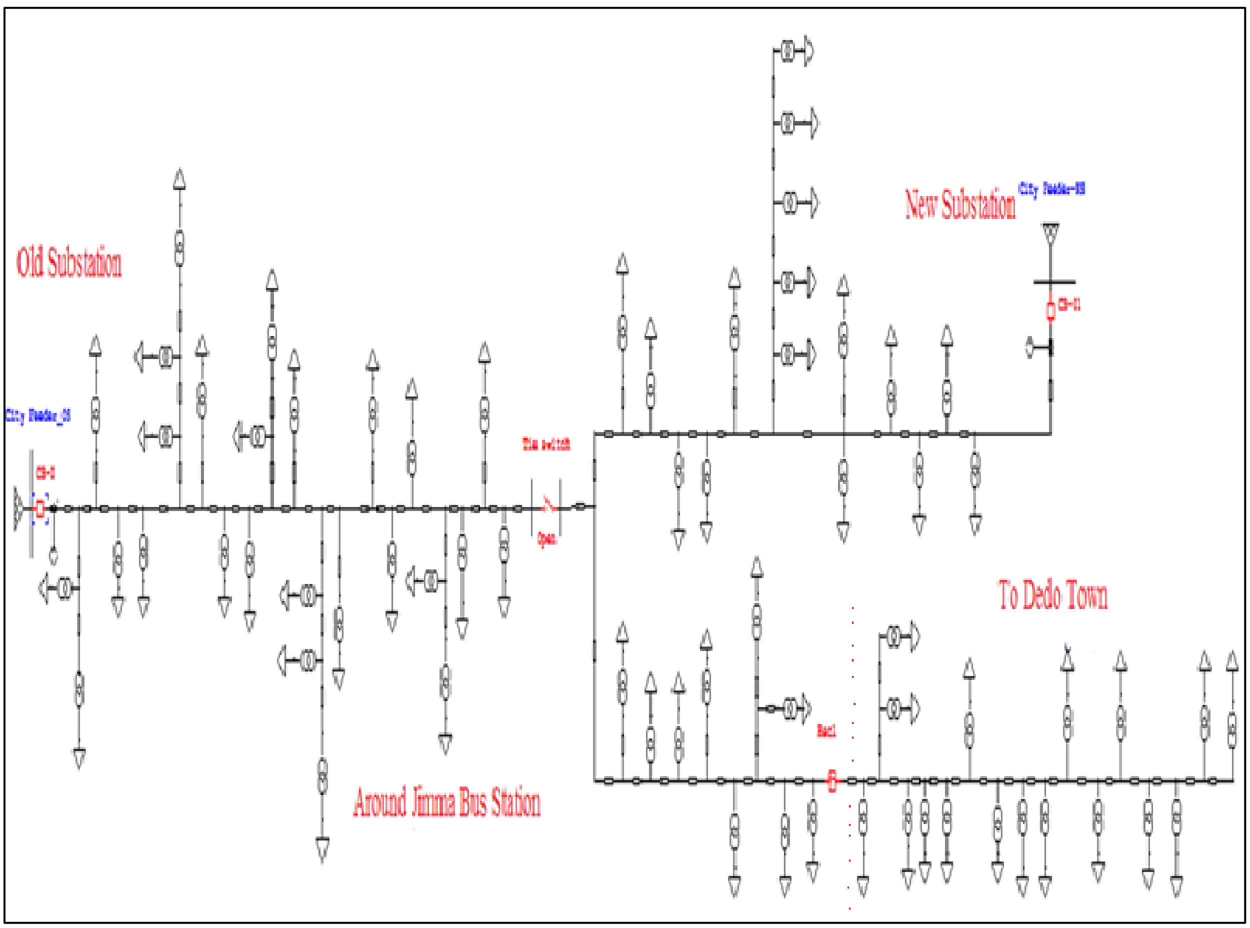


Figure 4.3: Single line diagram of the system for Case-3

In case-3, as shown clearly from Table 4.3 the expected number of outages per year is reduced from 435.5062 to 161.517 and the yearly outage time duration has been reduced to 99.3715 hours as compared with the existing system results.

TABLE 4.3: RELIABILITY INDICES SIMULATION RESULTS FOR CASE-3

Project:	Reliability on Distribution	ETAP	Page:	1
Location:	Jimma, Oromia	12.6.0H	Date:	11-12-2016
Contract:			SN:	
Engineer:	Eyasu Berhanu	Study Case-3: RA	Revision:	Base
Filename:	Main city		Config.:	Normal

SUMMARY

System Indexes

SAIFI	161.5170	f / customer.yr
SAIDI	99.3715	hr / customer.yr
CAIDI	0.615	hr / customer interruption
ASAI	0.9887	pu
ASUI	0.01134	pu
EENS	418.930	MW hr / yr

Case-4: Using Tie Switch and Isolating Dedo Woreda

In case-4 (Figure 5.2) as clearly shown below, the long line run to DEDO woreda has been permanently isolated from the existing city feeder at the exit of the Jima town. The two substation circuit breakers CB-0 and CB-01 and the normally open tie switch have been coordinated and interlocked together.

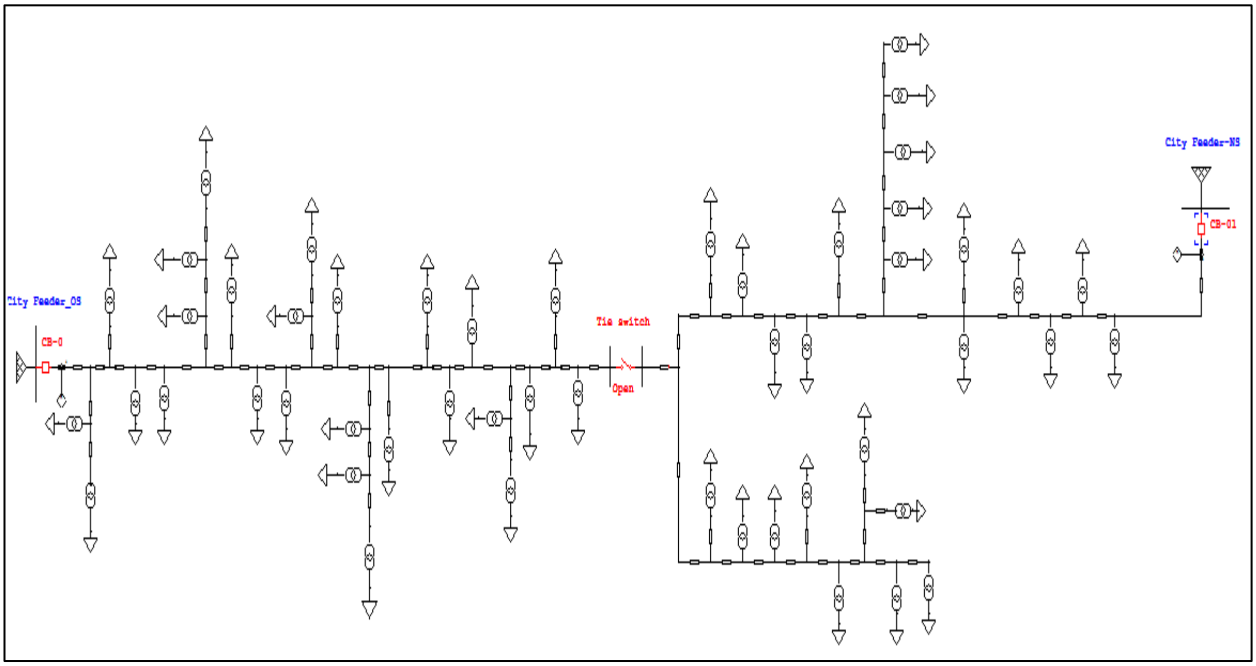


Figure 4.4: Single line diagram of the system for Case-4

In this case (Case-4), the very important thing is isolating the 15KV power line goes to Dedo woreda from the existing system and replacing it with 33KV line; and connecting to the 33KV power line that runs to Shebie Sembo woreda. Isolating Dedo line increases the reliability of the feeder in Jimma town. With the emergence of small villages and increment of electricity demand, Replacing 15KV by 33KV may also solve the power quality and reliability problems in the Dedo woreda. For long distances the power transfer capability of 33KV power line is better than 15KV Power lines.

As clearly shown from the ETAP 12.6.0 software output in Table 4.4, SAIFI has been reduced by 79.8 % as compared with the reliability of the actual distribution system. In the same case SAIDI, EENS and ECOST have been reduced by 80.1 %, 84.6 % and 84.6 % respectively.

TABLE 4.4: RELIABILITY INDICES SIMULATION RESULTS FOR CASE-4

Project:	Reliability on Distribution	ETAP		Page:	1
Location:	Jimma, Oromia	12.6.0H		Date:	18-12-2016
Contract:				SN:	
Engineer:	Eyasu Berhanu	Study Case-4:	Using Tie switch and Recloser	Revision:	Base
Filename:	Main city			Config.:	Normal

SUMMARY

System Indexes

SAIFI	88.0539	f / customer.yr
SAIDI	54.1752	hr / customer.yr
CAIDI	0.615	hr / customer interruption
ASAI	0.9938	pu
ASUI	0.00618	pu
EENS	227.768	MW hr / yr

Dedo Line which consists of curently 17 transformers (6 with 100KVA, 5 with 50KVA, 4 with 200KVA and 2 of 25KVA ratings) and covers about 34km outside of Jimma Town, should change and connect to the shebie sembo 33KV line. The shebie sembo 33 KV line is one of the two out going 33KV lines from Jimma substation. Its capacity is 3.5 MW, but the actual peak load of the feeder is 0.8 MW only, which is about 23% of its capacity. It's exit from Jimma town to Shebie is in the same direction with the exit to Dedo woreda.

