

**Reliability Assessment and its Improvement of Power
Distribution Systems**

(Case Study of Harar Substation III)

Mandefro Teshome Aseffa

Advisor: Getachew Biru (Dr.-Ing)



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Approval of Board of Examiners

We, the undersigned, members of the Board of Examiners of the final open defense by Mandefro Teshome have read and evaluated his thesis entitled “**RELIABILITY ASSESSMENT AND IMPROVEMENT OF POWER DISTRIBUTION SYSTEM**” (**Case Study of Harar Substation III**) and examine the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Masters of Science in Electrical Power Engineering.

_____ Advisor	_____ Signature	_____ Date
_____ Chair Person	_____ Signature	_____ Date
_____ Internal Examiner	_____ Signature	_____ Date
_____ External Examiner	_____ Signature	_____ Date

DECLARATION

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

Mandefro Teshome

Student Name

Signature

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ACRONOMYS

A	Ampere
AAC	All Aluminum Conductor
AENS	Average Energy Not Supplied
ALIDI	Average Load Interruption Duration Index
ALIFI	Average Load Interruption Frequency Index
ASAI	Average Service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
DUR	Duration of Interruption
EEA	Ethiopia Electric Agency
EEP	Ethiopia Electric Power
EEU	Ethiopia Electric Utility
EEPCO	Ethiopia Electric Power Corporation
EENS	Expected Energy Not Supplied
ETAPS	Electrical Transient Analysis Program Software
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
KVAr	Kilo Volt Ampere reactive
KWh	Kilowatt hour

MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
MVA	Mega Volt Ampere
Rec	Recloser
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
TCC	Time Current Curve

ABSTRACT

Unreliable electric power distribution affects daily activity and drags the modern lifestyle. The existing substation has encountered frequent power interruptions problems. The interruptions are caused mainly by the short circuit (SC) and earth fault (EF). There are also planned outages for operation and maintenance purpose. The substation's System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) are 521.46 interruptions per customer per year and 446.82 hours per customer per year, respectively. The substation is not reliable by the standard of Ethiopian Electric Agency (EEA) which has set SAIFI as equal to 20 interruptions per customer per year and SAIDI which is around 25 hours per customer per year. This reliability gap calls for exploring effective methods for improving the reliability of the distribution system. Thus, the objective of the study is to assess the reliability of the existing distribution system and suggest solutions for reliability improvement in heuristic techniques. To limit the scope of the study, 15 kV Harar city feeder of the substation has been chosen for reliability improvement measures. The historical outage interruption data of years 2016-2018 G.C has been used as a base year. The study has evaluated five different mitigation scenarios to improve the system reliability. From the mitigation scenarios with the lowest SAIDI, SAIFI and Expected Energy Not Supplied (EENS) at a reasonable cost has been selected. The simulation results have been done with the help of Electrical Transient Analysis Program (ETAP 12.6) software. The result of this thesis work reveals that the reliability of the system has been improved significantly by implementing reliability improvement solutions that are justified economically. The researcher identifies scenario five (Using Three Recloser, Tie Switch, Isolator and New Substation) as the optimum one after comparing the power reliability improvement and the cost. Hence, the overall reliability of Harar city feeder indices SAIFI by 83.23%, SAIDI by 89.48% and EENS by 97.51%, have been improved as compared with the existing system for the simulated best option. The economic analysis shows that the selected solution results in a cost saving of 2,105,530.3 ETB per year from the unsold energy of one feeder only with 1.18 payback period investment. Satisfaction of the society has been considered as a priceless benefit as well.

Key words: Distribution System, Distribution Reliability, Network Reconfiguration, Power Reliability, Reliability Indices, ETAP Software.

CHAPTER ONE

1. INTRODUCTION

1.1. Background

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

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

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

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

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

predetermined time. Thus, it decreases the length of outages and improves system reliability [6-8].

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

1.2. Statement of the problem

The issue of power reliability is a great concern in Ethiopia. Since Harar is preferred location for some of the industries in Ethiopia, considerable share of the electric power supply is directed towards the city. Due to this fact, Harar has been another load center of Ethiopian electric power. Due to frequent and long power interruptions, all residential, commercial and industrial customers are victims of the problem. Especially for factories and industries, power reliability is a matter of death and life [12]. Associated with these problems, Frequent interruption is felt in each part of the city for longer time and a large amount of electric energy is wasted in the feeders (cables) in the form of heat (I^2R loss) as the feeders are subject to carry a huge amount of reactive power. The substations are usually overloaded during peak times. This thesis aims to make a detailed analysis of these problems, identifying their root causes and effects and trying to find optimum solutions which can be implemented to solve the problems.

1.3. General and specific objectives

1.3.1. General Objective

The main objective of the thesis is to study the power reliability problems and mitigation technique for a distribution system in Harar city.

1.3.2. Specific objective

The specific objectives of this thesis are listed below:

- Assess Harar city power distribution system in terms of its reliability problems.
- Identify the major causes of power interruptions in the existing system based on historical outage data.

- Evaluate system reliability indices based on selected base year's interruption data of the city feeder using an available reliability analysis tool (ETAP12.6.0).

1.4. Scope of the study

This thesis covers, studying the existing power system reliability problems of the substation and compare the techniques to develop optimum methods, their causes, percentage of improvements gained by different techniques to the present Harar substation III. The reliability models have been developed using Etaps software.

1.5. Significance of the study

The economic and social effects of loss of electric service have significant impacts on both the utility supplying electric energy and the end users of electric service. Therefore, maintaining a reliable power supply is a very important issue for power systems design and operation [4].

1.6. Thesis Layout

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

CHAPTER TWO

2. THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1. Introduction

Reliability is a branch of power quality which investigates the impact of electric interruption on costumer's day to day activities. In other words, reliability is simply a subset of power quality. Even the clear cut boundary that separates the two is not well defined. Sustained interruptions (more than a few minutes) have always been categorized as a reliability issue, though many utilities have also classified momentary interruptions (less than a few minutes) as a power quality issue. This is because momentary interruptions are occurred via planned operating practices, in which such interruptions exert a little impact on the costumer's activity and are difficult to measure. Currently, momentary interruptions are a big customer's issue and are considered as a parameter of power reliability. Power interruption can be expressed in terms of availability (when the percentage of time a voltage source is uninterrupted) and unavailability (when the percentage of time a voltage source is interrupted). Therefore, availability and unavailability can be considered as subset of power reliability. The hierarchy of power quality, reliability, and availability is summarized below (Figure 2.1).

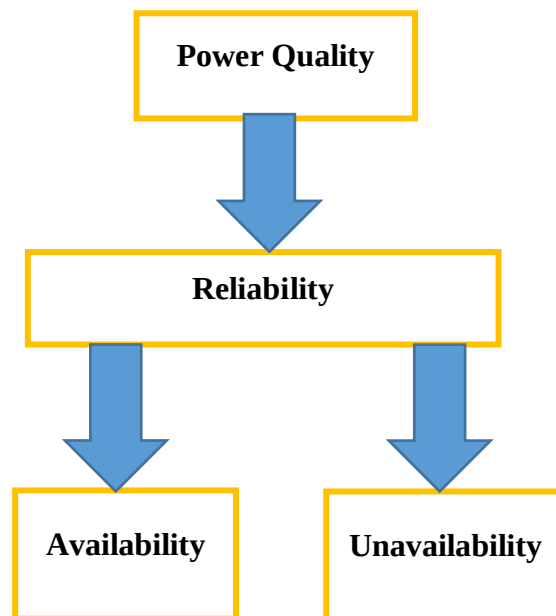


Figure 2.1: Hierarchy of power quality, reliability, and availability [13].

Availability is a subset of reliability and reliability is a subset of power quality. Power quality deals with any deviation from a perfect sinusoidal voltage source. Reliability deals

with interruptions and availability deals with the probability of being in an interrupted state [13].

Reliability measures the power system's ability to supply electricity to its customers within accepted standards and in the magnitude desired, for the period of time intended, under the operating conditions required. There are two aspects of reliability:

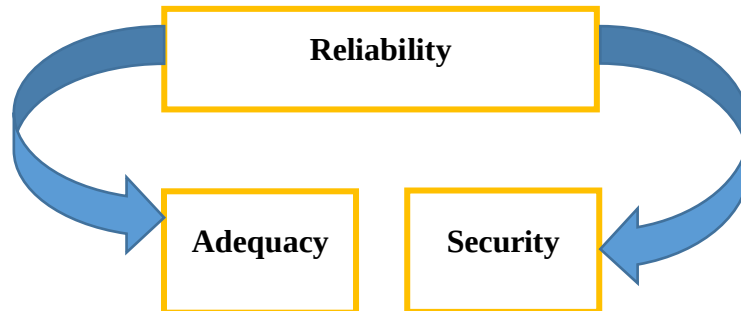


Figure 2.2: Two aspects of reliability [12]

Adequacy: refers to the existence of adequate generating, transmitting and distributing facilities within the system to satisfy the consumer load demand at all times; considering planned/ unplanned outages. It is assessed using the power flow (AC/DC) solutions.

Security: refers to the ability of the electric systems to react against to sudden disturbances arising within that system, such as earth fault and short circuit.

Adequacy is particularly associated with the planning of the grid and security is linked with the operation of the grid [12].

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

Reliability $R(t)$: refers to the probability that a component practices no failure during a time period.

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

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

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

Availability: is the probability that an item is available for application or use when needed.

Failure Frequency (f): refers to the number of failures that may happen to a time period. In this study, the unit of the failure rate frequency is failure per year.

$$f = \frac{\text{Number of Failures}}{\text{Studied Period} \times \text{Circuit Length of Transmission lines or Cables}} \quad (2.1)$$

Mean Time to Failure (MTTF): The average time it takes to the occurrence of the component or system failure measured from $t = 0$.

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

The relationship between the failure frequency and the mean time to failure is given by;

$$f = \frac{1}{\text{MTTF} + \text{MTTR}} \quad (2.2)$$

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

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

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

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

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

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

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

$$U = 1 - A \quad (2.6)$$

2.2. Electrical fault

Most of the time faults are caused by breakdown of insulation systems and can be classified as self-clearing, temporary and permanent. A self-clearing fault will extinguish itself without any external intervention (e.g., a fault occurring on a secondary network that persists until it burns clear). A temporary fault is a short circuit that will clear if

deenergized and then re-energized. A permanent fault is a short circuit that will continue until repaired by human intervention. Some types of faults are discussed as follows.

2.2.1. Outage: An outage occurs when a part of equipment is de-energized. Outages can be either programmed or unprogrammed. Programmed outages are known in advance (e.g., outages for periodic maintenance). Unprogrammed outages result from contingencies [13].

2.2.2. Transient Faults: A transient fault is a fault that disappears either by itself or by de-energization of the faulted circuit and it does not require any immediate repair work. Transient faults occur mainly on outdoor equipment or overhead feeders where air is the main insulating medium. Common causes of Transient faults are momentary tree contacts with conductor and flashovers initiated either by lighting or by conductors temporarily swinging together. In this thesis it is assumed that in the event of a transient fault, reclosing of the associated circuit breaker or reclosing is always successful, though it might not be successful on the first or second attempt [13, 14].

2.3. Power Interruption

Customer power interruptions are caused by a wide range of phenomena including equipment failure, animals, trees, severe weather and human error. These causes are at the root of distribution reliability, and understanding them allows abstract topics like reliability modeling and computer optimization to be viewed from a practical perspective. In addition, identifying and addressing physical root causes is often the most cost effective way to address reliability problems.

There are different types of power interruption and are discussed below.

2.3.1. Momentary Interruption

A momentary interruption occurs when a customer is de-energized for less than a few minutes. Most of momentary interruptions result from reclosing or automated switching. Multiple reclosing operations result in multiple momentary interruptions (e.g., two recloser operations equals two momentary interruptions for downstream customers).

2.3.2. Sustained Interruption

A sustained interruption happens when a customer is de-energized for more than a few minutes. Most sustained interruptions result from open circuits and faults [13].

2.3.3. Temporary Interruption

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

2.3.4. Planned Interruption

Planned interruption is a loss of electric power that results when a component is purposely taken out of service at a selected time. This is usually done for the purposes of construction preventative maintenance, or repair [16].

2.4. 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 numerical combinations of reliability data for a set of loads, components or customers. The reliability of the power supply is calculated using the reliability indices. These indices of distribution system analysis include energy-oriented indices and customer-oriented indices. [17].

A. Customer Oriented Indices

(i) 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.

$$SAIFI = \frac{\text{Total Number of Customer Interrupted}}{\text{Total Number of Customer Served}} = \frac{\sum \lambda_i N_i}{\sum N_i} \quad (2.7)$$

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

(ii) Consumer 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.

$$CAIFI = \frac{\text{Total Number of Customer Interruptions}}{\text{Total Number of Customers Affected}} \quad (2.8)$$

This index differs from SAIFI only in the value of the denominator. It is particularly useful when a given calendar year is compared with other calendar years since, in any given calendar year, not all customers will be affected and many will experience complete continuity of supply. The value of CAIFI therefore is very useful in recognizing chronological trends in the reliability of a particular distribution system.

In the application of this index, the customers affected should be counted only once, regardless of the number of interruptions they may have experienced in the year.