Case-5: Using Two Auto reclosers, Tie Switch and Isolating Dedo Woreda

The two reclosers in both sides of the normally open tie switch are placed by considering length of the feeder, number of customers and criticality of the location. Recloser (Rec-1) has been placed almost at a midpoint by considering the length and number of the customers connected to the new substation. The same thing was considered for recloser (Rec-2) which has been placed to the old substation side.

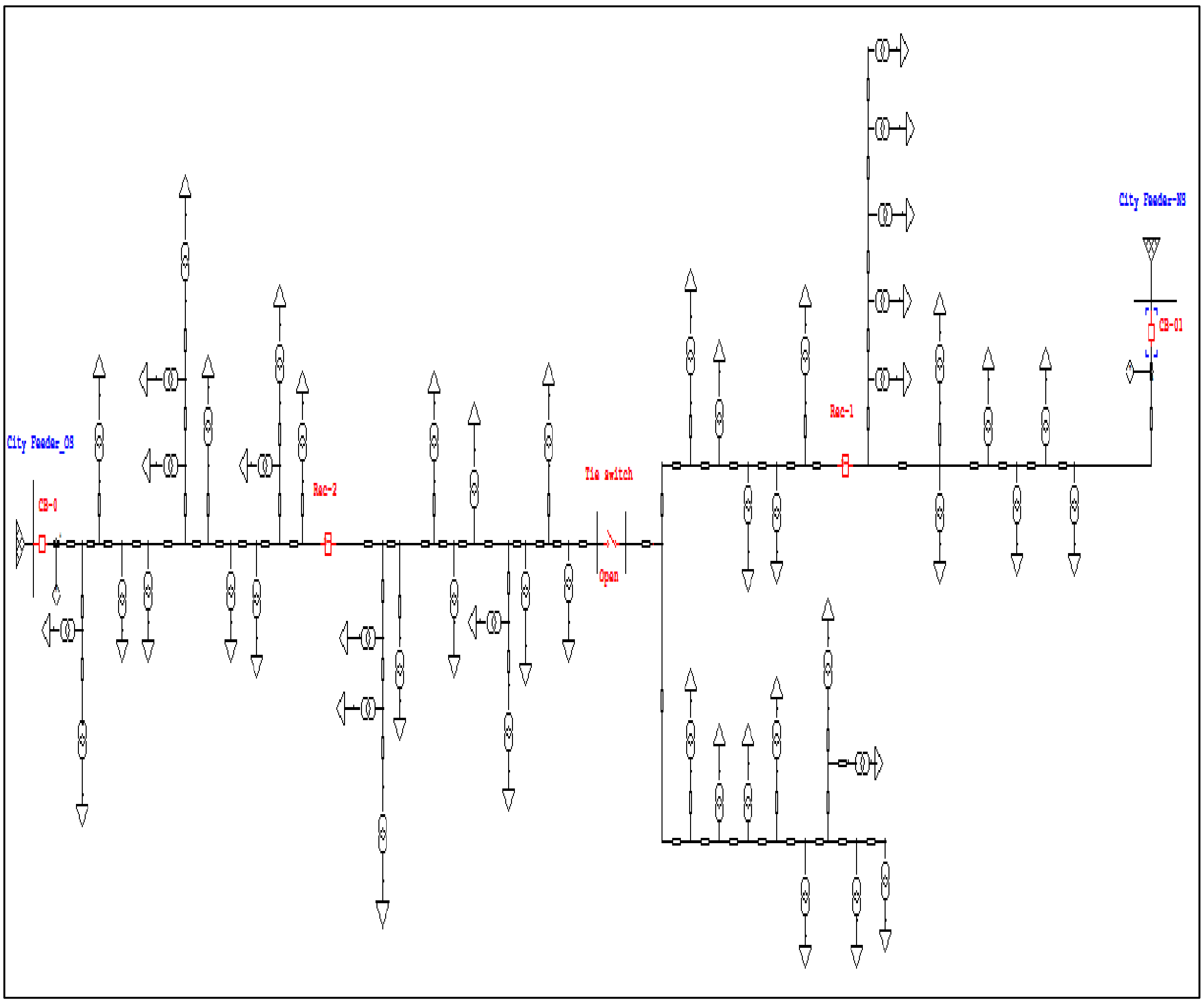


Figure 4.5: Single line diagram of the system for Case-5

Table 4.5 (Case -5), shown below, demonstrates the value of using the two reclosers, tie switch and permanently isolating the line goes to Dedo woreda from the 15KV city feeder. As can be seen from the table, the two reclosers together with the tie switch significantly enhances the reliability of the system. The expected number of outages per year per customer has been reduced from 435.5062 to 66.42 (84.75% system reliability improvement), and the annul outage duration has been reduced from 272 to 40.844 hours (85% reduction in outage duration) as compared with the selected base years.

TABLE 4.5: RELIABILITY INDICES SIMULATION RESULTS FOR CASE-5

Project:	Reliability on Distribution	ETAP		Page:	1
Location:	Jimma, Oromia	12.6.0H		Date:	22-02-2017
Contract:				SN:	
Engineer:	Eyasu Berhanu	Study Case:	RA...Case 5	Revision:	Base
Filename:	Main city			Config.:	Normal

SUMMARY

System Indexes

SAIFI	66.4190	f / customer. yr
SAIDI	40.8441	hr. / customer. yr
CAIDI	0.615	hr. / customer interruption
ASAI	0.9953	pu
ASUI	0.00466	pu
EENS	168.339	MW hr. / yr

Table 4.6, summarizes the results of all cases and percentage reduction of the selected common indices with compared to the base years values.

TABLE 4.6: SUMMARY OF RELIABILITY INDICES VALUES FOR ALL CASES

Cases	SAIFI	SAIDI	EENS (MWh/yr.)	ECOST (US Dollar)	% Reduction in SAIFI	% Reduction in SAIDI	% Reduction in EENS	% in Cost Reduction
Existing	435.5	272	1483.3	29406.7	0	0	0	0
Case-1	297.6	185.2	863.2	17112.3	31.7	31.9	41.8	41.8
Case-2	199.1	123.8	529.5	10497.9	54.3	54.5	64.3	64.3
Case-3	161.5	99.4	418.9	8305.1	62.9	63.5	71.8	71.8
Case-4	88.05	54.2	227.8	4515.4	79.8	80.1	84.6	84.6
Case-5	66.42	40.844	168.339	3337.246	84.75	85	88.651	88.651

As revealed from the cases, incresing the number of the auto recloser leads to improvement in the system reliability, but only adding these devices to the system should not be considered as the only solution. Scheduled preventive maintenance, additional rehabilitation works on entier parts of the system, improving man power problem, management strutagy and solve other related problems will have a great role to the system reliability enhancement.

4.3 Protection Coordination, Interlocking and Switching Sequence

For a fault occurred anywhere in the system, different protection devices may operate differently as a result of varying sensitivities, operating times and tolerances. When a fault occurs, the protection device closest to the fault should operate first to isolate the faulty circuit. If a protection device higher in the hierarchy trips first, multiple loads may unnecessarily lose service.

To accommodate for the varying tolerances and to ensure that multiple protection devices do not unnecessarily trip for the same fault current, the protection devices should be coordinated to each other based on their settled pickup currents and tripping times [19].

Protection coordination has been performed in this paper using star view page in ETAP software. Star is a fully integrated system protective device coordination and selectivity module within ETAP. Star offers the state-of-the-art tool for performing device coordination, protection, and testing. This is achieved by utilizing intelligent one-line diagrams, comprehensive device libraries, and an integrated multi-dimensional database. A time-overcurrent relay characteristic is generally plotted as a single-line curve. Curves for specific relays and reclosers are provided on log-log paper and include the available range of time-delay (or time-dial) and current settings.

To obtain selectivity over wide ranges of short-circuit currents and tripping times a relay and a recloser whose time-current curves have the same degree of inverseness have been selected. As magnitude of the short circuit current flowing through any of the protection devices in the modeled system is dependent mainly upon the location of the fault, and only slightly or not at all upon the generation in service, to obtained a faster clearing a very-inverse-time-overcurrent characteristic has been selected for both the relay and the reclosers.

The protection devices (the relay and the recloser) has been designed to sense the minimum fault current from the operational rush current in the system. Short circuit analysis has been evaluated by creating a fault at different potential locations in the feeder; and short circuit current values used for coordination has been identified.

TABLE 4.7: SUMMARY OF SHORT CIRCUIT CURRENT VALUES

Bus		3-Phase Fault			Line-to-Ground Fault			Line-to-Line Fault			Line-to-Line-to-Ground		
ID	KV	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.
B2	15.00	4.995	-8.078	9.497	0.084	-0.641	0.646	6.995	4.325	8.225	6.976	4.491	8.297
B65	15.00	1.595	-1.024	1.895	0.145	-0.464	0.486	0.887	1.381	1.641	0.859	1.513	1.739
B88	15.00	1.055	-0.626	1.227	0.152	-0.384	0.413	0.542	0.914	1.063	0.512	1.028	1.149
B100	15.00	0.963	-0.543	1.105	0.156	-0.367	0.398	0.470	0.834	0.957	0.439	0.945	1.042
B132	15.00	1.025	-0.606	1.191	0.152	-0.379	0.408	0.525	0.888	1.032	0.495	1.001	1.117
B158	15.00	0.281	-0.149	0.318	0.102	-0.150	0.181	0.129	0.243	0.276	0.105	0.298	0.316

Table 4.7 shows the short circuit current values for a fault at different locations in the existing system. The table demonastrates that the short circuit current values are different for different fault types. In the table the green couloured buses (B2 and B65) are locations found on the upstream(to source side) from the recloser.

The protection coordination for line and ground faults has been analysed separately. Figure 4.6, demonastrates the coordination between the substation relay and the recloser (Rec1) in Case-1 (Figure 4.1) for line faults. The minimum line fault current for faults occurred in the area between the source and the recloser is 1641A (at B65). In Figure 4.6, the blue coloured time current cureve shows as the relay (Rly-1) trips the minimum line fault current (1641A) in less than 1 second.

Coordination has been implemented in between Rly-1 and recloser (Rec1) for faults occurred downstream of the recloser. For the minimu line to line fault current (276A) at the far end of the feeder at bus (B158), The recloser is provided with one, two, three or four operations depending upon the adjustment in an attempt to clear the fault. After the fourth operation, if the fault is still on the line, the recloser should be locked. However, since a permanent fault will still be on the line at the end of these operations, it must be cleared away by the substation breaker. The relay has been designed to trip 276A after total operations of the recloser.

The Time Current Curve (Figure 4.7) illustrates Coordination of Rly-1 and Rec1 for ground faults. The minimum line to ground fault current (486 A) upstream of the recloser interrupts Rly-1 in lessthan 1 second. The minimum line to ground fault current (181A) for a fault occurred at downstream of the recloser is designed to trip recloser (Rec1) depending upon the operations. If the fault is not cleared after the last operation of the recloser, the substation breaker should trip the feeder from the source.