(iii) 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.

$$SAIDI = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total Number of Customers Served}} = \frac{\sum U_i N_i}{\sum N_i} \quad (2.9)$$

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

(iv) Customer average interruption duration index. CAIDI

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.

$$CAIDI = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total Number of Customer Interruptions}} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \quad (2.10)$$

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

(v) Average service availability (unavailability) index, ASAI (ASUI)

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

$$ASAI = \frac{\text{Customer Hours of Available Service}}{\text{Customer Hours Demanded}}$$

$$ASAI = \frac{\sum N_i \times 8760 - \sum U_i N_i}{\sum N_i \times 8760}$$

$$ASUI = 1 - ASAI \quad (2.11)$$

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

B. Load- and energy-orientated indices

One of the important parameters required in the evaluation of load- and energy-orientated indices is the average load at each load-point bus bar.

- (i) Energy not supplied index, ENS

This index represents the total energy not supplied by the system.

$$ENS = \sum L_{a(i)} U_i \quad (2.12)$$

Where, $L_{a(i)}$ is the average load connected to load point i.

- (ii) Average energy not supplied, AENS or average system curtailment index, ASCI.

This index represents the average energy not supplied by the system.

$$AENS = \frac{\text{Total Energy not Supplied}}{\text{Total Number of Customers Served}} = \frac{\sum L_{a(i)} U_i}{\sum N_i} \quad (2.13)$$

- (iii) Average customer curtailment index, ACCI

This index represents the total energy not supplied per affected customer by the system.

$$ACCI = \frac{\text{Total Energy not Supplied}}{\text{Total Number of Customers Affected}} \quad (2.14)$$

This index differs from AENS in the same way that CAIFI differs from SAIFI. It is therefore a useful index for monitoring the changes of average energy not supplied between one calendar year and another.

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 [17, 18].

2.5. Power reliability improvement techniques

There are many types of techniques used to improve power reliability. Some of them are listed below.

- Distribution system reconfiguration
- Recloser
- Sectionalizers

2.5.1. Distribution system reconfiguration

Network reconfiguration is used to search the better switching combination that increases the voltage stability, voltage profile and reliability decreases losses by considering a tie switch and sectionalised switch. This search continues till there is no improvement in voltage stability and there is no reduction in power loss and reliability indices. Before the reconfiguration is established, a flow investigation is needed to make sure that the losses and performance of indices are decreased. If the resulted load is negative, the reconfiguration network must reset to previous network condition [19].

2.5.2. Recloser

A re-closer is a device which sense short circuit and earthling fault overcurrent conditions, to interrupt the circuit if the overcurrent continues after a preset time, and then to automatically reclose to re-energize the line. If the fault that created the operation still happens, 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 percent of the faults are of a temporary fault. Thus, the re-closer, with its opening/closing characteristic, stops a distribution circuit out of service for temporary faults [17].

Recloser mostly trips during overcurrent events. Besides, reclosers can also be used to isolate loads in a feeder under normal conditions. Like that of automatic sectionalizer, reclosers are remotely operable with the help of Intelligent Electronic Devices (IEDs). Line recloser is used to isolate fault in some part of feeder while the rest part of the feeder remains energized. Recloser can be coordinated to substation circuit breaker to isolate fault on a feeder [15].

Organization with other protection devices is important in order to warrant that, when a fault occurs, the smallest section of the circuit is detached to reduce disruption of supplies

to customers. Generally, the time characteristic and the sequence of operation of the re-closer are selected to organize with mechanisms upstream towards the source. After selecting the size and sequence of operation of the re-closer, the devices downstream are attuned in order to achieve correct coordination. The first shot is carried out in immediate mode to clear temporary faults before they cause damage to the lines. The three later ones operate in a timed way with programmed time settings. If the fault is unchanging, the time-delay operation permits other protection devices nearer to the fault to open, limiting the amount of the network being disconnected [17].

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.

2.5.3. Sectionalizers

A sectionalizer is a method that automatically isolates faulted segments of a distribution circuit once an upstream breaker or recloser has disconnected the fault current. It is commonly connected downstream of a recloser. Since sectionalizers have no ability to interrupt fault current, they must be used with a backup device that has fault current interrupting capacity. Sectionalizers count the number of activities of the recloser during fault conditions. After a preselected number of recloser openings, and while the recloser is open, the sectionalizer opens and separates the faulty section of the line. This permits the recloser to close and supplies to those areas free of faults. If the fault is temporary, the operating mechanism of the sectionalizer is retuned. Sectionalizers are formed in single or three phase arrangements with hydraulic or electronic operating mechanisms. It can be used in between two protecting devices [8].

Sectionalizers with hydraulic operating mechanisms have an operating coil in sequence with the line. Each time an overcurrent happens at the coil drives a piston that activates a counting mechanism when the circuit is opened and the current is zero by the displacement of oil across the chambers of the sectionalizer. After a prearranged number of circuit openings, the sectionalizer contacts are opened by means of pretension springs. This category of sectionalizer can be closed manually. Sectionalizers with electronic operating

mechanisms are more flexible in operation and easier to set. The load current is measured by means of current transformers (CTs) and the secondary current is fed to a control circuit which counts the number of operations of the recloser, then sends a tripping signal to the opening mechanism. This type of sectionalizer is constructed with manual or motor closing [8].

The following factors should be considered when selecting a sectionalizer:

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

2.6. Coordination of protection devices

Coordination of protection system is used to sense and isolate the affected portion of the system whenever a short circuit or other abnormality occurs that might cause damage.

The essential 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 trend.

Selectivity is the ability of the relay to distinguish between those conditions for which immediate action is taken and those for which no action or a time-delayed operation is required.

Speed is the capability of the relay to operate in the necessary time period. Speed is a significant in clearing a fault. The critical goal of the protecting equipment is to remove the faulty 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 protection and operate first to disconnect 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. Similarly, 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. In overcurrent relay time varies inversely as the current flowing in the relay. The three most frequently used time-overcurrent features are inverse, very inverse, and extremely inverse. In these curves as the relay operating time decreases the current increases. In practice, selectivity between overcurrent relays protecting different system elements can be achieved 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 fault before the backup protection operates, or continue to operate until the circuit is detached.

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 selected to be half of the lowest single phase to ground fault current [7].

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

$$T_{i,j} = \left(\frac{A_k}{(I_{ij}/I_{pi})^{C_{k-1}}} + B_k \right) * TDS_i \quad (2.14)$$

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 relay 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. These constants have standard value for Moderately Inverse, Very Inverse and Extremely Inverse. 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 [14].

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

2.6.1. Recloser-relay coordination

Two issues should be taken into justification 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.

2.6.2. 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. 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.

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 [17].

2.7. Literature Reviews

The research publications which are related to power distribution system reliability improvements are discussed in this section. Power interruption becomes a serious problem in Ethiopia. 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.

Paper [20] presented a sectionalizing switch separates a faulted section of the system. So that the healthy part can still be electrically supplied, however a tie switch recovers loads that have been disconnected by transferring some of loads to other supporting distribution feeders.

Paper [21] discussed that network reconfiguration of distribution systems is done to improve system operating conditions and reduce system cost. It is a procedure that alters feeder topological construction, shifting the open/close status of sectionalizing switches and tie switches in system. Approximately 80% of the customer interruptions occur due to the problems in distribution networks.

A Paper entitled [22], “Reconfiguration of Actual Distribution Network with Optimum Power Flow for Loss Reduction” described that radial operation constraint makes it

compulsory to open the distribution feeders connected to multiple sources or to a single source from a suitable switching location. According to his description, meshed networks offer many other configuration choices and it is possible to reconfigure the network by exchanging the switching locations. Exact choice of switching positions would decrease losses, increase the lifetime of equipment and enhance power reliability by balancing the system loading.

Paper [19] suggested that networks are reconfigured to decrease system real power losses and achieve load balancing. The reliability of the Electrical Distribution Systems (EDS) can be improved if the loads are rearranged by network reconfiguration which also allows smoothing the peak demands, improves the voltage profile.

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

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

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

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

CHAPTER THREE

3. DATA COLLECTION AND ANALYSIS

3.1. Introduction

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

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

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

Assessment of the existing network: an assessment of the physical system on site has been done.

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

- Three years (2016 -2018 G.C) the interruption, data has been collected from Harar substation III which helps to carry out reliability analysis.
- The rating of Transformers, number of customers and feeder length hav been collected from the distribution in Harar district.
- Load of the existing system has been gathered from the district.
- The collected data has been used to clearly analyze the problems of the Harar city feeder.

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

basic electrical data of power system equipment which are necessary for reliability analysis are presented.

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

3.2. Description of Harar Substation III

Harar substation III receives electric power through 132 kV transmission lines from Dire Dewa substation and it supplies electric power to Harar city and the nearby areas. Ethiopian Electric Power (EEP) and Ethiopia Electric utility (EEU) are service provider of electric power in the country. A 132 kV transmission line is stretched into the Harar substation III, then stepped down to 66 kV, 33kV and 15 kV with two parallel connected transformers in Harar substation III and one transformer which is tapped from 66kV of three winding transformer, and 66kV stepped down to 15kV and supplied to Harar city. The substation has two types of transformers which is two winding and three winding transformer. The two winding transformer step down the power from 66kV to 15kV and the three winding transformer step down 132kV to 66kV and 33kV as shown in Figure 3.1. The distribution system in the city has a primary voltage of 15 kV and also this voltage value is stepped down to 400/220V in three phase and single phase respectively. The network topology of Harar substation III is radial. The bus bar scheme or bus bar layout is parallel to the single bus bar system. The single bus bar scheme has only one three phase to which the various incoming and out coming circuits are connected. This configuration lacks of operational flexibility in case of bus fault or circuit breaker failure as the entire bus has to be de-energized during fault, but it has low cost, with simple protection system. Harar substation III consists of eleven outgoing feeders. The nominal voltage of one feeder is 132kV, the two feeders are 66kV, the four feeders are 15 kV and the remaining four feeders are 33 kV. From three winding transformer 66kV is sent to Haromaya substation.

The main primary feeder branches into various primary laterals which in turn separate into several sub-laterals to serve all the distribution transformers. The main feeder and sub feeders before the transformer are three phase three wire circuit and the laterals are three phase four wire or single phase two wire circuit. In this substation 132kV is stepped down and distributed by 15 and 33kV feeders as shown in Figure 3.1. The eight feeders which are served from 33kV and 15kV are named by the local names of the area they are serving. These are: Kombolcha, Bisidimo, Aweday and Hamaressa Oil feeders, and these feeders

are of 15kV which is stepped down from 66kV. The remaining four feeders which are distributed from 33kV are Harar Water, Industry Zone, Fedis and Bedasa feeders. These feeders serves different area, namely, **Kombolcha** feeder serves Kombolcha town, Jarso and Dire Teyara, **Bisidimo** feeder supply Harar town and Bisidimo, **Aweday** feeder supplies Aweday town, **Hamaressa oil** serves Hamaressa oil factory. While **Harar-Water** feeder supply Harar water town, **Industry Zone** supplies industry zone, **Fedis** feeder supplies Fedis town and **Bedasa** feeder supplies Bedasa.

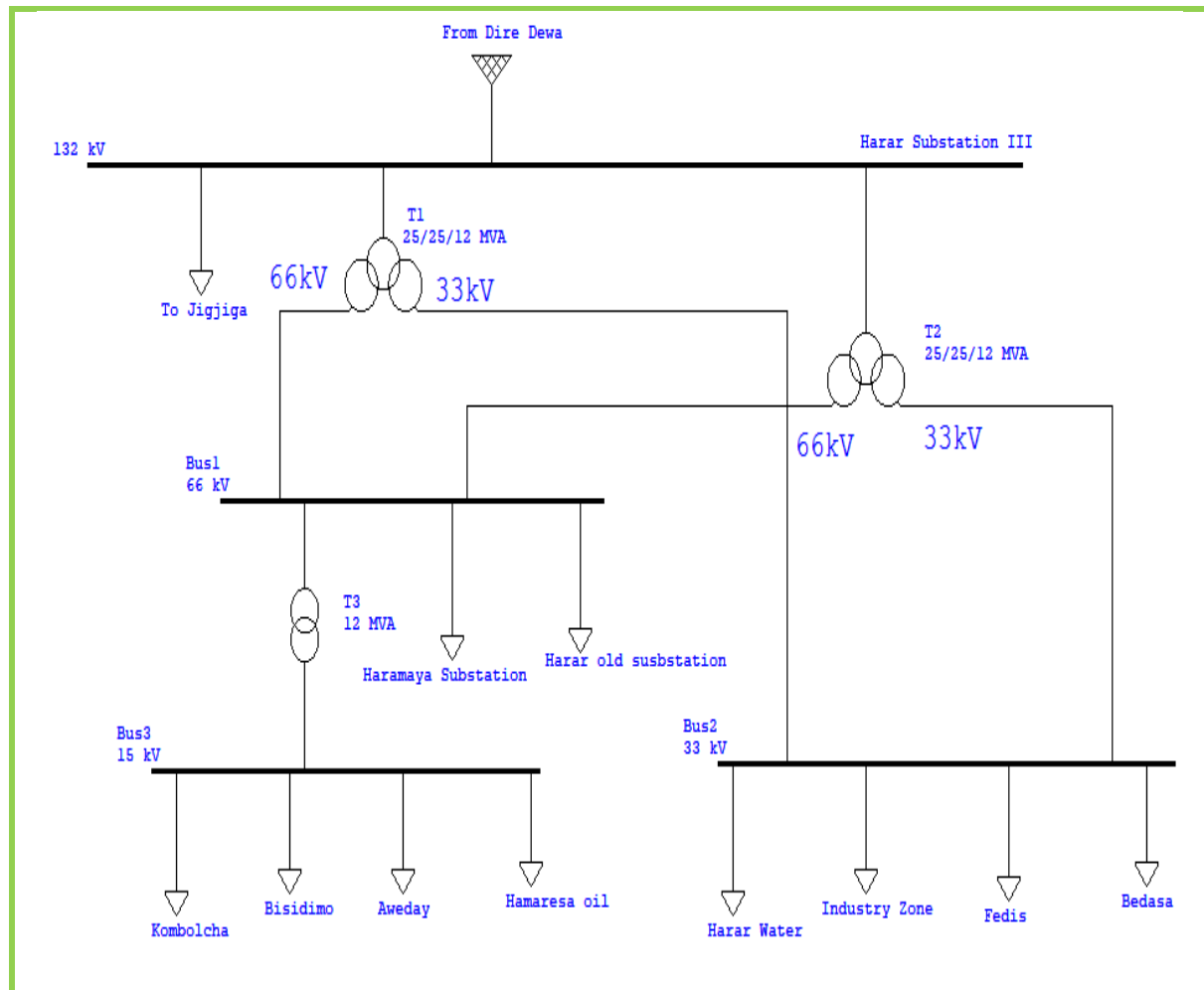


Figure 3. 1: Single line diagram of Harar Substation

Harar substation III has a lot of equipment's which are listed and discussed below

1. Wave Trapper
2. Current Transformer
3. Potential Transformer
4. Circuit Breakers
5. Isolators
6. Bus bars
7. Power Transformer

1. Wave Trapper:

As shown with the red arrow on Figure 3.2 the wave trapper is one of the substation apparatuses which are sited on the incoming lines. Wave trapper is installed in the substation for trapping the high frequency communication signal sent from remote substation and diverting them to the telecom panel in substation control room. The purpose of trapping high frequency is because of it troubling the voltage and current [25].

2. Current Transformer:

As shown by green arrow in Figure 3.2 a current transformer is a transformer that changes higher value currents into lower values. It produces a current in its secondary which is proportional to the current in its primary value [26].

3. Potential Transformer:

As shown by yellow arrow in Figure 3.2 the potential transformers are the same in characteristics as current transformers but are utilized for changing high voltages to lower voltages for protection of relay system and for lower rating metering of voltage measurements [26].

4, Circuit Breakers:

As shown by green arrow in Figure 3.3, circuit breakers are switches which are utilized for closing or opening circuits at the time when a fault occurs within the system. The circuit breaker has 2 movable contacts which are in OFF condition in normal situations. At the time when any fault happens in the system, a relay is sending the tripped command to the circuit breaker which moves the contacts apart, hence avoiding any damage to the circuitry [26].

5, Isolators:

As shown by yellow arrow in Figure. 3.3, isolators in substations are used to detach circuit mechanically when there is an interruption of current. These are also known with the name of separated switches operation under no-load situations and are not fortified with arc-quenching devices [26].

6, Busbars:

Bus bar is used as junction and has outgoing and incoming current paths as shown by red arrow in Figure 3.3. Whenever a fault happens in the bus bar, entire components connected

to that specific segment should be tripped for giving thorough isolation in a small time. These are of different types such as ring bus, double bus, and single bus etc. [26]



Figure 3.2: Harar Substation III incoming side [15]



Figure 3.3: Harar Substation III [15]

7, Power Transformer

As indicated by yellow arrow in Figure 3.4, a power transformer is an electrical device which is used to transfer power from one circuit to another through electromagnetic induction. The power transfer is accompanied without frequency change. As shown in figure 3.1 the power transformer type is three winding and two winding transformer and the three winding transformer steps down power from 132kV to 66kV and 33kV voltage [26]. The third winding is constructed in addition to the primary and secondary windings. The third winding is named the tertiary winding, and because of the three windings, the transformer is called the three winding transformer. The voltage ratings of all the three windings of the transformer are usually imbalanced. The primary winding has the maximum voltage rating, while the tertiary has the lowest voltage rating, and the secondary has the intermediate voltage rating. The main advantage of the three winding transformers is an economy of construction. The most important advantage of the third winding is that the harmonic generated by the primary and secondary winding extinguish by the third winding [27].



Figure 3. 4: Harar Substation III three winding Power transformer [15]



Figure 3.5: Partial view of Harar Substation III Control Room [15]

3.3. Data Collected

Primary data has been collected by the direct involvement of the researcher and workers of EEP and EEU from Harar for the purpose of this research. During the site survey, the

primary data necessary for this study were rating and type of each transformer, topology and layout of the system, conductor type, and others.

Table 3.1: Data for Harar Substation III for Three Winding Transformers

Name of Substation	Number of Transformer	Voltage Level (KV)	Transformer Capacity (MVA)		Total Capacity (MVA)	
			With fan	Without fan	With fan	Without fan
Harar substation III	2	132/66/33	25	20	50	40

Table 3.2: Data for Harar Substation III three winding power transformer

Unit	Line					
	HV		MV		LV	
	With fan	Without fan	With fan	Without fan	With fan	Without fan
MVA	25	20	25	20	12	9.6
V	132000		66000		33000	
A	109.3	87.5	219	175	210	168

Table 3.3: Data for Harar Substation III two winding power transformer

Unit	Line			
	HV		LV	
	With fan	Without fan	With fan	Without fan
MVA	12	9.6	12	9.6
V	66000		15000	
A	105	84	462	370

Table 3.4: Name and voltage levels of Harar substation III outgoing feeders

Feeder code	Voltage Level in KV	Circuit Breaker Type	CT Ratio
Feeder 1	15	Vacuum	100/1
Feeder 2	15	Vacuum	200/1
Feeder 3	15	Vacuum	200/1
Feeder 4	15	Vacuum	100/1
Feeder 1	33	Vacuum	150/1
Feeder 2	33	Vacuum	150/1
Feeder 3	33	Vacuum	150/1
Feeder 4	33	Vacuum	150/1
Main feeder of 15Kv	15	Vacuum	500/1
Main feeder of 33Kv	33	Vacuum	300/1

Table 3.5: Length of feeder and number of distribution transformer connected on feeder

Feeder Code	Voltage Level in KV	Feeder Name	No of customers	Length of feeder in Km	Number of distribution transformer	KVA of Distribution transformer
Feeder 1	15	Kombolcha	1750	147.5	10	1625
Feeder 2	15	Bisidimo	14165	19.6	56	13150
Feeder 3	15	Aweday	5165	25.6	28	4795
Feeder 4	15	Hameresa oil	8079	23.2	6	7500
Feeder 1	33	Harar Water	3363	21.5	10	3120
Feeder 2	33	Industry zone	862	4.6	1	800
Feeder 3	33	Fedis	756	160	4	700
Feeder 4	33	Bedasa	860	248	10	800

Table 3.5 contains the data about 15 kV feeders and 33 kV feeders. In Table 3.5, as the name indicates Kombolcha, Bisidimo, Aweday and Hamerese oil Feeders represent the outgoing feeder lines from 15 kV bus bar, while Harar Water, Industry Zone, Fedis and Bedasa Feeders represent the outgoing feeder lines from 33 kV bus bar. There was no active, reactive and apparent power and energy data for Feeders Fedis and Bedasa feeders since the potential transformer (PT) was burned down.

Table 3.6: Annual average energy and Power consumption each feeder for 2018 G.C

Feeder Name	Average MVA	Average Power Consumption		Average Energy Consumption	
		Average Active Power (MW)	Average Reactive Power (MVar)	Average Active Energy (KWh)	Average Reactive Energy (KVarh)
Kombolcha	0.14	0.1382	0.0213	1,210,333.333	186,333.333
Bisidimo	0.22	0.19470	0.0979	1,705,583.33	857,333.33
Aweday	0.17	0.16730	0.0297	1,465,250	259,750
Hameresa oil	0.061	0.051	0.0341	443,083.33	299,000
Total	0.591	0.5512	0.183	4,824,250	1602,416.7

$$PF = \cos(\tan^{-1}(Q/P)) \quad (3.1)$$

$$PF = \cos(\tan^{-1}(0.183/0.5512)) = 0.95$$

Where,

Q= Reactive Power in (MVar)

PF= Power factor

P= Active Power in (MW)

The power factor obtained from equation 3.1 is 0.95, which is only for 15kV feeders. But, the power factor including the rest of feeders is 0.87 as per the information obtained from the technician of the institution.

Table 3.7: Average and Peak Load of the Substation in 2018 G.C

Feeder Name	Minimum Load (MW)	Peak load (MW)	Average Load (MW)
Kombolcha	0.63	3.13	1.88
Bisidimo	0.25	4.32	2.285
Aweday	0.84	4.32	2.58
Hameresa oil	0.07	3.82	1.945
Harar water	0.15	1.43	0.79
Industry zone	0.15	1.33	0.74
Total	2.09	18.35	10.22

Table 3.8: Hourly load (MW) each feeder of Harar Substation III, 28/2/2018

Feeder Name Hours	Kombolcha	Bisidimo	Aweday	Hamara Oil	Fedis	Bedasa	Total
8	2.18	3.22	2.65	0.97	0.41	0.82	10.25
9	2.2	3.22	2.66	0.94	0.41	0.82	10.25
10	2.17	3.27	2.46	0.93	0.41	0.71	12.41
11	2.3	3.89	2.47	0.96	0.41	0.71	9.95
12	2.55	3.58	2.68	0.88	0.41	0.72	10.82
13	2.57	3.52	2.70	0.89	0.66	0.66	11.00
14	2.25	2.17	2.31	0.81	0.66	0.66	8.86
15	2.27	2.60	2.33	0.83	0.77	0.66	9.46
16	2.22	2.60	2.33	0.83	0.77	0.66	9.41
17	2.27	2.54	2.43	0.79	0.87	0.92	9.82
18	2.71	3.06	2.99	0.83	0.97	0.92	11.48
19	2.9	3.53	3.69	0.93	0.97	0.87	12.89
20	2.89	3.56	3.65	0.92	0.77	0.82	12.61
21	2.58	2.44	2.65	0.68	0.56	0.77	9.68
22	2.54	2.46	2.63	0.66	0.51	0.82	9.62
23	2.50	2.78	2.60	0.67	0.46	0.71	9.72
24	1.91	1.45	1.73	0.69	0.41	0.71	6.9
1	1.59	1.43	1.70	0.68	0.25	0.71	6.36
2	1.88	1.41	1.68	0.68	0.25	0.71	6.61
3	1.30	1.21	1.28	0.76	0.27	0.66	5.48
4	1.86	1.25	1.27	0.63	0.29	0.66	5.96
5	1.88	1.41	1.37	0.66	0.32	0.66	6.30
6	1.22	1.73	1.56	0.76	0.32	0.66	6.25
7	1.74	2.72	2.16	0.72	0.31	0.66	6.78

3.4. Major Interruption Causes of Harar Substation III

In Harar substation III, the major faults occurring frequently are short circuit, earth fault, blackout, overload, and under frequency. And there are planned outages for operational and maintenance purpose. The major faults occurring can either be of temporary and permanent type. Permanent or Sustained interruptions are long-duration interruptions which last longer than 5 minutes; whereas interruptions with duration of less than 5 minutes are termed momentary interruptions. Usually, only data on sustained interruptions is reported to the regulatory authority. 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 [12].

Tree

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

Over Load

Based on the questionnaire and the discussion with line technicians overload is ranked first as a cause of power interruption. Transformers, lines and equipment's 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.

3.4.1. Interruption Data from 2016 G.C to 2018 G.C

Among the different types of power system faults, frequently occurring faults at Harar substation III include permanent and transient earth fault, permanent and transient short circuit, and interruptions due to operation/maintenance. Table 3.9 shows the duration and frequency of these different types of faults such as permanent Earth Fault (PEF),

Permanent Short circuit (PSC), Transient Earth fault (TEF) and Transient Short circuit (TSC) [12].

Table 3.9: Planned and Unplanned power interruption 2016 G.C

Feeder Name	OPR		TSC		PSC		TEF		PEF	
	Freq	Dur.	Freq	Dur	Freq	Dur	Freq	Dur	Freq	Dur
Kombolcha	123	152	96	4.44	53	135	121	2.8	76	171
Bisidimo	128	144	107	2.4	59	71.9	125	2.9	63	65
Aweday	90	140	94	1.66	22	51.6	72	1.8	29	79
Hameresa oil	8	19.2	14	0.28	6	60.8	6	1.0	6	69
Fedis	40	160	89	2.32	58	494	59	2.1	22	428
Bedasa	43	50.3	62	3.58	53	377	106	2.1	75	204
Total	432	666	462	14.7	251	1190	489	12	271	101

Harar water and Industry zone feeder are new and connected to the system three months ago, so there are no data available these feeders.

As collected data shows in Harar substation III, interruption is classified into two that is planned and unplanned. Planned interruption is voluntary interruption for the purpose of maintenance; unplanned interruption is involuntary interruption which is classified into temporary short circuit (TSC), permanent short circuit (PSC), temporary earth fault (TEF) and permanent earth fault (PEF).