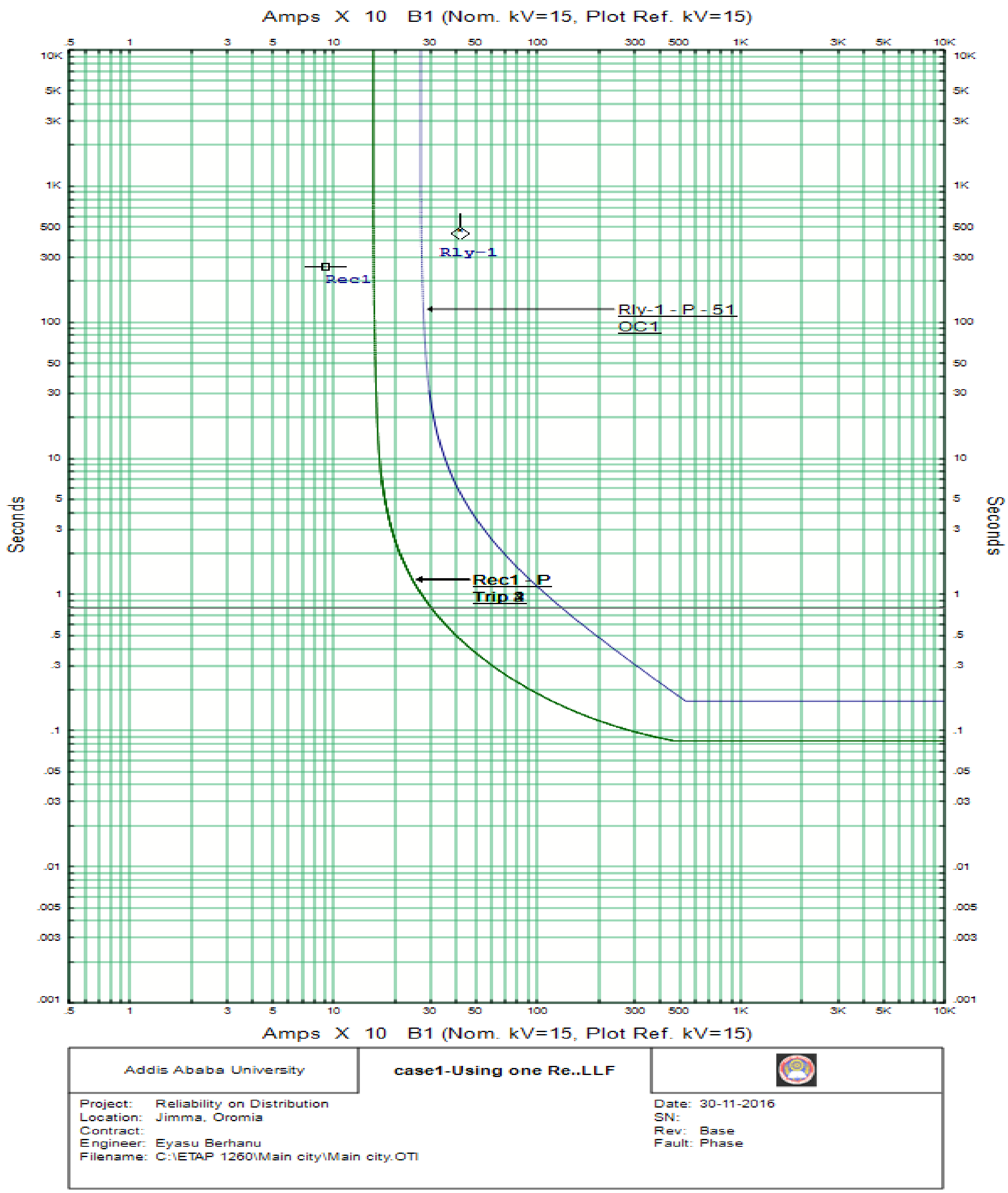


Figure 4.6: Relay1 and Recloser coordination for line Faults in Case-1

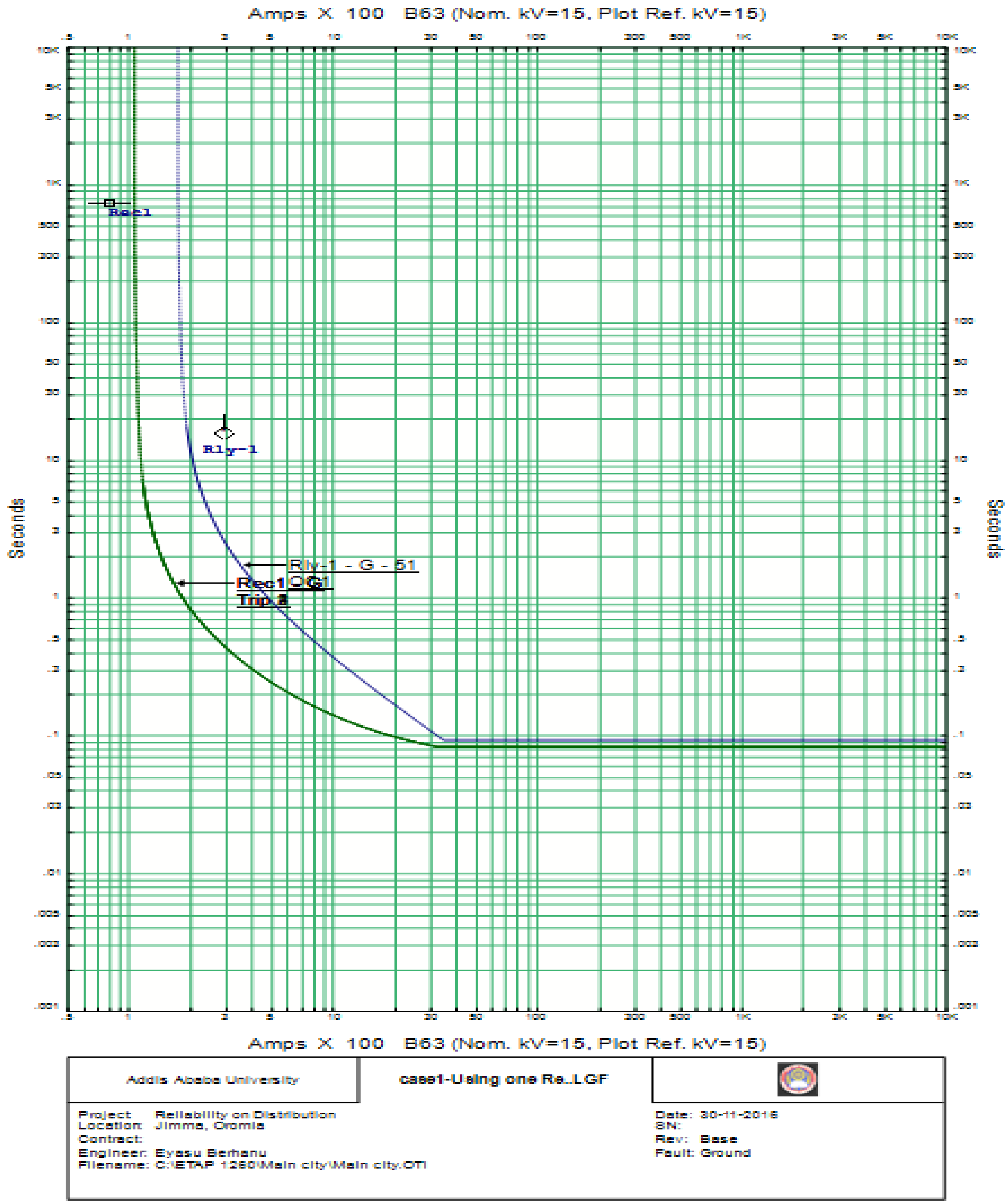


Figure 4.7: Relay1 and Recloser coordination for ground Faults in Case-1

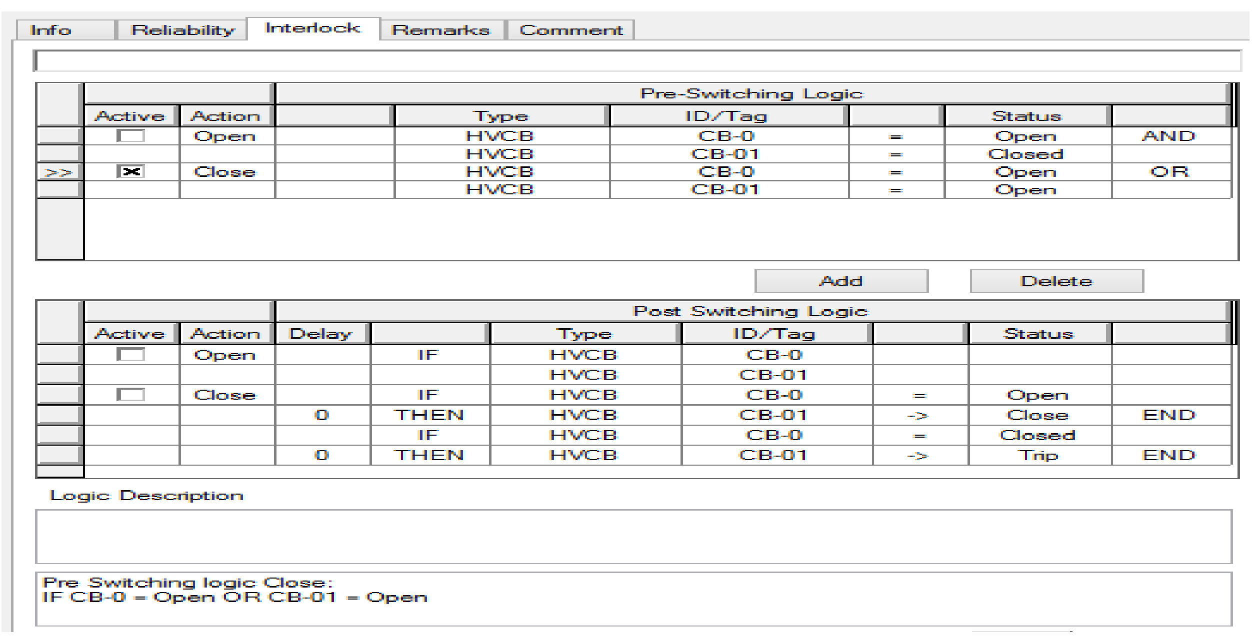
Interlocking and switching sequences are two important things in distribution system automation. Interlocking ampng protection devices may be implemented mechanically, electrically or in other ways. These are mainly used to keep service continuity and maintain overall saftey of the system.

Table 4.8 clearly demonestrates the interlocking among the two substation circuit breakers (CB-0 and CB-01) and the Tie switch; so that the tie switch should note close unless one of the two breakers is open. This implies that the three switchs never be closed at the same time as the two substations are not synchronized to feed the same load at a time.

A switching sequence is a series of status changes of switching devices (switches and circuit breakers) to accomplish a specific task, such as transferring loads from one source to another or energizing/de-energizing loads for maintenance. This uses to understand system behavior before it is actually implemented in the real world [Software Library].

Table 4.9 explains the switching sequences intended to be experienced by the three devices (CB-0, CB-01 and the Tie switch) under different situations. Four different conditions has been demonastrated as shown in sequences -1, 2, 3 and -4 in the table.In Sequence-1, the High Voltage Circuit Breaker (CB-0) must be opened before making the Tie switch. Sequence-4 reveals that the Tie switch should be opened before closing CB-01.

TABLE 4.8: INTERLOCKING AMONG CB-0, CB-01 AND THE TIE SWITCH



Info | Reliability | Interlock | Remarks | Comment

Pre-Switching Logic

	Active	Action		Type	ID/Tag		Status	
	☐	Open		HVCB	CB-0	=	Open	AND
				HVCB	CB-01	=	Closed	
>>	☒	Close		HVCB	CB-0	=	Open	OR
				HVCB	CB-01	=	Open	

Add | Delete

Post Switching Logic

	Active	Action	Delay		Type	ID/Tag		Status	
	☐	Open		IF	HVCB	CB-0			
					HVCB	CB-01			
	☐	Close		IF	HVCB	CB-0	=	Open	
			0	THEN	HVCB	CB-01	->	Close	END
				IF	HVCB	CB-0	=	Closed	
			0	THEN	HVCB	CB-01	->	Trip	END

Logic Description

Pre Switching logic Close:
IF CB-0 = Open OR CB-01 = Open

TABLE 4.9: SWITCHING SEQUENCES FOR DIFFERENT OPERATIONS OF THE PROTECTION DEVICES

Switch Sequence

ID: Sequence-1 ☑ Save Last Config Normal

				Device/Logic		Operation					Modification		
	Action #	Group #	Active	Type	ID	Delay T (H:M:S)	Action	Crew	Remarks	Cost ($)	Name	Date	Time
	1	1	☑	HV CB	CB-0	0:00:00.000	Open			0.00	eyas	12-16-2016	9:21:09
>>	2	2	☑	Switch	Tie switch	0:00:00.000	Close			0.00	eyas	12-16-2016	9:21:17

Switch Sequence

ID: Sequence-2 ☑ Save Last Config Normal

				Device/Logic		Operation					Modification		
	Action #	Group #	Active	Type	ID	Delay T (H:M:S)	Action	Crew	Remarks	Cost ($)	Name	Date	Time
	1	1	☑	HV CB	CB-01	0:00:00.000	Open			0.00	eyas	12-16-2016	12:15:17
>>	2	2	☑	Switch	Tie switch	0:00:00.000	Close			0.00	eyas	12-16-2016	12:15:26

Switch Sequence

ID: Sequence-3 ☑ Save Last Config Normal

				Device/Logic		Operation					Modification		
	Action #	Group #	Active	Type	ID	Delay T (H:M:S)	Action	Crew	Remarks	Cost ($)	Name	Date	Time
	1	1	☑	Switch	Tie switch	0:00:00.000	Open			0.00	eyas	12-16-2016	7:22:00
>>	2	2	☑	HV CB	CB-0	0:00:00.000	Close			0.00	eyas	12-16-2016	7:22:04

Switch Sequence

ID: Sequence-4 ☑ Save Last Config Normal

				Device/Logic		Operation					Modification		
	Action #	Group #	Active	Type	ID	Delay T (H:M:S)	Action	Crew	Remarks	Cost ($)	Name	Date	Time
	1	1	☑	Switch	Tie switch	0:00:00.000	Open			0.00	eyas	12-16-2016	7:20:13
>>	2	2	☑	HV CB	CB-01	0:00:00.000	Close			0.00	eyas	12-16-2016	7:20:18

4.4 Cost Analysis

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

For small industries, electricity supply interruption costs are strongly related to production losses and to costs involved in restoring production. In addition, interruptions also cause property damages and revenue loses for industries, commercial customers and for private individuals.

It is difficult to estimate the exact value of interruption costs and economical loses, since the properties of each customer are different and difficult to found important data. In this paper interruption cost only related to the utility side has been analyzed by using Expected Energy Not Supplied (EENS) of each cases. For case -1, after the reliability of the existing power distribution system is improved by using one auto recloser the annual average unsold energy is reduced from 1483.3 to 683.2 MWh per year as shown in Table 4.6 above. Therefore, the revenue saved due to reliability improvement can be estimated as follows.

The revenue saved after improvement due to the unsold energy is:

$$\frac{[1483300 - 863200]\text{kWh}}{\text{year}} \text{x} \frac{0.4407\text{birr}}{\text{kWh}} = \ 273278 \text{ ETB.}$$

The investment cost can be calculated by using the cost of one out door high voltage auto recloser used to design the system in Case-1. Average cost of one Recloser is 15,000 (USD) [20] and Based on exchange rate of the Commercial Bank of Ethiopia on 21 November, 2016 which equates One US Dollar (USD) to 22.23 Ethiopian Birr (ETB), the cost of one 15KV, 800A pole mounted out door Recloser is: 15,000*22.23 = 333450 ETB.

Payback period of the designed system is an important factor whether to undertake the case. Payback period is the period or length of time required to recoup the cost expended in an investment. It is the ratio of the cost of investment to the annual saving by using that investment.

The payback period of a given investment or project is an important determinant of whether to undertake the position or project, as longer payback periods are typically not desirable for investment positions.

Thus, for case-1 the payback period is:

Payback Period = 333450 Birr $/273278$ = 1.22year

Hence, the payback period indicates that it takes 1.22 years to get back the investment cost. In this case (Case-1), the reliability indices SAIFI and SAIDI has been reduced by about 31% only.

For cases 3, 4 and 5 other costs including the rehabilitation budget new line connection that connects the feeder to the new substation should be considered, as it needs high cost, compared with the recloser cost.

The new line connection (1.12 Km) cost mainly consists of material cost, labor cost and transport cost. The line should be 15KV, 12meter wooden pole, and three phase 50 mm^2 AAC conductor with overhead triangular configuration.

By dividing the total length (1120 meter) to the span length (50 meter) total number of poles are estimated to be about 23 (12 meters poles). Adding 5 with 11m poles for support and necessary materials for each pole. As per the Ethiopian Electric Utility price List version 2008 E.C, the total materials cost as shown in Table 4.10, is 162857.54 ETB.