Table 3.10: Planned and Unplanned power interruption 2017 G.C

Feeders	OPR		TSC		PSC		TEF		PEF	
	Freq	Dur	Freq	Dur	Freq	Dur	Freq	Dur	Freq	Dur
Kombolcha	70	24.4	97	1.86	41	110	75	1.56	38	138.9
Bisidimo	105	39.6	101	2.03	62	87.9	76	1.68	74	130.8
Aweday	87	63.8	47	1.66	25	96.2	102	1.82	41	123.5
Hameresa oil	10	9.64	17	1.1	28	75	32	1.00	9	61.27
Fedis	32	15.6	56	1.12	18	164	90	1.85	56	557
Bedasa	98	160	96	1.58	70	398	103	2.08	109	524.7
Total	402	313	414	9.35	244	930	478	9.99	327	1536

Table 3.11: Planned and Unplanned power interruption 2018 G.C

Feeders	OPR		TSC		PSC		TEF		PEF	
	Freq	Dur	Freq	Dur	Freq	Dur	Freq	Dur	Freq	Dur
Kombolch	100	88.3	89	1.78	62	210	84	1.67	48	173.5
Bisidimo	129	37.8	173	2.844	73	121	156	2.8	133	177.4

Aweday	76	51.4	81	2.54	41	152	131	2.61	45	105.0
Hameresa	18	20.7	4	0.44	1	5.05	62	0.86	8	27.24
Fedis	46	38.9	67	1.66	41	206	142	2.95	53	292.2
Bedasa	95	151	151	2.92	130	536	156	2.45	156	655.5
Total	464	388	565	12.1	348	1232	731	13.34	443	1431

As seen from table 3.9, 3.10, and 3.11 Bisidimo feeder has got maximum interruption, and Hamerese oil feeder has got minimum interruption.

Table 3.12: Frequency Interruptions from 2016 G.C to 2018 G.C

Feeders	2016 G.C			2017 G.C			2018 G.C		
	Unplanned	Planned	Total	Unplanned	Planned	Total	Unplanned	Planned	Total
Kombolcha	346	123	469	251	70	321	283	100	383
Bisidimo	354	128	482	313	105	418	535	129	664
Aweday	217	90	307	215	87	302	298	76	374
Hameresa	32	8	40	86	10	96	75	18	93
Fedis	228	40	268	220	32	252	303	46	349
Bedasa	296	43	339	378	98	476	593	95	688
Total	1,473	432	1,905	1,463	402	1,865	2,087	464	2,551

From table 3.12 the total frequency interruption is occurred more in 2018 G.C. that is in 2016 G.C it is 1,905, in 2017 G.C it is 1,865 and in 2018 G.C it is 2551 and the minimum interruption was occurred in 2017 G.C.

Table 3.13: Duration Interruptions from 2016 G.C to 2018 G.C

Feeders	2016			2017			2018		
	Unplanned	Planned	Total	Unplanned	Planned	Total	Unplanned	Planned	Total
Kombolcha	314.52	152	466.5	252.32	24.4	276.7	387.0	88.3	475.3
Bisidimo	143.06	144	287.1	222.41	39.6	262.0	304.0	37.8	341.8
Aweday	134.58	140	274.6	223.18	63.8	286.9	262.15	51.4	313.6
Hameresa	131.47	19.2	150.7	138.37	9.64	148.0	33.59	20.7	54.29
Fedis	925.9	160	1086	724.0	15.6	739.6	502.81	38.9	541.7
Bedasa	586.5	50.3	636.8	926.36	160	1,086	1,197	151.0	1348
Total	2,236	665	2902	2,486.7	312.6	2,800	2,687	388.1	3075

Table 3.14: Three years power interruption

Feeders	OPR		TSC		PSC		TEF		PEF	
	Freq	Dur	Freq	Dur	Freq	Dur	Freq	Dur	Freq	Dur.
Kombolcha	293	265	282	8.08	156	456	280	6.01	162	484
Bisidimo	372	221	381	7.27	194	281	357	7.44	270	374
Aweday	253	255	222	5.86	88	300	305	6.21	115	308
Hameresa										

oil	36	49.5	35	1.82	35	141	100	2.88	23	158
Fedis	118	215	212	5.1	117	864	291	6.88	131	127
Bedasa	236	361	309	8.08	253	1311	365	6.65	340	138
Total	1,308	1366	1441	36.21	843	3353	1698	36.1	1041	398

Table 3.15: Percentage of the cause of average duration and frequency interruptions of different fault.

Feeders	Operational		TSC		PSC		TEF		PEF	
	%Fre	%Dur	%Fre	%Dur	%Fre	%Dur	%Fre	%Dur	%Fre	%Dur
Kombolcha	24.9	21.7	24.0	0.663	13.3	37.4	23.87	0.495	13.8	39.7
Bisidimo	23.6	24.8	24.2	0.816	12.3	31.5	22.68	0.836	17.1	374
Aweday	25.7	29.1	22.6	0.67	8.95	34.3	31.0	0.71	11.7	35.2
Hameresa oil	15.7	14.0	15.3	0.52	15.2	39.9	43.6	0.815	10.0	44.73
Fedis	13.6	9.08	24.4	0.215	13.5	34.5	33.5	0.291	15.0	53.93
Bedasa	15.7	11.8	20.5	0.263	16.8	42.7	24.2	0.216	22.6	45.07
Average	20.6	15.6	22.7	0.413	13.3	38.2	26.82	0.411	16.44	45.41

Table 3.16 and Table 3.17; shows as the percentage of each of the cause of fault in Harar Substation III.

Table 3.16: Percentage average frequency interruption of each type of fault

Cuases	Operation	TSC	PSC	TEF	PEF
%Frequency(Int/Year)	20.66	22.76	13.31	26.82	16.44

Another fault includes, overload, blackout (total loss of power to an area), under frequency, Transmission line fault etc.

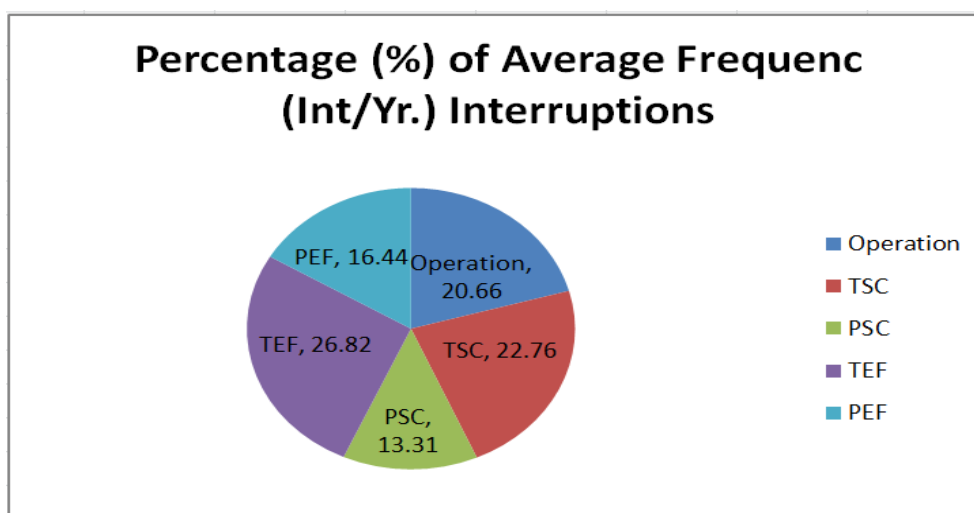


Figure 3.5: Percentage of three years frequency interruptions of overall system of Harar Substation III As shown in the above pie chart (Figure. 3.5), 20.66, 16.84, 13.31, 26.82 and

22.76% (Hr.) of the interruption duration of the overall system are due the operation and maintenance, distribution permanent earth fault, distribution permanent short circuit, distribution temporary earth fault and temporary short circuit, respectively.

Table 3.17: Percentage average interruption duration of each type of fault

Causes	Operation	TSC	PSC	TEF	PEF
%Duration(Hr)	15.6	0.413	38.2	0.411	45.41

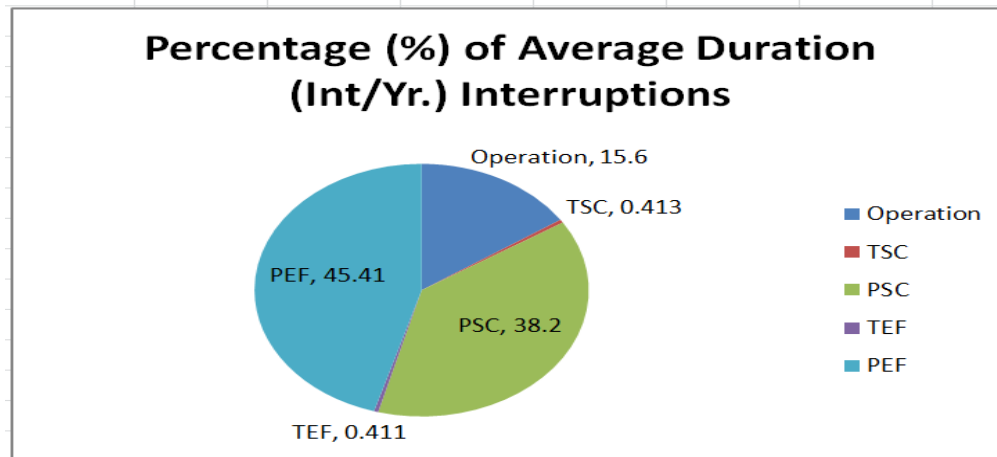


Figure 3.6: Percentage of three years duration interruptions of overall system of Harar Substation.

Percentage of three years duration interruptions of overall system of Harar Substation III From the above pie chart (Figure 3.6), 15.6% (Hr.) of the interruption duration of the overall system are due to operation and maintenance, 45.41% is due to a distribution permanent earth fault, 38.2% is due to distribution permanent short circuit, 0.411% is due to distribution temporary earth fault and 0.413% is due to temporary short circuit.

3.5 Reliability Indices Calculation

The reliability indices of the existing substation can be calculated using equations (2.7) to (2.14), which are given in chapter two. Based on the data given in Tables 3.9, 3.10 and 3.11, we can calculate the reliability indices for 2016 to 2018 and the average of the three years.

Table 3.18: Calculated reliability indices of Harar Substation III in 2016

Feeders	SAIFI Int/Cust/Yr	SAIDI Hr/cust/Yr	CAIDI Hr/inter	ASAI %	ASUI %	EENS (MWh)	AENS (MWh/ Co)
Kombolcha	469	462	0.985	0.947	0.05274	746.05	0.7343
Bisidimo	482	472	0.97925	0.96278	0.0372	3508.1	0.4265

Aweday	307	284.83	0.92778	0.96748	0.0325	284.7	0.09493
Hameresa oil	40	122.664	3.07	0.986	0.014	731.12	0.15586
Fedis	268	1034.3	3.86	0.882	0.118	752.92	1.719
Bedasa	339	1155	3.4	0.86815	0.1318	947.30	1.89461
Average	317.5	564.1323	2.2037	0.93557	0.06437	1,161.7	0.83753

Harar Table 3.19: Calculated reliability indices of 2017 Substation III

Feeders	SAIFI Int/Cust/ Yr	SAIDI Hr/cust/Yr	CAIDI Hr/inter	ASAI %	ASUI %	EENS (MWh)	AENS (MWh/ Co)
Kombolcha	321	264.182	0.823	0.9698	0.0302	697.242	0.6863
Bisidimo	418	292.77	0.7004	0.9665	0.0334	3465.52	0.4213
Aweday	302	312.31	1.34	0.9643	0.0356	1404.93	0.4685
Hameresa oil	96	148	1.542	0.9831	0.0169	1304.59	0.2781
Fedis	252	734.229	2.9136	0.9162	0.0838	514.24	1.174
Bedasa	476	819.88	1.7224	0.9064	0.0936	875.79	1.7516
Average	310.833	428.5618	1.5069	0.9510	0.0489	1,377.05	0.7966

Table 3.20: Calculated reliability indices of 2018 Harar Substation III

Feeders	SAIFI Int/Cust/Yr	SAIDI Hr/cust/Yr	CAIDI Hr/inter	ASAI %	ASUI %	EENS (MWh)	AENS (MWh/ Co)
Kombolcha	383	457.1595	1.1936	0.9478	0.0522	778.59	0.766
Bisidimo	664	574.6382	0.8654	0.9640	0.0359	4896.9	0.595
Aweday	374	270.181	0.7224	0.96915	0.0308	1,283.3	0.428
Hameresa	93	76.4441	0.82198	0.99127	0.0087	238.90	0.051
Fedis	349	721.861	2.06837	0.91759	0.0824	450.67	1.0289
Bedasa	688	1294.08	1.88093	0.85227	0.1477	1228.2	2.456
Average	425.17	522.393	1.25878	0.94036	0.0596	1,479.4	0.888

Table 3.21: Calculated reliability indices the average of three years at Harar Substation III

Feeders	SAIFI Int/Cust/Yr	SAIDI Hr/cust/Yr	CAIDI Hr/inter	ASAI %	ASUI %	EENS (MWh)	AENS (MWh)
Kombolcha	391	394.45	1.0005	0.955	0.4503	740.63	0.729
Bisidimo	521.33	446.2127	0.856	0.9645	0.0355	3,947.8	0.481
Aweday	327..67	289.11	0.997	0.967	0.033	990.97	0.3304
Hameresa	76.33	115.70	115.70	0.9868	0.0132	758.21	0.1616
Fedis	289.67	870.36	2.947	0.905265	0.0947	572.61	1.3073
Bedasa	501	1089.65	2.334	0.8756	0.1244	1026.1	2.0341
Average	351.167	505.03	1.618	0.9423	0.0576	1339.4	0.8406