TABLE 4.10: SUMMARY OF MATERIALS NEEDED TO CONSTRUCT THE NEW LINE AND THEIR COSTS

Stock Number	Materials	Unit	Unit Price/ ETB	Amount	Total Cost (ETB)
02-06-110	HOOK INSULATOR N-95	Each	97.03	79.00	7,665.37
03-01-000	INSULATOR HT 18/5MM2 15KV	Each	382.00	79.00	30,178.00
04-04-920	AAC.ALL ALUMINIUM CONDUCTOR 50MM	Meter	21.91	3,360.00	73,617.60
09-02-130	POLE WOOD IMPREGNATED 11M	Each	1,697.25	5.00	8,486.25
09-02-140	POLE WOOD IMPREGNATED 12M	Each	1,851.29	23.00	42,579.67
12-04-860	LONG BOLT GALVANIZED 5/8" 40CM	Each	66.13	5.00	330.65
Total					**162,857.54**

As per the price list, labor cost per one km of MV line, LV line construction and for a single transformer erection is 10725.12, 8651.92, and 2106.72 in Ethiopian Birr respectively. And the transport cost for one km of MV line, LV line construction and for a single transformer erection is 1643.76, 1898.10 and 2656.26 ETBs respectively. To construct the new 1.12 km MV line the labor and transport cost is 12012.14 ETB and 1841ETB respectively. The sum of the labor and the transport cost to construct 1.12 km is 13853.15 ETB. The interruption time to connect the new system with the existing one should be very short (in minutes only), otherwise its cost should be included.

The sum of the material (Table 4.10), labor, transport cost and prices of the new devices (recloser) should be the total investment costs for cases 3, 4 and 5.

Table 4.11 shows the average Expected Energy Not Served (EENS), interruption cost, investment cost and the payback period for each cases. Note that Tie switch is the same in cost with the auto recloser.

TABLE 4.11: SUMMARY AND COMPARISON OF PAYBACK PERIODS FOR ALL THE CASES

Cases	**EENS (MWh)**	**Interruption Cost (ETB)**	**Investment Cost(ETB)**	**Annual Revenue Saved (ETB)**	**Payback Period (year)**
Existing	1483.3	653710.941	0		
Case – 1	863.2	380412.29	333450	273278	1.22
Case – 2	529.5	233368.317	666900	420342.624	1.59
Case – 3	418.9	184622.373	843610.69	469088.568	1.8
Case – 4	227.8	100377.342	677854.27	553333.6	1.22
Case – 5	168.339	74186.98	1177060.69	579523.96	2.03

Table 4.11 reveals that the payback period of case-1 is small as compared with the other alternatives, but as clearly shown in Table 4.6, the percentage reduction for SAIFI and SAIDI compared with the selected base years is minimum. In cases 2 and 3 the system reliability enhancement is not good enough as compared to cases four and five.

When coming to case four the percentage reduction for SAIFI and SAIDI is about 80 percent as compared to the existing system and the payback period is interesting, but using only a tie switch has its own problem in the system operation and maintenance.

Case-5 has been enhanced the reliability of the system very well and the payback period is only 2.03 years. And when coming to the real system, using only a tie switch (Case-4) cannot solve the problem with in the feeder. For maintenance purpose or to isolate faulted areas in the case of permanent faults, auto reclosers can manually operate to use as load break switches. And this prevents frequently opening and closing of the substation breaker.

TABLE 4.12: SUMMARY AND COMPARISON OF RELIABILITY INDICES VALUES

Country		SAIFI	SAIDI
United State		1.5	4
Australia		0.9	1.2
France		1	1.03
Germany		0.5	0.383
Italy		2.2	0.967
Spain		2.2	1.73
United Kingdom		0.8	1.5
Ethiopia		20	25
Jimma, City-Feeder	Existing	435.5	272
	Case-1	297.6	185.2
	Case-2	199.1	123.8
	Case-3	161.5	99.4
	Case-4	88.05	54.2
	Case- 5	66.419	40.8441

Table 4.12 shows the comparison of the most commonly used reliability indices (SAIFI and SAIDI) of Jima town, city feeder, with the requirements of the Ethiopian Electric Agency (EEA) and the best experienced countries.

As it is observed from Table 4.12, both the SAIFI value in interruptions per year per customer and the SAIDI value in hours per year per customer of city feeder has been improved by 85% as compared with the base years values.

In the selected case (Case-5), the reliability indices values of the case study area should be further improved by using scheduled preventive maintenance, strategic management system, keeping fit the workers, by further rehabilitating all the system and by solving other related problems. And the values of SAIFI and SAID should be comparable with the other countries best values and the Ethiopian energy agency settled values.

CHAPTER FIVE

5 Conclusion and Recommendations

5.1 Conclusions

This research paper was conducted in one of the oldest cities of Ethiopia, Jimma city, which has an old and poor electrical distribution system. The system modeling and simulation study is carried out on one of the 15kV distribution feeder to assess the performance of the present system and also predictive reliability analysis for the future. The interruption data of years 2010-2015 has been used as a base years.

Based on the interruption data of the base years and the questionnaire about the causes of interruptions, it can be seen that City feeder experienced highest number of outages and the outages are mainly due to overload, tree, windy rain, distribution equipment failures, scheduled outages and others.

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

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

SAIFI and SAIDI are used as the main driver for evaluating of each alternative. EENS was also monitored during this process. Cost-effectiveness is considered as the main constraint of any analysis in this paper. Cost- effectiveness is defined as the ratio of the cost of implementing an alternative using a recloser versus its corresponding reliability indices improvement.

During the evaluation process, the distribution model was thoroughly reviewed to identify potential locations for the recloser, and to evaluate its cost-effectiveness.

After deep analysis of the five alternatives, it was determined and concluded that the most effective alternative for improving the reliability of the study area was installing tie switch, two auto reclosers at critically selected locations and permanently isolating the long and faulty line goes to Dedo woreda from the existing feeder.

The tie switch and the high voltage circuit breakers are remotely controlled and have the ability of being operated in an automated scheme. This allows the automatic transfer of load from one feeder to another during an outage.

In order to achieve this objective, a computer program ETAP12.6.0 is used to run load flow, short circuit and reliability analysis, thus selecting the alternatives based on reliability indices and on cost benefit.

SAIFI has been reduced by 84.75 % as compared with the average reliability indices value of the system in the base years. In the same case SAIDI and EENS have been reduced by 85% and 88.651% respectively.

The author of this thesis paper believes that reconfiguration of the system using tie switch and two auto reclosers and isolating the long line goes to the Dedo woreda should be an effective and plausible solutions for the overloading problems and temporary faults. The reliability of the system could be further improved by scheduled preventive maintenance, additional rehabilitation works which can reduce risk or vulnerability in the system.

The proposed solution has been saved 579523.96 ETB per year from the unsold energy of one feeder only with 2.03 years payback period investment. Satisfaction of the society has been considered as a priceless advantage.

Protection system coordination, interlocking and switching sequences has been monitored carefully in each system setup.

5.2 Recommendations and Future Works

This section brings up topics of future research works that would complement the work presented in this thesis.

- The primary purpose of the system is to satisfy customer requirements and since the proper functioning and longevity of the system should found to be essential requisites for continued satisfaction.
- The interruption data recording have to be made systematic and rationalized meaning that all individual component failure data, localized fault data, have to be precisely recorded if future system analysis should represent true state of the system. As of now, the data have been recorded only when there is fault on the feeder. And all the hard copy data are not kept properly.
- As naturally Jima is found in a thick forest zone, Scheduled tree trimming and pruning programs will have a vital role in distribution system reliability enhancement and can have profound effect on minimizing the failure rate of overhead lines. And another way to reduce number of vegetation related failure is to replace bare 15kv overhead conductor with covered conductor, which can have significant effect both on SAIDI and SAIFI.
- As this thesis is conducted on one feeder, doing reliability assessment analysis for whole part of the city is recommended.
- Practical implementation of the recommended alternative solution is also important to improve the reliability of the power distribution system.
- I highly recommended for Engineers to put their hands on solving such real time problems.

References

1) Mr. Vinod Kumar Khare, “Transformation of Ethiopian electric utility,” Ethiopian Elec. Utility, Addis Ababa, Ethiopia, 10th June 2015.
2) Yohannes Tesfaye, “Assessment of Power Interruptions in Addis Ababa,” MSc thesis, Mgt. Addis Ababa Uni. Addis Ababa, Ethiopia, July 2015.
3) Richard E. Brown, “Distribution systems, “in Electric Power Distribution Reliability, Second Edition, by Taylor & Francis Group, LLC, 2009,Chapter-1.
4) IEEE Guide for Electric Power Distribution Reliability Indices, IEEE Std. 1366™-2012, 31 May 2012.
5) D. Haughton and G. T. Heydt, “Smart Distribution System Design: Automatic Reconfiguration for Improved Reliability,” unpublished.
6) IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power System, IEEE Std. 242-2001, June 2001.
7) Xuebei Yu, “Distribution System Reliability Enhancement,” MSc thesis, Elec. and Comp. Eng., Georgia Institute of Technology, August 2011.
8) Hesam Hosseinzadeh, “Distrib ution system protection,” in Power system protection, University of Western Ontario, June, 2008.
9) CEB SPECIFICATION, “Three Phase Outdoor 12kv to 36kv Automatic Circuit Reclosers,” Ceylon electricity board, Sri Lanka, 2015.
10) D. O. Koval and A. A. Chowdhury “Reliability Analysis of the Isolation and Restoration Procedures of Distribution Feeders,” in 0-7803-9193-4/06/$20.00, 2006 © IEEE.
11) A. Merlin and H. Back, “Search for a minimal loss operating spanning tree configuration for an urban power distribution system”, Proceedings of the 5th Power System Computation Conference (PSOC), Cambridge, 1975, pp. 1-18
12) Sung-Yul Kim and Jin-O Kim, “Reliability Evaluation of Distribution Network With DG Considering the Reliability of Protective Devices Affected by SFCL,” in 1051-8223/$26.00, 2011 © IEEE.
13) M.R Emjedi, K.Awodele, S.Chowdhury and S.P.Chowdhury, “Reliability Evaluation of Distribution Networks Using Fuzzy Logic,” in 978-1-4244-6551-4/10/$26.00, 2010© IEEE.
14) Roy Billinton and Ronald N. Allan, “Evaluation of reliability worth,” Reliability Evaluation of Power Systems, Second Edition, Plenum Press, New York, 1996.

15) Kristina Hamachi La Commare and Joseph H.Eto., “Cost of Power Interruptions to Electricity Consumers in the United States,” USA, February 2006.
16) Corporate Marketing and Sales Process Estimation Manual, Ethiopian Electric Power Co., Ethiopia, February 2013.
17) Neil O’Sullivan and Bruno Kimura, (May 10, 2013), Only Smart Reclosers Build Smart Grids. Available:http://www.nojapower.co.uk/dl/.../only-smart-reclosers-build0 smartgrids.pdf.
18) Schneider–electric Company, (February 2017), Nulec, Available: http://www.schneider electric.co.za/ sites/…/nulec page.
19) Interlocking of protection devices (2016), Available: http://www.freepatentsonline.com/... Interlocking of protection devices.html.
20) Solomon Derbie, “Study on Reliability Improvement of Adama City Power Supply Using Smart Grid Technology,” MSc thesis, Elec. Eng., AAIT, Addis Ababa, Ethiopia, 2014.

Appendix

Appendix: A

Daily Power Interruption data of year 2010

No.	Date	Month	Year (E.C)	Date	Month	Year	Feeder Name	Time	Duration in time	Duration in	Load Befor Interruption in (MW)	Unsupplied Energy in (MWh)	Causes of the fault
1	23	4	2002	1	1	2010	City Line	7:00	0:05	0.0833	1.8	0.14994	
2	23	4	2002	1	1	2010	City Line	18:00	0:05	0.0833	1.68	0.139944	
3	24	4	2002	2	1	2010	City Line	14:00	0:26	0.4333	0.8	0.34664	
4	26	4	2002	4	1	2010	City Line	16:00	0:05	0.08333	1.3	0.108329	
5	29	4	2002	7	1	2010	City Line	21:00	0:26	0.4333	1.3	0.56329	
6	29	4	2002	7	1	2010	City Line	6:00	3:25	3.41666	1.4	4.783324	
7	30	4	2002	8	1	2010	City Line	10:00	1:05	1.08333	2.08	2.2533264	
8	30	4	2002	8	1	2010	City Line	12:00	0:20	0.333	1.98	0.65934	
9	30	4	2002	8	1	2010	City Line	16:00	0:05	0.08333	2	0.16666	
10	24	5	2002	1	2	2010	City Line	14:00	2:00	2	1.76	3.52	
11	25	5	2002	2	2	2010	City Line	12:00	0:35	0.58333	2.8	1.633324	
12	25	5	2002	2	2	2010	City Line	18:00	2:05	2.08333	1.35	2.8124955	
13	25	5	2002	3	2	2010	City Line	23:00	0:05	0.08333	1.8	0.149994	
14	26	5	2002	4	2	2010	City Line	14:00	0:12	0.2	1.68	0.336	
15	28	5	2002	6	2	2010	City Line	9:00	0:05	0.08333	0.8	0.066664	
16	28	5	2002	6	2	2010	City Line	12:00	0:10	0.16666	1.3	0.216658	
17	29	5	2002	7	2	2010	City Line	12:00	0:27	0.45	1.1	0.495	
18	30	5	2002	8	2	2010	City Line	7:00	0:05	0.08333	0.8	0.066664	
19	1	6	2002	9	2	2010	City Line	10:00	0:05	0.08333	0.9	0.074997	
20	2	6	2002	10	2	2010	City Line	10:00	0:05	0.08333	1	0.08333	
21	2	6	2002	10	2	2010	City Line	13:00	2:00	2	1	2	
22	4	6	2002	12	2	2010	City Line	14:00	0:30	0.5	1.6	0.8	
23	4	6	2002	12	2	2010	City Line	17:00	2:00	2	1.9	3.8	
24	5	6	2002	13	2	2010	City Line	15:00	2:00	2	2.1	4.2	

25	6	6	2002	14	2	2010	City Line	8:00	0:05	0.08333	0.8	0.066664	
26	6	6	2002	14	2	2010	City Line	11:00	0:17	0.28333	1	0.28333	
27	7	6	2002	15	2	2010	City Line	17:00	0:05	0.08333	1.8	0.149994	
28	8	6	2002	16	2	2010	City Line	17:00	1:00	1	1.5	1.5	
29	11	6	2002	19	2	2010	City Line	19:00	0:05	0.08333	2	0.16666	
30	14	6	2002	22	2	2010	City Line	20:00	0:05	0.08333	2.3	0.191659	
31	15	6	2002	23	2	2010	City Line	13:00	2:00	2	1.2	2.4	
32	15	6	2002	23	2	2010	City Line	17:00	0:10	0.1666	1.8	0.29988	
33	17	6	2002	25	2	2010	City Line	14:00	2:00	2	1.4	2.8	
34	20	6	2002	28	2	2010	City Line	2:00	5:00	5	0.8	4	
35	24	6	2002	3	3	2010	City Line	8:00	7:00	7	1.1	7.7	
36	24	6	2002	3	3	2010	City Line	21:00	0:47	0.78333	1.9	1.488327	
37	25	6	2002	4	3	2010	City Line	14:00	0:12	0.2	1.2	0.24	
38	25	6	2002	4	3	2010	City Line	10:00	0:30	0.5	0.9	0.45	
39	26	6	2002	5	3	2010	City Line	8:00	7:00	7	0.8	5.6	
40	29	6	2002	8	3	2010	City Line	8:00	7:00	7	1.2	8.4	
41	29	6	2002	8	3	2010	City Line	19:00	1:55	1.91666	1.9	3.641654	
42	1	7	2002	10	3	2010	City Line	17:00	4:00	4	1.8	7.2	
43	12	7	2002	21	3	2010	City Line	18:00	0:19	0.31666	1.7	0.538322	
44	13	7	2002	22	3	2010	City Line	8:00	0:05	0.08333	1.1	0.091663	
45	14	7	2002	23	3	2010	City Line	8:00	0:05	0.08333	1.2	0.099996	
46	16	7	2002	25	3	2010	City Line	7:00	0:05	0.08333	0.9	0.074997	
47	18	7	2002	27	3	2010	City Line	15:00	1:09	1.15	1.6	1.84	
48	20	7	2002	29	3	2010	City Line	2:00	1:42	1.7	0.8	1.36	
49	22	7	2002	31	3	2010	City Line	20:00	0:05	0.08333	2.1	0.174993	
50	25	7	2002	3	4	2010	City Line	15:00	0:05	0.08333	1.4	0.116662	
51	25	7	2002	3	4	2010	City Line	15:00	0:05	0.08333	1.4	0.116662	
52	25	7	2002	3	4	2010	City Line	18:00	0:05	0.08333	1.6	0.133328	
53	25	7	2002	3	4	2010	City Line	18:00	0:51	0.85	1.6	1.36	
54	25	7	2002	3	4	2010	City Line	19:00	0:05	0.08333	1.8	0.149994	
55	26	7	2002	4	4	2010	City Line	16:00	0:05	0.08333	1.4	0.116662	
56	28	7	2002	6	4	2010	City Line	18:00	0:20	0.333	1.5	0.4995	
57	30	7	2002	8	4	2010	City Line	17:00	1:03	1.05	1.7	1.785	
58	3	8	2002	12	4	2010	City Line	8:00	0:05	0.08333	0.9	0.074997	

59	7	8	2002	16	4	2010	City Line	1:00	0:05	0.08333	0.9	0.074997	
60	8	8	2002	17	4	2010	City Line	23:00	0:05	0.08333	1.4	0.116662	
61	9	8	2002	18	4	2010	City Line	20:00	0:05	0.08333	2	0.16666	
62	10	8	2002	19	4	2010	City Line	9:00	0:31	0.51666	1.1	0.568326	
63	10	8	2002	19	4	2010	City Line	22:00	0:05	0.08333	1.4	0.116662	
64	10	8	2002	19	4	2010	City Line	22:00	0:05	0.08333	1.4	0.116662	
65	10	8	2002	19	4	2010	City Line	23:00	0:15	0.25	1.7	0.425	
66	11	8	2002	20	4	2010	City Line	17:00	0:06	0.1	1.8	0.18	
67	13	8	2002	22	4	2010	City Line	7:00		25.4	1	25.4	
68	21	8	2002	30	4	2010	City Line	7:00	0:05	0.08333	1	0.08333	
69	22	8	2002	31	4	2010	City Line	1:00	0:05	0.08333	0.9	0.074997	
70	25	8	2002	3	5	2010	City Line	3:00	23:24	23.4	1	23.4	
71	25	8	2002	3	5	2010	City Line	19:00	0:06	0.1	1.9	0.19	
72	27	8	2002	5	5	2010	City Line	18:00	0:05	0.08333	2.4	0.199992	
73	28	8	2002	6	5	2010	City Line	24:00	0:05	0.08333	1.4	0.116662	
74	29	8	2002	7	5	2010	City Line	6:00	0:05	0.08333	1.2	0.099996	
75	2	9	2002	10	5	2010	City Line	20:00	0:30		1.88	0	
76	13	9	2002	21	5	2010	City Line	15:00	0:05	0.08333	1.4	0.116662	
77	15	9	2002	23	5	2010	City Line	6:00	0:05	0.08333	1.26	0.1049958	
78	15	9	2002	23	5	2010	City Line	6:00	0:14		1.76	0	
79	21	9	2002	29	5	2010	City Line	9:00	1:07		1.9	0	
80	25	9	2002	2	6	2010	City Line	19:00	0:30		1.6	0	
81	27	9	2002	4	6	2010	City Line	22:00	0:05	0.08333	1.24	0.1033292	
82	28	9	2002	5	6	2010	City Line	20:00	0:27		2.08	0	
83	29	9	2002	6	6	2010	City Line	9:00	0:05	0.08333	1.4	0.116662	
84	30	9	2002	7	6	2010	City Line	6:00	1:00		1.26	0	
85	30	9	2002	7	6	2010	City Line	10:00	0:05	0.08333	1.56	0.1299948	
86	30	9	2002	7	6	2010	City Line	21:00	0:05	0.08333	1.8	0.149994	
87	30	9	2002	7	6	2010	City Line	18:00	0:05	0.08333	2.08	0.1733264	
88	3	10	2002	10	6	2010	City Line	19:00	0:25	0.4	1.75	0.7	
89	10	10	2002	17	6	2010	City Line	8:00	0:05	0.08333	1	0.08333	
90	17	10	2002	24	6	2010	City Line	5:00	0:05	0.08333	1.08	0.0899964	
91	17	10	2002	24	6	2010	City Line	7:00	1:40	1.666	1.08	1.79928	
92	18	10	2002	25	6	2010	City Line	17:00	0:05	0.08333	1.28	0.1066624	