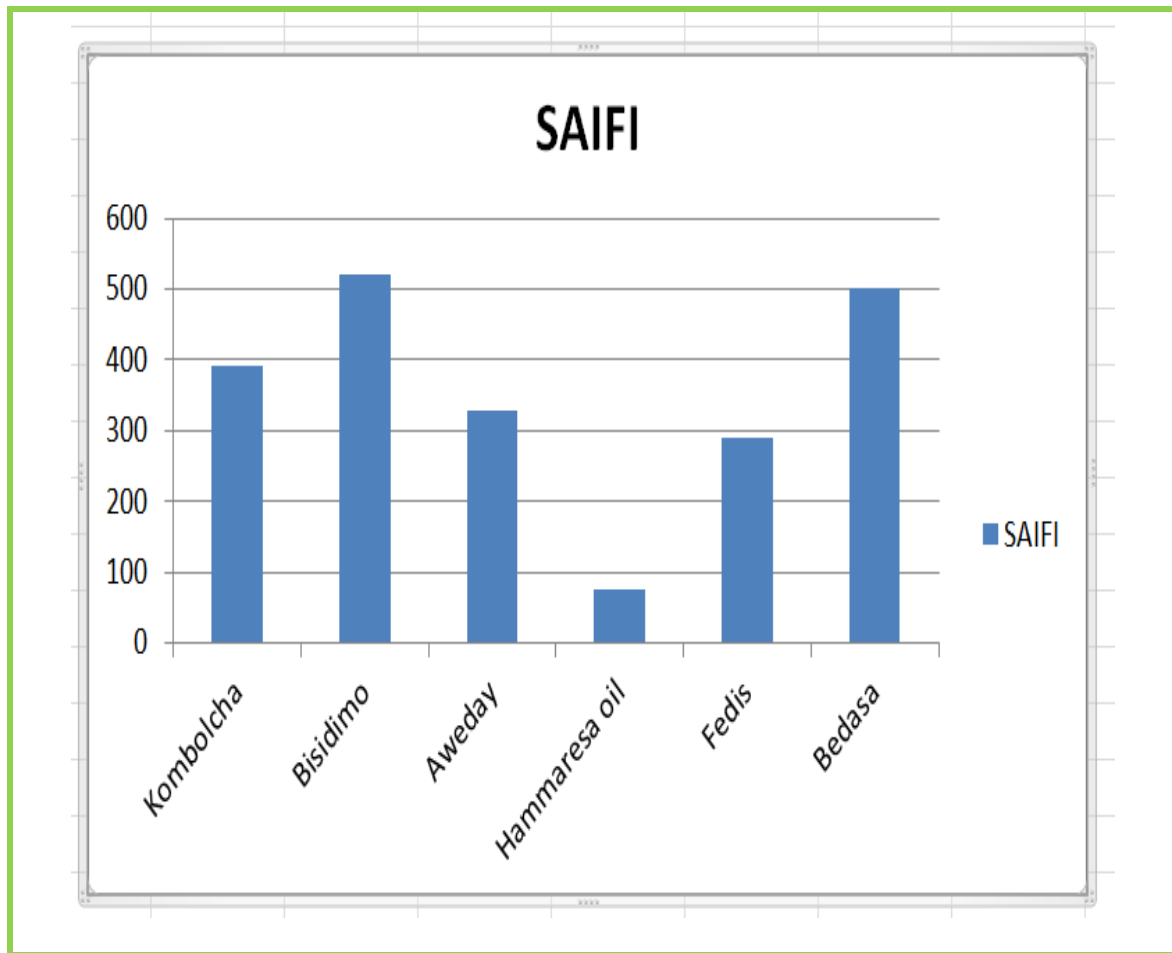


Figure 3. 7: Three years average value of SAIFI for Harar substation III Feeders

In this thesis, a special emphasis is given only to feeder line two (Bisidimo) of Harar city. This is because as per the data obtained from Harar substation III and shown in figure 3.7, the mentioned city feeder has more frequency and duration interruptions than the other feeders in the existing substation.

Table 3.22: Calculated reliability indices of Harar city feeder for year 2016-2018 G.C

Feeder Name	Reliability Indices	2016 G.C	2017 G.C	2018 G.C	Average
Harar Substation III Feeder 2 (Bisidimo)	SAIFI (Int/Cust/Yr)	482	418	664	521.33
	SAIDI (Hr/cust/Yr)	472.292	292.77	574.6382	446.5667
	CAIDI (Hr/inter)	0.98	0.7	0.865	0.848
	ASAI %	0.963	0.967	0.964	0.965
	ASUI %	0.0372	0.0334	0.0359	0.0355
	EENS (MWr)	3508.15	3465.527	4896.94	3956.87

	AENS (MWr)	0.4265	0.4213	0.5953	0.481
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From Table 3.8: Average hourly loads of Bisidimo feeder is represented as follows

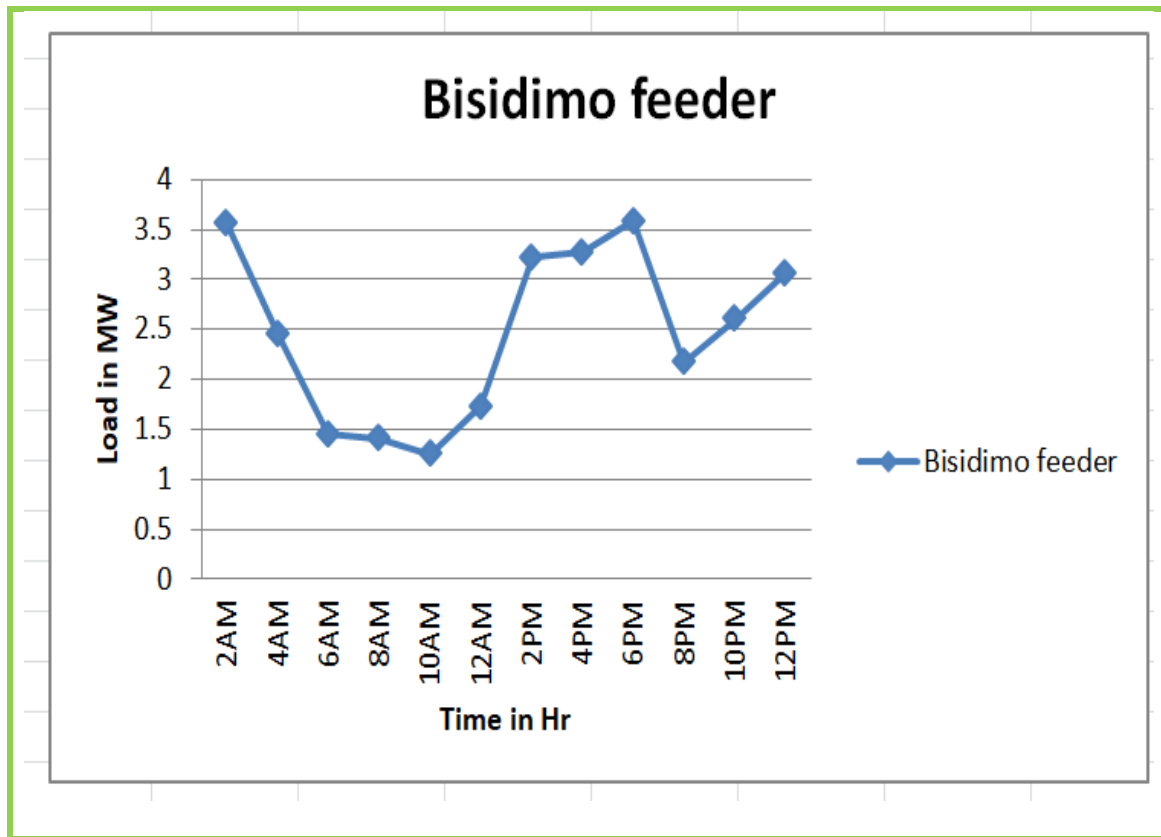


Figure 3. 8: Average hourly loads Harar Substation III Bisidimo feeder

Figure 3.8 shows the load measured during 24 hours of a day. Hourly load denotes a load measured during that corresponding time Bisidimo feeder. So the maximum overall load of the system is observed from 2:00 AM and 4:00 PM day time (due to the desert area most customers, which are used to air condition and ventilator) which is 3.62 MW.

3.5.1 Comparison of the Calculated values of Reliability Indices with benchmarks

In the Table 3.23 bellow, shows the calculated Reliability indices values of Harar city feeder line L2 compared with Ethiopia Electric Agency standard and other country benchmark values most commonly used reliability indices. This thesis also focuses on the customer oriented reliability indices and energy oriented indices.

Table 3.23: Comparisons of SAIFI and SAIDI values with different countries

Countries	SAIFI (Int./Year/Customer)	SAIDI (Hr./Year/Customer)
United States of America	1.5	4
Italy	2.2	0.967
France	1.0	1.03
Denmark	0.5	0.4
Australia	0.9	1.2
Spain	2.2	1.73
Canada	3.4	6.9
United Kingdom	0.8	1.5
Germany	0.5	0.383
Netherland	0.3	0.55
Ethiopia	20	25
Harar City L2(Bisidimo feeder)	521	446.5667

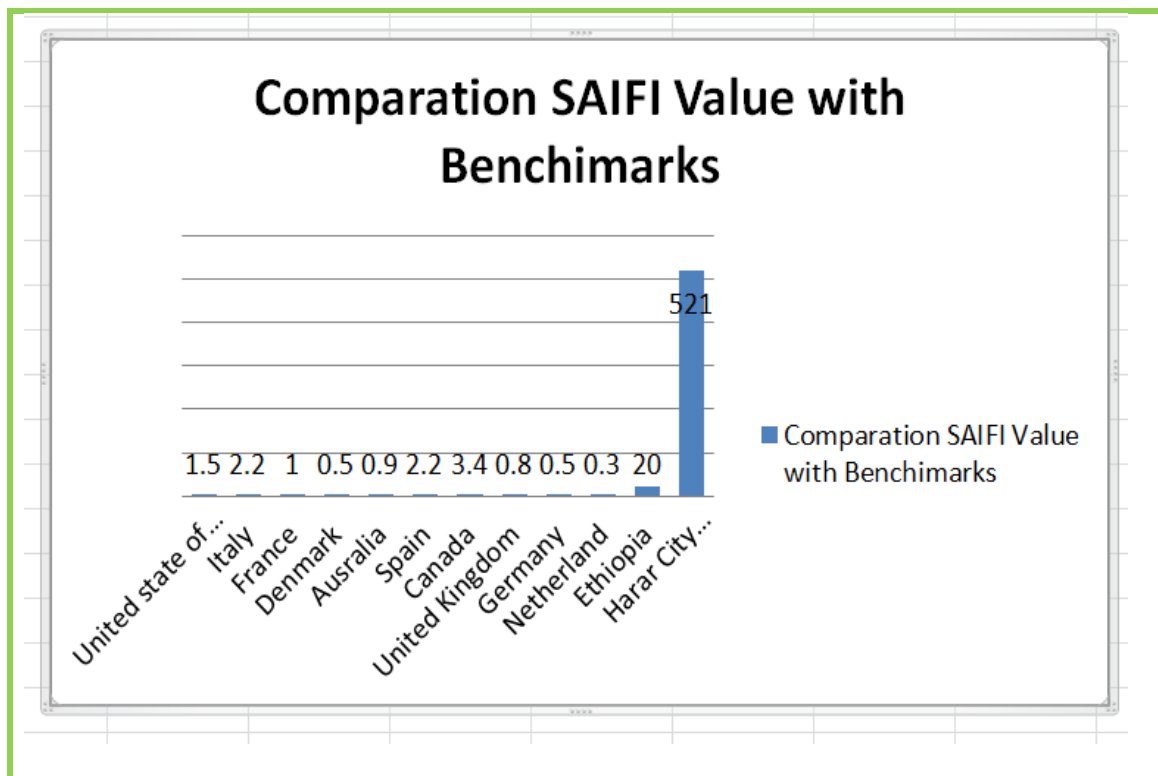


Figure 3. 9: Comparison of SAIFI value with different countries standards

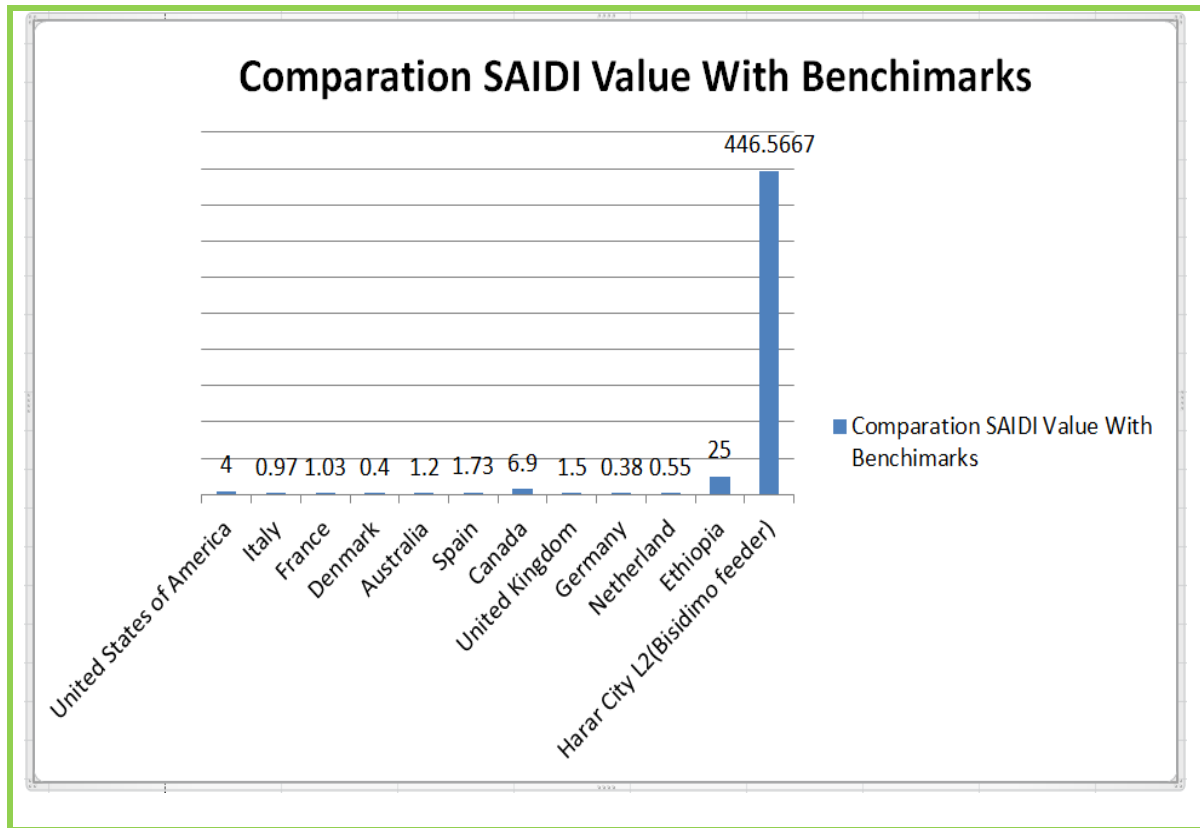


Figure 3.10: Comparison of SAIDI value with different countries standards

3.6 Outage Cost Evaluation of Harar City Feeder Line

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

In the case study area, Harar city, power interruptions data are usually recorded 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. By using the recording Mega Watt (MW) load before the 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.