93	20	10	2002	27	6	2010	City Line	2:00	0:05	0.08333	1.2	0.099996	
94	25	10	2002	2	7	2010	City Line	6:00	0:05	0.08333	1.1	0.091663	
95	25	10	2002	2	7	2010	City Line	6:00	0:05	0.08333	1.26	0.1049958	
96	25	10	2002	2	7	2010	City Line	1:00	3:50	3.8333	0.89	3.411637	
97	28	10	2002	5	7	2010	City Line	15:00	0:16	0.2666	1.35	0.35991	
98	28	10	2002	5	7	2010	City Line	10:00	0:05	0.08333	1.8	0.149994	
99	7	11	2002	14	6	2010	City Line	11:00	0:05	0.08333	1.68	0.1399944	
100	13	11	2002	20	7	2010	City Line	13:00	0:14	0.2333	0.8	0.18664	
101	14	11	2002	21	7	2010	City Line	14:00	0:05	0.08333	1.3	0.108329	
102	18	11	2002	25	7	2010	City Line	11:00	0:05	0.08333	1.3	0.108329	
103	24	11	2002	31	7	2010	City Line	11:00	0:15	0.25	1.4	0.35	
104	25	11	2002	1	8	2010	City Line	19:00	0:05	0.08333	2.08	0.1733264	
105	27	11	2002	3	8	2010	City Line	19:00	0:05	0.08333	1.76	0.1466608	
106	28	11	2002	4	8	2010	City Line	20:00	1:05	1.08333	1.9	2.058327	
107	28	11	2002	4	8	2010	City Line	22:00	0:20	0.333	1.6	0.5328	
108	29	11	2002	5	8	2010	City Line	6:00	0:05	0.08333	1.24	0.1033292	
109	30	11	2002	6	8	2010	City Line	10:00	0:05	0.08333	1.08	0.0899964	
110	30	11	2002	6	8	2010	City Line	14:00	1:51	1.85	1.75	3.2375	
111	1	12	2002	7	8	2010	City Line	3:00	23:24	23.4	1.2	28.08	
112	2	12	2002	8	8	2010	City Line	19:00	0:06	0.1	2.08	0.208	
113	7	12	2002	13	8	2010	City Line	18:00	0:05	0.08333	2.08	0.1733264	
114	12	12	2002	18	8	2010	City Line	24:00	0:05	0.08333	1.74	0.1449942	
115	14	12	2002	20	8	2010	City Line	6:00	0:05	0.08333	1.22	0.1016626	
116	16	12	2002	22	8	2010	City Line	20:00	0:30	0.5	1.92	0.96	
117	17	12	2002	23	8	2010	City Line	15:00	0:05	0.08333	1.6	0.133328	
118	17	12	2002	23	8	2010	City Line	6:00	0:05	0.08333	1.6	0.133328	
119	21	12	2002	27	8	2010	City Line	11:00	0:28	0.4666	1	0.4666	
120	22	12	2002	28	8	2010	City Line	17:00	0:24	0.4	1.58	0.632	
121	24	12	2002	30	8	2010	City Line	19:00	0:36	0.6	1.9	1.14	
122	25	12	2002	31	8	2010	City Line	21:00	1:24	1.4	2	2.8	
123	27	12	2002	2	9	2010	City Line	10:00	0:05	0.08333	1.1	0.091663	
124	28	12	2002	3	9	2010	City Line	7:00	0:12	0.2	0.98	0.196	
125	29	12	2002	4	9	2010	City Line	16:00	1:45	1.75	1.21	2.1175	
126	1	1	2003	11	9	2010	City Line	5:00	4:42	4.7	1.23	5.781	

127	5	1	2003	15	9	2010	City Line	6:00	0:05	0.0833	1.12	0.093296	
128	5	1	2003	15	9	2010	City Line	15:00	0:05	0.0833	0.48	0.039984	
129	5	1	2003	15	9	2010	City Line	19:00	0:34	0.566	2.4	1.3584	
130	6	1	2003	16	9	2010	City Line	11:00	0:14	0.23333	0.64	0.1493312	
131	6	1	2003	16	9	2010	City Line	17:00	0:05	0.0833	1.24	0.103292	
132	6	1	2003	16	9	2010	City Line	18:00	0:14	0.2333	1.24	0.289292	
133	7	1	2003	17	9	2010	City Line	18:00	0:19	0.3166	1.98	0.626868	
134	8	1	2003	18	9	2010	City Line	14:00	0:45	0.75	2	1.5	
135	10	1	2003	20	9	2010	City Line	14:00	0:35	0.58333	1.76	1.0266608	
136	11	1	2003	21	9	2010	City Line	18:00	0:39	0.65	2.8	1.82	
137	12	1	2003	22	9	2010	City Line	18:00	0:13	0.2166	1.35	0.29241	
138	13	1	2003	23	9	2010	City Line	19:00	1:50	1.8333	1.8	3.29994	
139	14	1	2003	34	9	2010	City Line	12:00	0:08	0.1333	1.68	0.223944	
140	15	1	2003	25	9	2010	City Line	3:00	1:28	1.4666	0.8	1.17328	
141	15	1	2003	25	9	2010	City Line	8:00	0:19	0.31666	1.3	0.411658	
142	15	1	2003	25	9	2010	City Line	9:00	0:05	0.08333	1.3	0.108329	
143	18	1	2003	28	9	2010	City Line	10:00	0:05	0.08333	1.4	0.116662	
144	22	1	2003	2	10	2010	City Line	18:00	0:48	0.8	2.08	1.664	
145	23	1	2003	3	10	2010	City Line	11:00	0:32	0.5333	1.76	0.938608	
146	23	1	2003	3	10	2010	City Line	22:00	0:21	0.35	1.9	0.665	
147	25	1	2003	5	10	2010	City Line	13:00	0:05	0.08333	1.6	0.133328	
148	25	1	2003	5	10	2010	City Line	10:00	0:05	0.08333	1.24	0.1033292	
149	26	1	2003	6	10	2010	City Line	12:00	0:05	0.08333	2.08	0.1733264	
150	26	1	2003	6	10	2010	City Line	12:00	0:13	0.21666	2.08	0.4506528	
151	27	1	2003	7	10	2010	City Line	18:00	0:11	0.18333	1.98	0.3629934	
152	28	1	2003	8	10	2010	City Line	19:00	0:05	0.08333	0.8	0.066664	
153	30	1	2003	10	10	2010	City Line	3:00	2:50	2.8333	0.96	2.719968	
154	30	1	2003	10	10	2010	City Line	8:00	0:16	0.2666	1.2	0.31992	
155	2	2	2003	12	10	2010	City Line	8:00	0:05	0.08333	1.2	0.099996	
156	2	2	2003	12	10	2010	City Line	11:00	0:35	0.58333	1.4	0.816662	
157	2	2	2003	12	10	2010	City Line	17:00	0:05	0.08333	1.4	0.116662	
158	2	2	2003	12	10	2010	City Line	19:00	3:12	3.2	2.08	6.656	
159	3	2	2003	13	10	2010	City Line	6:00	0:05	0.08333	1.1	0.091663	
160	3	2	2003	13	10	2010	City Line	13:00	0:08	0.1333	1.3	0.17329	

161	3	2	2003	13	10	2010	City Line	17:00	0:05	0.08333	1.4	0.116662	
162	4	2	2003	14	10	2010	City Line	8:00	0:05	0.08333	0.96	0.0799968	
163	6	2	2003	16	10	2010	City Line	6:00	1:03	1.05	1	1.05	
164	6	2	2003	16	10	2010	City Line	19:00	1:30	1.5	2.1	3.15	
165	8	2	2003	18	10	2010	City Line	6:00	0:05	0.083333	1.24	0.1033329	
166	8	2	2003	18	10	2010	City Line	7:00	0:05	0.08333	1.35	0.1124955	
167	9	2	2003	19	10	2010	City Line	18:00	1:25	1.41666	2	2.83332	
168	12	2	2003	22	10	2010	City Line	8:00	0:05	0.08333	1.4	0.116662	
169	12	2	2003	22	10	2010	City Line	11:00	0:25	0.41666	1.6	0.666656	
170	12	2	2003	22	10	2010	City Line	12:00	0:05	0.08333	1.3	0.108329	
171	12	2	2003	22	10	2010	City Line	15:00	1:50	1.8333	1.5	2.74995	
172	14	2	2003	24	10	2010	City Line	8:00	0:40	0.666	1.1	0.7326	
173	14	2	2003	24	10	2010	City Line	17:00	0:14	0.2333	1.8	0.41994	
174	16	2	2003	26	10	2010	City Line	16:00	0:05	0.08333	1.5	0.124995	
175	17	2	2003	27	10	2010	City Line	7:00	0:05	0.08333	0.95	0.0791635	
176	18	2	2003	28	10	2010	City Line	9:00	0:05	0.08333	1.3	0.108329	
177	18	2	2003	8	10	2010	City Line	10:00	0:05	0.08333	1.9	0.158327	
178	18	2	2003	28	10	2010	City Line	11:00	0:05	0.08333	1.5	0.124995	
179	18	2	2003	28	10	2010	City Line	21:00	0:05	0.08333	1.4	0.116662	
180	21	2	2003	31	10	2010	City Line	9:00	0:05	0.08333	0.9	0.074997	
181	22	2	2003	1	11	2010	City Line	18:00	1:18	1.3	1.6	2.08	
182	26	2	2003	5	11	2010	City Line	18:00	1:17	1.28333	1.6	2.053328	
183	27	2	2003	6	11	2010	City Line	6:00	1:18	1.3	0.7	0.91	
184	29	2	2003	8	11	2010	City Line	7:00	0:05	0.0833	1.44	0.119952	
185	29	2	2003	8	11	2010	City Line	14:00	0:21	0.35	1.6	0.56	
186	29	2	2003	8	11	2010	City Line	18:00	1:10	1.1666	0.5	0.5833	
187	3	3	2003	12	11	2010	City Line	10:00	0:05	0.0833	1.92	0.159936	
188	3	3	2003	12	11	2010	City Line	18:00	1:16	1.2667	2.08	2.634736	
189	5	3	2003	14	11	2010	City Line	7:00	0:05	0.08333	1.6	0.133328	
190	6	3	2003	15	11	2010	City Line	6:00	0:05	0.08333	1.6	0.133328	
191	6	3	2003	15	11	2010	City Line	7:00	0:05	0.08333	1.6	0.133328	
192	7	3	2003	16	11	2010	City Line	8:00	0:05	0.08333	1.3	0.108329	
193	9	3	2003	18	11	2010	City Line	8:00	0:05	0.08333	1.5	0.124995	
194	10	3	2003	19	11	2010	City Line	18:00	1:30	1.5	2.4	3.6	

195	11	3	2003	20	11	2010	City Line	17:00	0:05	0.0833	1.4	0.11662	
196	12	3	2003	21	11	2010	City Line	17:00	0:17	0.28333	1.2	0.339996	
197	13	3	2003	22	11	2010	City Line	18:00	0:05	0.08333	1.08	0.0899964	
198	14	3	2003	23	11	2010	City Line	6:00	0:22	0.3666	1.2	0.43992	
199	15	3	2003	24	11	2010	City Line	4:00	0:05	0.08333	1.12	0.0933296	
200	15	3	2003	24	11	2010	City Line	14:00	0:20	0.333	1.7	0.5661	
201	16	3	2003	25	11	2010	City Line	16:00	0:06	0.1111	1.6	0.17776	
202	18	3	2003	27	11	2010	City Line	6:00	1:03	1.05	1.4	1.47	
203	18	3	2003	27	11	2010	City Line	10:00	0:23	0.38333	1.62	0.6209946	
204	19	3	2003	28	11	2010	City Line	11:00	0:13	0.21666	1.44	0.3119904	
205	19	3	2003	28	11	2010	City Line	6:00	3:20	3.333	1.12	3.73296	
206	21	3	2003	30	11	2010	City Line	14:00	2:10	2.1666	1.96	4.246536	
207	21	3	2003	30	11	2010	City Line	18:00	1:20	1.333	2.04	2.71932	
208	22	3	2003	1	12	2010	City Line	6:00	2:16	2.2666	1.12	2.538592	
209	25	3	2003	4	12	2010	City Line	12:00	0:50	0.8333	2.4	1.99992	
210	28	3	2003	7	12	2010	City Line	18:00	1:10	1.1666	1.76	2.053216	
211	29	3	2003	8	12	2010	City Line	3:00	0:15	0.25	0.88	0.22	
212	29	3	2003	8	12	2010	City Line	19:00	1:01	1.01666	2.64	2.6839824	
213	30	3	2003	9	12	2010	City Line	13:00	0:18	0.3	2.2	0.66	
214	1	4	2003	10	12	2010	City Line	14:00	0:05	0.08333	1.6	0.133328	
215	1	4	2003	10	12	2010	City Line	18:00	0:53	0.88333	1.4	1.236662	
216	2	4	2003	11	12	2010	City Line	2:00	0:30	0.5	1.12	0.56	
217	2	4	2003	11	12	2010	City Line	15:00	1:30	1.5	2.08	3.12	
218	3	4	2003	12	12	2010	City Line	18:00	1:00	1	2.08	2.08	
219	5	4	2003	14	12	2010	City Line	6:00	0:05	0.08333	1.4	0.116662	
220	5	4	2003	14	12	2010	City Line	8:00	0:14	0.2333	1.4	0.32662	
221	5	4	2003	14	12	2010	City Line	8:00	0:12	0.2	1.4	0.28	
222	5	4	2003	14	12	2010	City Line	17:00	0:12	0.2	1.7	0.34	
223	6	4	2003	15	12	2010	City Line	6:00	0:11	0.18333	1.2	0.219996	
224	6	4	2003	15	12	2010	City Line	11:00	0:21	0.35	1.8	0.63	
225	6	4	2003	15	12	2010	City Line	14:00	0:40	0.666	2.08	1.38528	
226	6	4	2003	15	12	2010	City Line	18:00	1:16	1.2666	1.75	2.21655	
227	7	4	2003	16	12	2010	City Line	15:00	0:11	0.18333	2	0.36666	
228	7	4	2003	16	12	2010	City Line	16:00	0:13	0.21666	2.08	0.4506528	

229	8	4	2003	17	12	2010	City Line	18:00	0:42	0.7	2.08	1.456	
230	10	4	2003	19	12	2010	City Line	7:00	0:05	0.0833	1.28	0.106624	
231	11	4	2003	20	12	2010	City Line	12:00	0:05	0.08333	2.08	0.1733264	
232	13	4	2003	22	12	2010	City Line	18:00	0:50	0.8333	1.6	1.33328	
233	16	4	2003	25	12	2010	City Line	11:00	0:08	0.1333	1.6	0.21328	
234	16	4	2003	25	12	2010	City Line	12:00	1:22	1.3666	1.6	2.18656	
235	17	4	2003	26	12	2010	City Line	16:00	0:11	0.18333	1.3	0.238329	
236	18	4	2003	27	12	2010	City Line	6:00	0:22	0.3666	1.52	0.557232	
237	18	4	2003	27	12	2010	City Line	8:00	7:33	7.55	1.52	11.476	
238	18	4	2003	27	12	2010	City Line	16:00	0:35	0.58333	1.52	0.8866616	
239	19	4	2003	28	12	2010	City Line	12:00	0:10	0.1666	0.72	0.119952	
240	19	4	2003	28	12	2010	City Line	2:00	6:58	6.9666	0.7	4.87662	
241	19	4	2003	28	12	2010	City Line	18:00	0:15	0.25	1.76	0.44	
TOTAL										**236.95406**	**359.51**	**311.30876**	

Appendix: B

Questionnaires about causes of power interruptions

This study is a part of partial fulfillment of the requirements for the Degree of Masters of Science in Electrical and Computer Engineering program in Addis Ababa University. The area of the research is selected on studies of power system reliability assessment and improvement in Jimma power distribution system.

The intention of the questionnaire is for gathering relevant data in relation to Assessment of Power Interruption in Jimma town, city feeder, for the purpose of identifying the root cause of power interruptions and to propose proper mitigation solutions for those potentially identified problems and to suggest recommendations to the concerning bodies. Through this participation, your answers will be helpful in enhancing the reliability performance of the power distribution system in Jimma town. Your response will only be used for research analysis purposes and I confirm your response is confidential. Thank you very much for your time and suggestions.

Instruction-1: Place an "X" mark in the box of your answer, you can mark more than one box for one question.

1) In which areas of responsibility you involved?

☐ In technical areas ☐ in non-technical areas ☐ Laborer

2) About your educational level

☐ Reading & Writing ☐ up to grade 4 ☐ Grade 5 to 9

☐ Grade 10/12 complete ☐ Collage Diploma ☐ Bachelor Degree

☐ 2nd Degree ☐ Doctorate (PHD) ☐ if other

3) How many years of experience in the company

☐ Up to 2 years ☐ 3-8 years ☐ 9-14 years

☐ 15–19 years ☐ above 20

Instruction-2: Please indicate your level of agreement or disagreement with each of these statements regarding factors contribute for the existing electric power interruptions. Place an "X" mark in the table of your answer.

No.	Causes of interruptions	Contributing factor agreement levels					Total points	Rank
		Strongly Agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**		
1	Feeder Overloaded							
2	Tree contact							
3	Wear out and Failure of distribution Materials							
4	Windy rain							
5	Vehicle accidents on distribution equipment							
6	Scheduled Interruptions							
7	Human errors							
8	Supply outage/Gibe I &II/							
9	Employees skill gaps or errors							
10	Natural phenomenon							
11	Animals and birds							
12	Unknown							
13	Others							

4) If you have any other ideas regarding the causes of the power interruptions in Jimma town distribution system, City feeder, please specify it here under.

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5) If you have any reasons for prolongation of the power outage durations please mention it

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6) If you have any suggestion about the solutions of the power interruption problems in Jimma town power distributions system, city feeder, please specify it

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Thank you for sharing your thoughts!!