Table 3.24: Ethiopia electricity tariff (Birr/KWh) since July 8, 2006 (1998 E.C)

	Monthly Consumption (KWh)	Price Rate (Birr/KWh)
Residential	Equivalent Flat Rate	0.4735
	0-50	0.2730
	51-100	0.3564
	101-200	0.4993
	201-300	0.5500
	301-400	0.5666
	401-500	0.5880
	Above 500	0.6943
Commercial	Equivalent Flat Rate	0.6723
	0-50	0.6088
	Above 500	0.6943
Low Voltage Time of Day Industry @15 KV		
Equivalent Flat Rate		0.5778
Peak		0.742
Off Peak		0.5354
High Voltage Industry @132 KV		
Peak		0.4736
Off Peak		0.3664

Based on Table 3.24, the interruption cost in the study area that is in Harar substation III can be calculated using the formula below; Interruption

$$\text{Cost} = \text{Unsupplied Energy (in kWh)} \times 0.4409 \text{ ETB/kWh} \quad (3.2)$$

Where, the tariff 0.4409 is taken from the average of the first block tariffs of residential and commercial customers, which most Ethiopian electricity customers are assumed to be grouped [24].

For Harar Substation III Bisidimo feeder (L2) in the year 2016 has 3508.15 MWh unsupplied Energy as seen in Table 3.18; then, Interruption cost is calculated as:

$$\text{Interruption Cocst} = 3508.15 \text{ kWh} \times 1000 \times 0.4409 \text{ ETB/kWh} = 1,546,743.335 \text{ ETB}$$

By the same procedure the interruption cost for the 3 years, that is, from 2016 to 2018 G.C is calculated and summarized in Table 3.23. Based on the exchange rate of the Commercial Bank of Ethiopia (CBE) on 26-Feb-2019, (1 \$= 28.3227 ETB).

Table 3.25: Summary of estimated interruption cost from 2016 to 2018 G.C in Harar city feeder line.

Years	EENS (MWh)	Interruption Cost (ETB)	Interruption Cost (USD)
2016 G.C	3508.15	1,546,743.335	54,611.43659
2017 G.C	3465.527	1,527,950.854	53,947.92354
2018 G.C	4896.94	2,159,060.846	76,230.75646
Max.	4896.94	2,159,060.846	76,230.75646

The maximum of the three year's interruption cost due to the unsold energy of the Harar city feeder line is 2,159,060.846ETB or 76,230.75646USD per year.

3.7 Data Analysis

Based on the data collected from Harar substation III we can summarize the power reliability indices of the Harar city Bisidimo feeder (line L2) in the following manner.

- SAIFI of the overall system as shown in Table 3.19 is 521.45 Int. /yr. As per Ethiopian Electrical Agency's (EEA's) standard, SAIFI should not exceed 20 interruptions per customer per year, which indicates that the current value is above the acceptable value by a large margin and also, when we compare the calculated SAIFI value with Denmark standard, it is much greater than the maximum limit [12]. This clearly indicates that there is serious reliability problem in the existing Harar city Bisidimo feeder.
- SAIDI of the overall system from Table 3.19 is 446.5667 hours per customer per year. This shows that every customer experiences 446.5667 Hr. interruption per year. This indicates that there is great reliability problem in the existing Harar city Bisidimo feeder. As per the Ethiopian Electrical Agency's (EEA), the SAIDI value should not exceed 25 hours per customer per year [12]. The permissible SAIDI value in Denmark is 0.4 hours per customer per year [12].
- ASAI: It is the average service availability index which shows the fraction of time that a customer has received power during the reporting period. From the Table 3.19 the power supply of the overall system for Harar city feeder, Bisidimo feeder is 0.955(95.5%) available. However, this value is still not good enough since the ASAI value should be greater than 99.98% as per Ethiopian Electrical Agency's standard [12].

- ENS: It shows the unsupplied energy or unsold energy of each feeder. From the Table 3.23 the maximum unsold energy for Harar city feeder, L2 was 4896.94MWh per year.
- AENS: This index shows the average energy not supplied per customer by the system. From the Table 3.19 the overall system for Harar city feeder, L2 has an AENS value of 0.729 MWh per customer.
- Due to power interruption per year for the Harar city feeder, L2 the average cost of unsold energy is 2,159,060.846ETB has been lost. This amount of money has a negative impact on the economic growth of our country.

Finally, based on the data analysis the following conclusions have derived.

- The power reliability of the Harar city feeder line, L2 does not meet the requirements set by the Ethiopian Electric Agency (EEA).
- The power reliability indices of Harar city feeder line, L2 is not a good performance as compared to the international reliability indices of best-experienced countries.
- In the study area of city feeder line, L2 has high unavailability of services in the system.
- The impact of planned and unplanned outages in the existing power grid of Harar city feeder line, L2 has more loss of unsupplied energy.

CHAPTER FOUR

4. RESULT ANALYSIS AND DISCUSSION

4.1. Introduction

This chapter presents the explanation of the modeling and simulation of the existing system with different mitigation alternative techniques to improve the system reliability of the Harar city feeder line at a reasonable cost. Different techniques have been analyzed by ETAP 12.6 Software simulation. The simulation focuses on evaluating the impact of using different techniques such as reclosers, reconfiguration, sectionalizing, using circuit breaker, isolator and other techniques.

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 [17].

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
- 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 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 [17].

4.2. Procedure for Distribution Reliability Analysis by ETAP Software

The reliability analysis is conducted by performing the following procedures in ETAP12.6.0 software.

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

4.3. System Modeling

In this thesis, Electrical Transient Analysis Program (ETAP 12.6.0 version) software has been used as a design, simulation and reliability assessment analysis tool. Load flow for the study has been calculated.

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

$$\lambda_A = \frac{\text{Total number of Interruptions}}{(\text{Total Feeder Length})(\text{Number of years})} \quad (\text{Int./km. year}) \quad (4.1)$$

$$\text{MTTR} = \frac{\text{Total Repair Time}}{\text{Total number of Interruption}} \quad (\text{Hr/Int}) \quad (4.2)$$

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

$$\lambda_A = 521.33/58.8 = 8.866(\text{Int./km.year}) \quad \text{And}$$

$$\text{MTTR} = 446.5667/521.33 = 0.8566(\text{Hr./Int})$$

To estimate the failure rate of a component, ETAP 12.6.0 uses a combination of active (λ_A) and passive (λ_P) failure rates together. The active failure rate is the 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 [ETAP Software Library]. As there is no means of isolating faulty areas in the system, λ_P is assumed as zero in the model.

The Harar city feeder (15 kV) has been constructed by 50 mm², seven stranded, Aluminum Conductor (ALC). This almost equals with Code LIBRA, Size 49.5mm² and seven Stranded which is found in ETAP Library.

In order to modeling the existing city distribution line and to analyze the current distribution reliability status, the following values have been considered as an input to ETAP 12.6 software.

- ✓ The city line data,
- ✓ Cable length,
- ✓ Number of customers,
- ✓ The connected load
- ✓ Number of transformers with their rating,
- ✓ Active failure rate
- ✓ Duration of interruption in hours
- ✓ Frequency of interruption

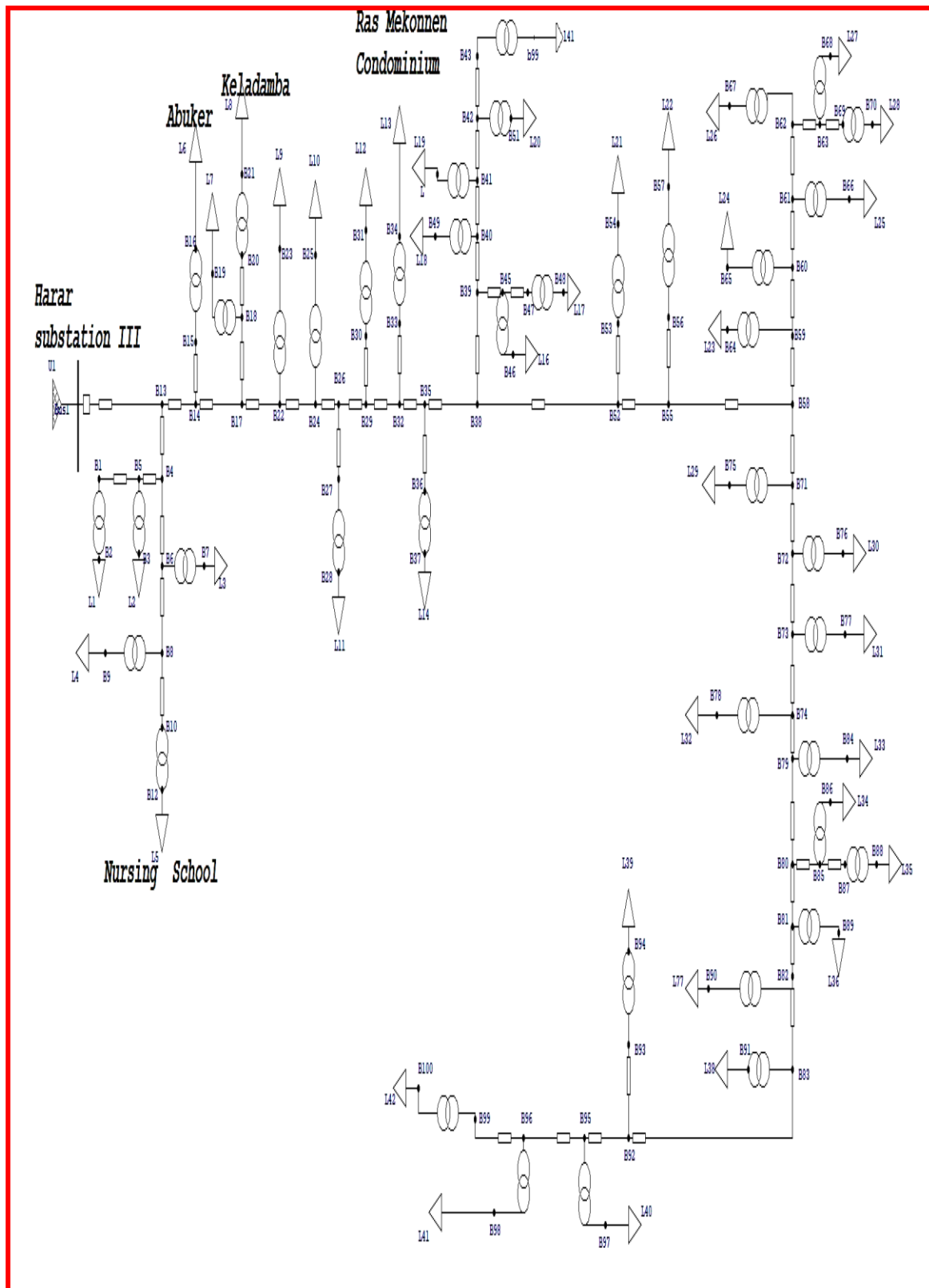


Figure 4.1: System modeling of the Harar City Bisidimo feeder (line, L2)

Figure 4.2 shows the project editor view, with the reliability page open. Parameter used in designing and analysis for the reliability of the system is shown on this page.

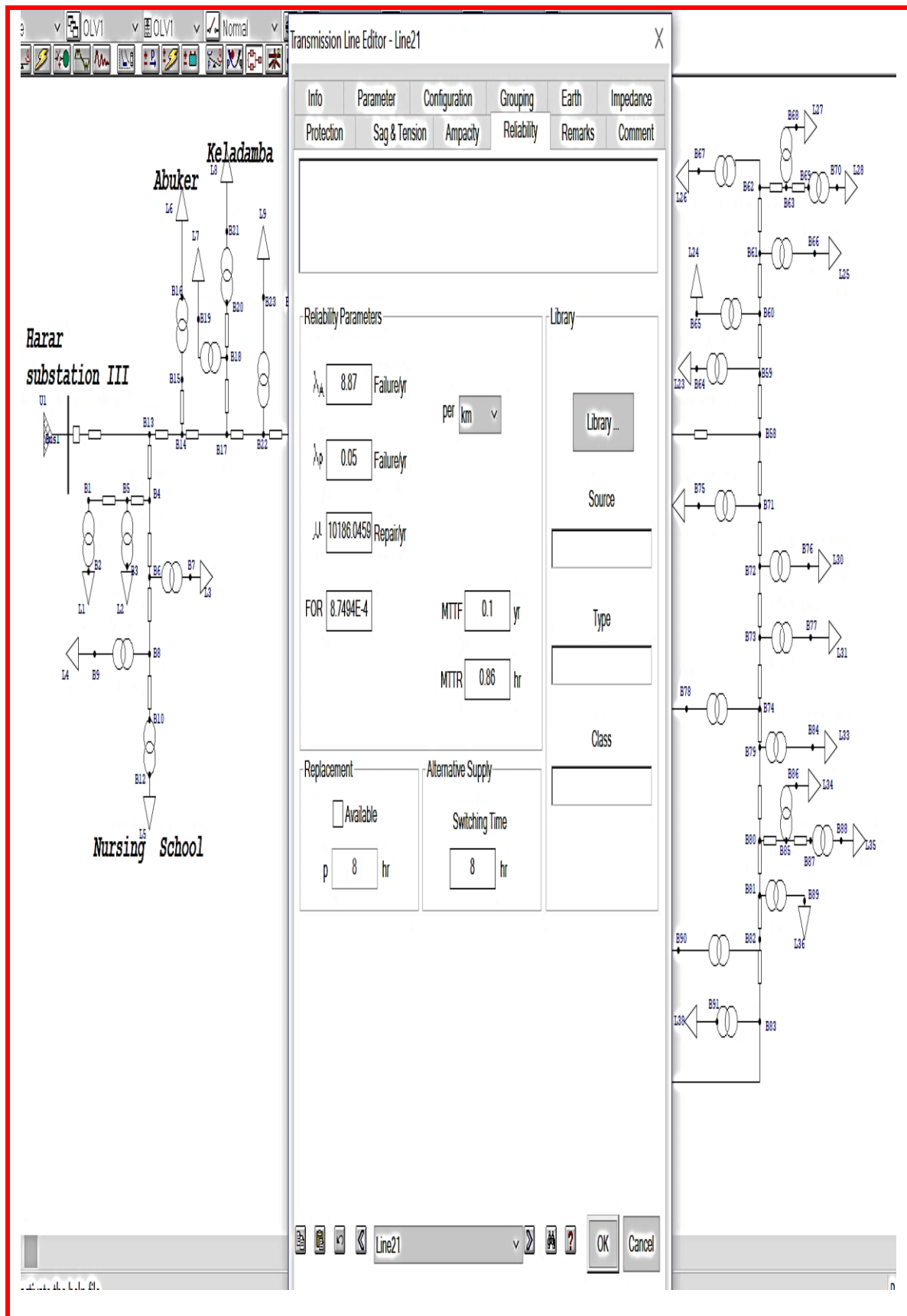


Figure 4.2: Window of ETAP 12.6 software existing system of reliability page opened

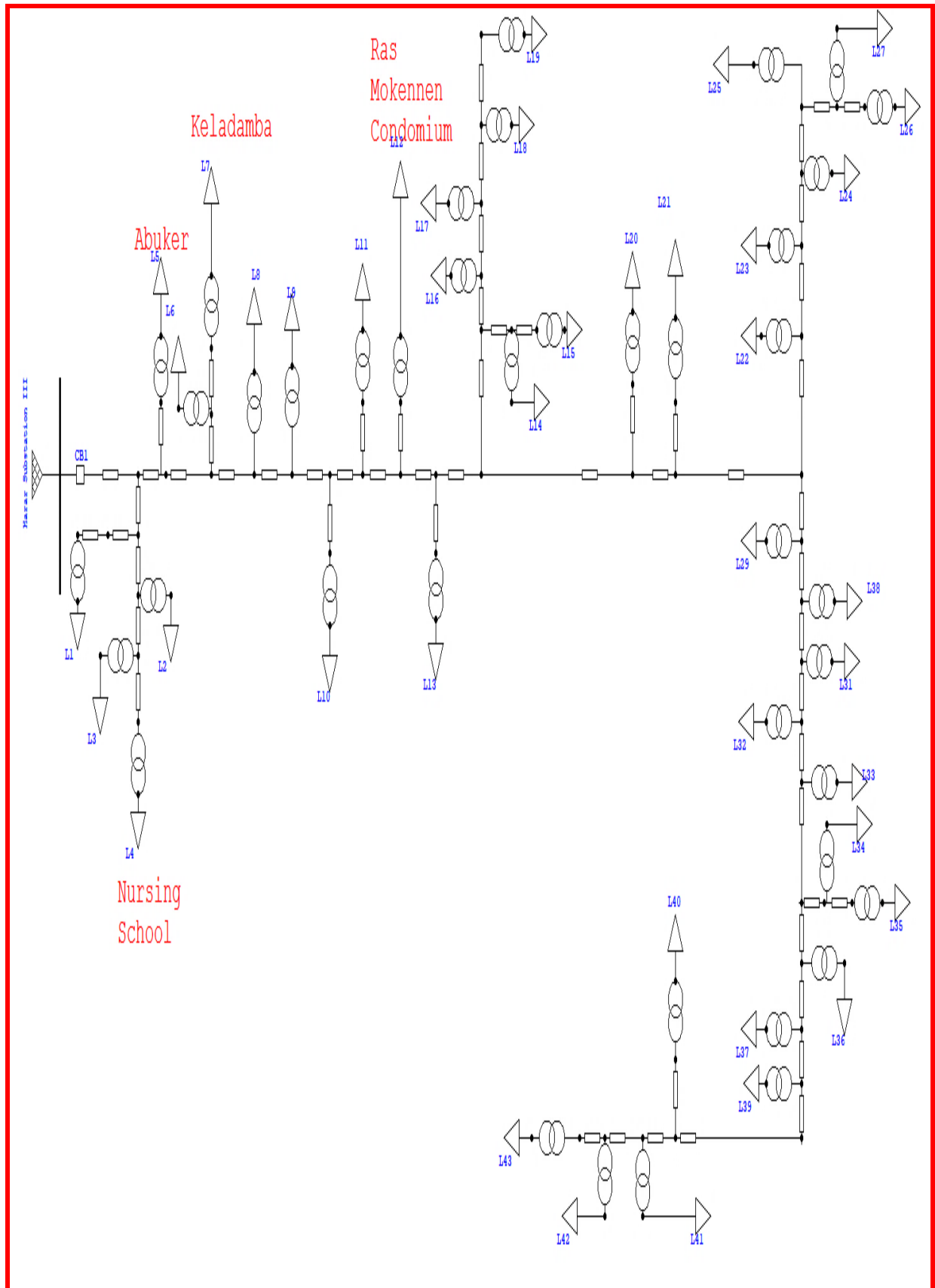


Figure 4.3: Harar city feeder line with existing SAIFI and SAIDI values

Table 4.1: Simulation result of reliability indices for existing system

Project: Power Reliability Improvement	ETAP	Page: 1
Location: Harar, Ethiopia	12.6.0H	Date: 09-11-2019
Contract: 0910734320		SN:
Engineer: Mandefro Teshome Aseffa	Study Case: RA	Revision: Base
Filename: Existing system		Config.: Normal
<u>System Indexes</u>		
SAIFI	521.4559 f / customer.yr	
SAIDI	445.8150 hr / customer.yr	
CAIDI	0.855 hr / customer interruption	
ASAI	0.9491 pu	
ASUI	0.05089 pu	
EENS	4897.065 MW hr / yr	
SAIFI	System Average Interruption Frequency Index	
SAIDI	System Average Interruption Duration Index	
CAIDI	Customer Average Interruption Duration Index	
ASAI	Average service Availability Index	
ASUI	Average Service Unavailability Index	
EENS	Expected Energy Not Supplied	

Table 4.1 shows that the designed system has given similar reliability indices values as found from the average of three years interruption data of Harar city. The two basic reliability indices, system average interruption frequency index and system average interruption duration index are 521.4559 and 445.82 respectively.

4.4. Simulation and Result Analysis of Harar substation III of Bisidimo Feeder

This part shows the simulation analysis of the distribution system with different reliability improvement techniques include in the model built above to evaluate their impact on the power reliability of the system.

4.4.1. Scenario- 1: Reconfigured Network with using One Recloser in Existing System

Every necessary parameter (connected load, number of customers, cable length and active failure rate are the major ones) used for distribution system reliability analysis is entered in the ETAP software. The interruption, data of years from 2016 to 2018 G.C is used as a base year. The Recloser has been placed on the line 29 as shown in Figure 4.4. The placement of the reclosure is based on the length of feeder. The reclosure which is used in this thesis is ANSI/IEEE standard C37.60 type reclosure and rated in voltage 15.5kV and current of 630A for short circuit and earth fault. The operating time of this reclosure have been 0.05 second to opening circuit and 0.1 second to closing circuit.

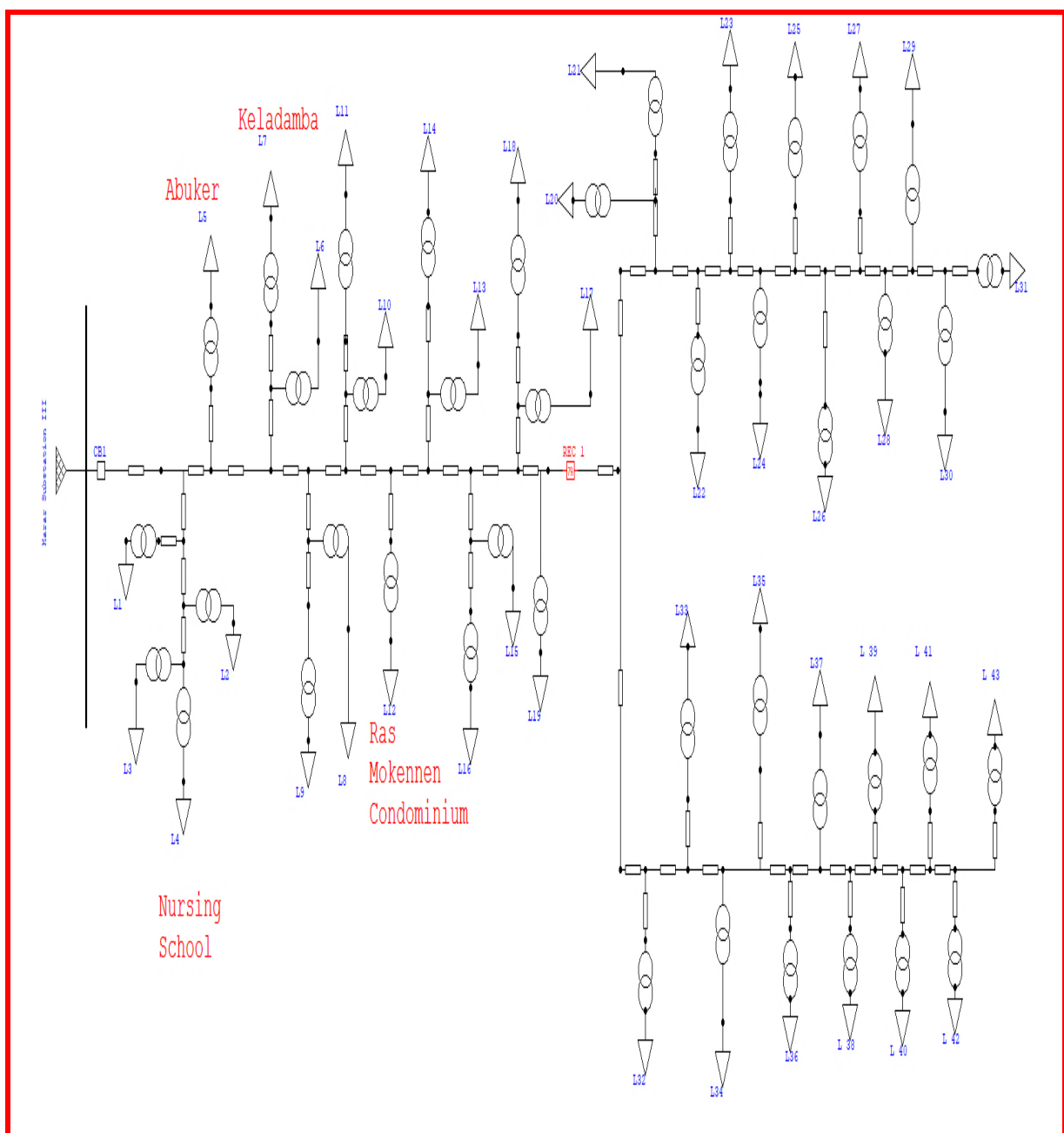


Figure 4.4: Single line diagram using Recloser on Distribution line for Scenario- 1

Table 4.2: Simulation result reliability of indices for Scenario- 1

Project: Power Reliability Improvement	ETAP	Page: 1
Location: Harar, Ethiopia	12.6.0H	Date: 09-17-2019
Contract: 0910734320		SN:
Engineer: Mandefro Teshome Aseffa	Study Case: RA	Revision: Base
Filename: Reliability improvement~~		Config.: Normal
<u>System Indexes</u>		
SAIFI	275.4183 f / customer.yr	
SAIDI	215.6193 hr / customer.yr	
CAIDI	0.783 hr / customer interruption	
ASAI	0.9754 pu	
ASUI	0.02461 pu	
EENS	2271.131 MW hr / yr	
SAIFI	System Average Interruption Frequency Index	
SAIDI	System Average Interruption Duration Index	
CAIDI	Customer Average Interruption Duration Index	
ASAI	Average service Availability Index	
ASUI	Average Service Unavailability Index	
EENS	Expected Energy Not Supplied	

Table 4.2 (Scenario- 1), is the screenshot from software for a model with Recloser in the feeder. As can be seen from the table, a Recloser with the substation breaker significantly improves the reliability of the system. The expected number of outages per year has been reduced from 521.33 to 275.42 (47.22% system reliability has improved), the annual outage duration has been reduced from 446.82 to 215.62 hours (51.79% reduction in outage duration) as compared with the existing system.

In Scenario-1 the reliability of Harar feeder is improved by 47.22%, 51.79% and 53.62% for SAIFI, SAIDI and EENS respectively. And also the interruption energy cost for (Scenario-1) can be calculated as,

$$\text{Interruption Cost} = 2271.131 \text{ MWh} \times 1000 \times 0.4409 \text{ ETB/kWh} = 1,001,341.66 \text{ ETB.}$$

Therefore the interruption energy cost has been decreased from 2,159,060.846 to 1,001,341.66ETB per year.

4.4.2. Scenario - 2: Reconfigured Network with using Two Reclosers in Existing System

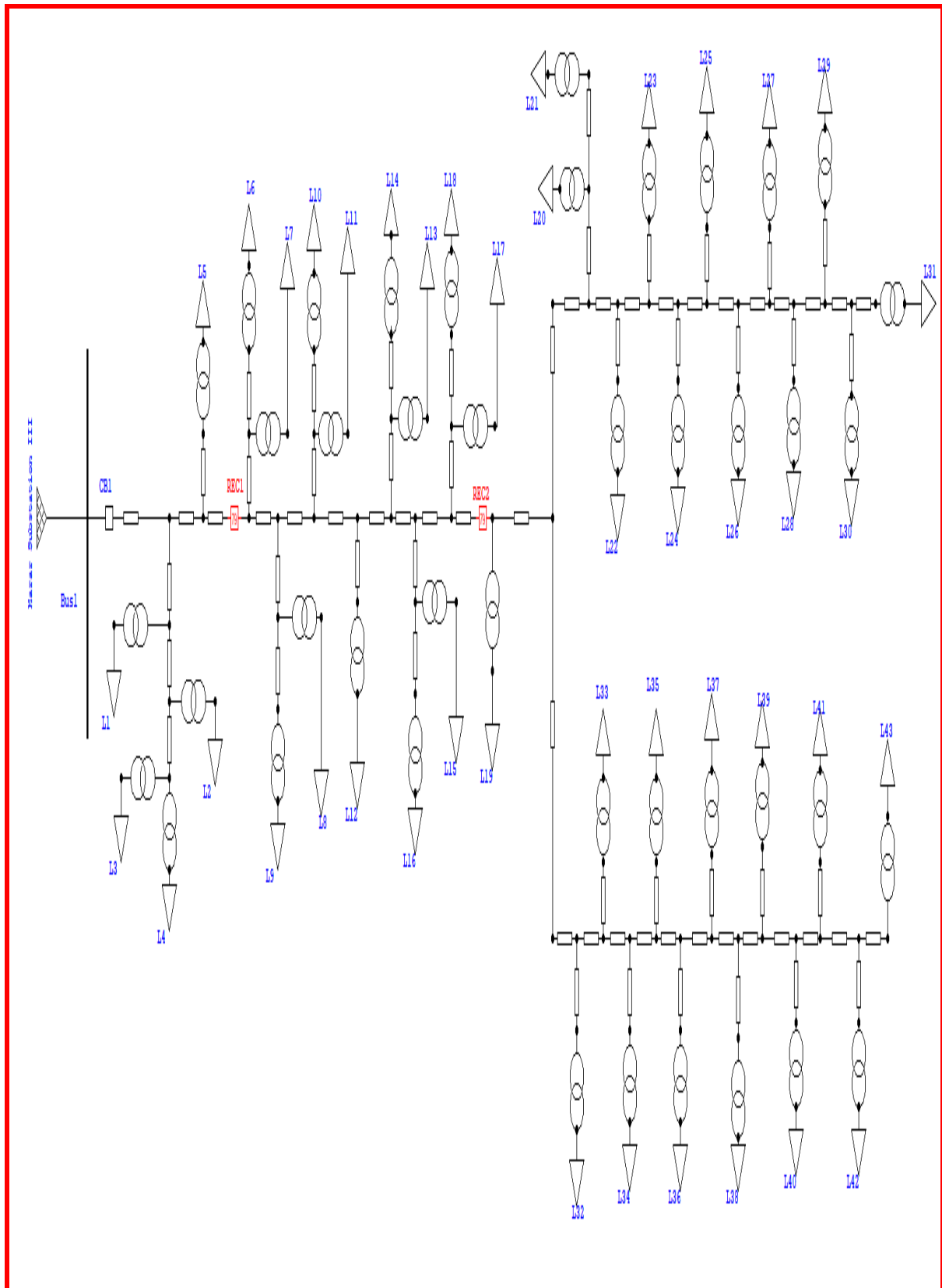


Figure 4.5: Single line diagram using Recloser on Distribution line for Scenario- 2

Table 4.3: Simulation result reliability of indices for Scenario- 2

Project: Power Reliability Improvement	ETAP	Page: 1
Location: Harar, Ethiopia	12.6.0H	Date: 09-17-2019
Contract: 0910734320		SN:
Engineer: Mandefro Teshome Aseffa	Study Case: RA	Revision: Base
Filename: Senario 2		Config.: Normal
<u>System Indexes</u>		
SAIFI	190.6407 f / customer.yr	
SAIDI	139.4736 hr / customer.yr	
CAIDI	0.732 hr / customer interruption	
ASAI	0.9841 pu	
ASUI	0.01592 pu	
EENS	1123.710 MW hr / yr	
SAIFI	System Average Interruption Frequency Index	
SAIDI	System Average Interruption Duration Index	
CAIDI	Customer Average Interruption Duration Index	
ASAI	Average service Availability Index	
ASUI	Average Service Unavailability Index	
EENS	Expected Energy Not Supplied	

Table 4.3 (Scenario- 2), is the screenshot from software for a model with using two recloser in existing system. As can be seen from the table, using two recloser in existing system significantly improves the reliability of the system. The expected number of outages per year has been reduced from 521.33 to 190.64 (63.526% system reliability has improved), the annual outage duration has been reduced from 446 to 139.5 hours (68.74% reduction in outage duration) as compared with the existing system. In Scenario-2 the reliability of Harar feeder is improved by 63.53%, 68.74% and 77.053% for SAIFI, SAIDI and EENS respectively. And also the interruption energy cost for (Scenario- 2) can be calculated as,

Interruption Cost = $1123.71 \text{ MWh} \times 1000 \times 0.4409 \frac{\text{ETB}}{\text{kWh}} = 495,443.739 \text{ ETB}$. Therefore the interruption energy cost has been decreased from 2,159,060.846 to 495,443.739 ETB per year.

4.4.3. Scenario- 3 Reconfiguring the System using Tie switch, Two Reclosures and New Substation

Currently, the number of customers in Harar city is rapidly increased every year which causes an over load on the Harar substation III. Because of this Harar substation III is over loaded. Presently, the highest load of the mentioned substation in Harar is 42.33 MW; and to reduce such load, a new Harar mobile substation installation is in a process which will be installed around Hiwot fana referral hospital (3.4 km far from the end of the feeder). It is expected to tap an electric power from Harar substation III through 132 kV prior to the stepping down process. That is, a 132 kV transmission line is first stretched into the new Harar mobile substation and then stepped down to 15 kV with 50 MVA transformer. Then, it will supply an electric power to Harar city and nearby areas. Harar mobile substation consists of four outgoing feeders with a radial network topology. The main primary feeder of the substation is branched into various primary laterals, which in turn separated into several sublaterals. The total peak load of Harar mobile substation is estimated about 22 MW [28]. Hence, one Bisidimo feeder can be connected by tie switch without causing any problem on the new substation.

Depending on this, the failure rate of the system or feeder is calculated as follows.

$$\lambda_A = 521.33/69 = 7.56(\text{Int./km.year})$$

And

$$\text{MTTR} = 0.8566(\text{Hr./year})$$

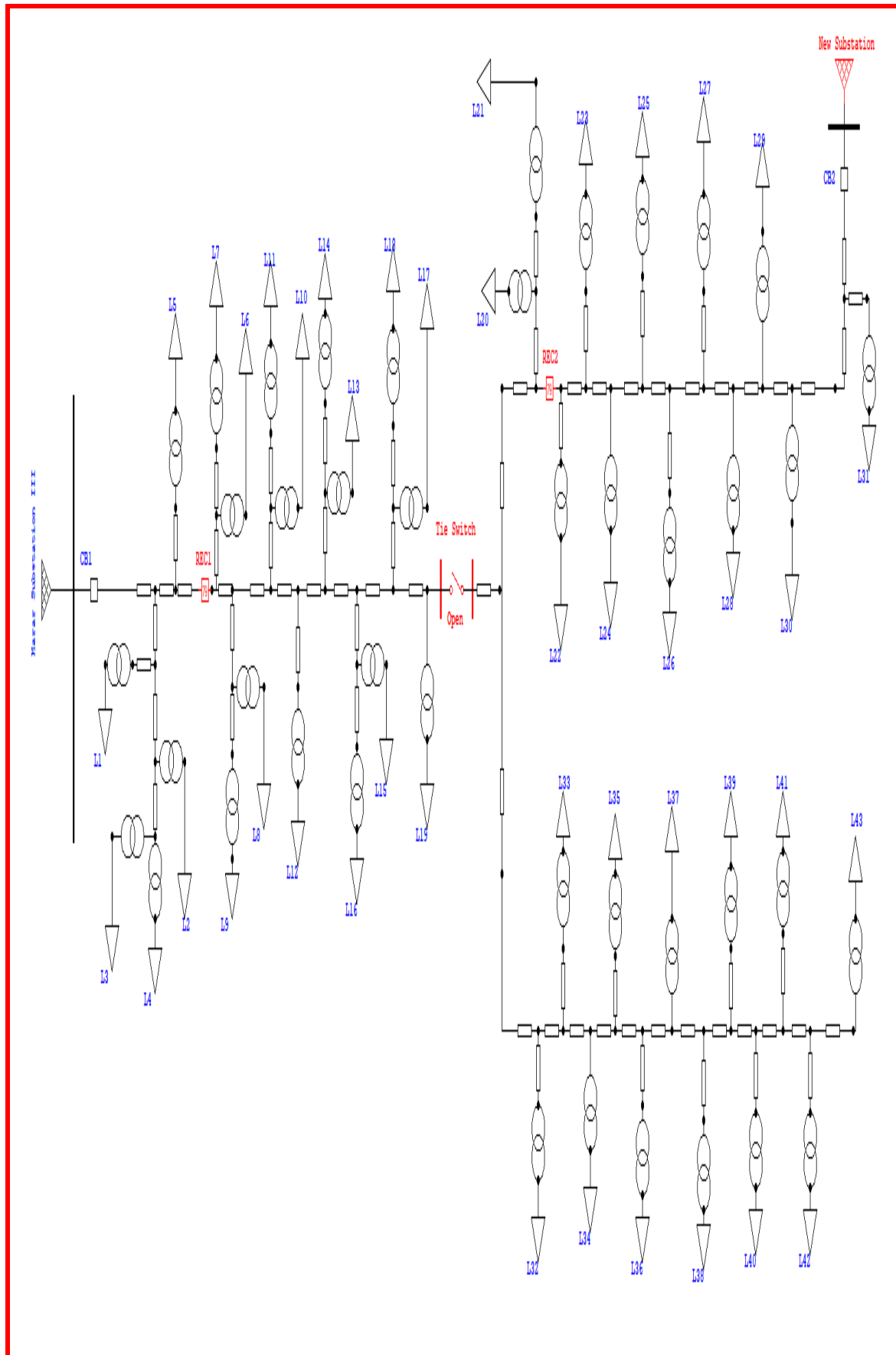


Figure 4.6: Single line diagram for Scenario -3

Table 4.4: Simulation result reliability of indices for Scenario- 3

Project: Power Reliability Improvement	ETAP	Page: 1
Location: Harar, Ethiopian	12.6.0H	Date: 08-31-2019
Contract: 0910734320		SN:
Engineer: Mandefro Teshome Aseffa	Study Case: RA	Revision: Base
Filename: Senario 3		Config.: Normal
<u>System Indexes</u>		
SAIFI	99.4667 f / customer.yr	
SAIDI	72.6889 hr / customer.yr	
CAIDI	0.731 hr / customer interruption	
ASAI	0.9917 pu	
ASUI	0.00830 pu	
EENS	364.786 MW hr / yr	
SAIFI	System Average Interruption Frequency Index	
SAIDI	System Average Interruption Duration Index	
CAIDI	Customer Average Interruption Duration Index	
ASAI	Average service Availability Index	
ASUI	Average Service Unavailability Index	
EENS	Expected Energy Not Supplied	

As shown in Table 4.4 (Scenario- 3), the expected number of outages per year has been reduced from 521.00 to 99.4212 (80.9% system reliability has improved), the annual outage duration has been reduced from 446 to 72.69hours (83.7% reduction in outage duration) as compared with the existing system. In Scenario-3 the reliability of Harar feeder is improved by 80.9%, 83.69% and 92.55% for SAIFI, SAIDI and EENS respectively. And also the interruption energy cost for (Scenario- 3) can be calculated as,

$$\text{Interruption Cost} = 364.897\text{MWh} \times 1000 \times 0.4409 \text{ ETB/kWh} = 160,883.1\text{ETB}.$$

Therefore the interruption energy cost has been decreased from 2,159,060.846 to 160,883.1ETB per year.

4.4.4 .Scenario - 4: Reconfiguring the System using Tie Switch, Four Reclosures and New Substation

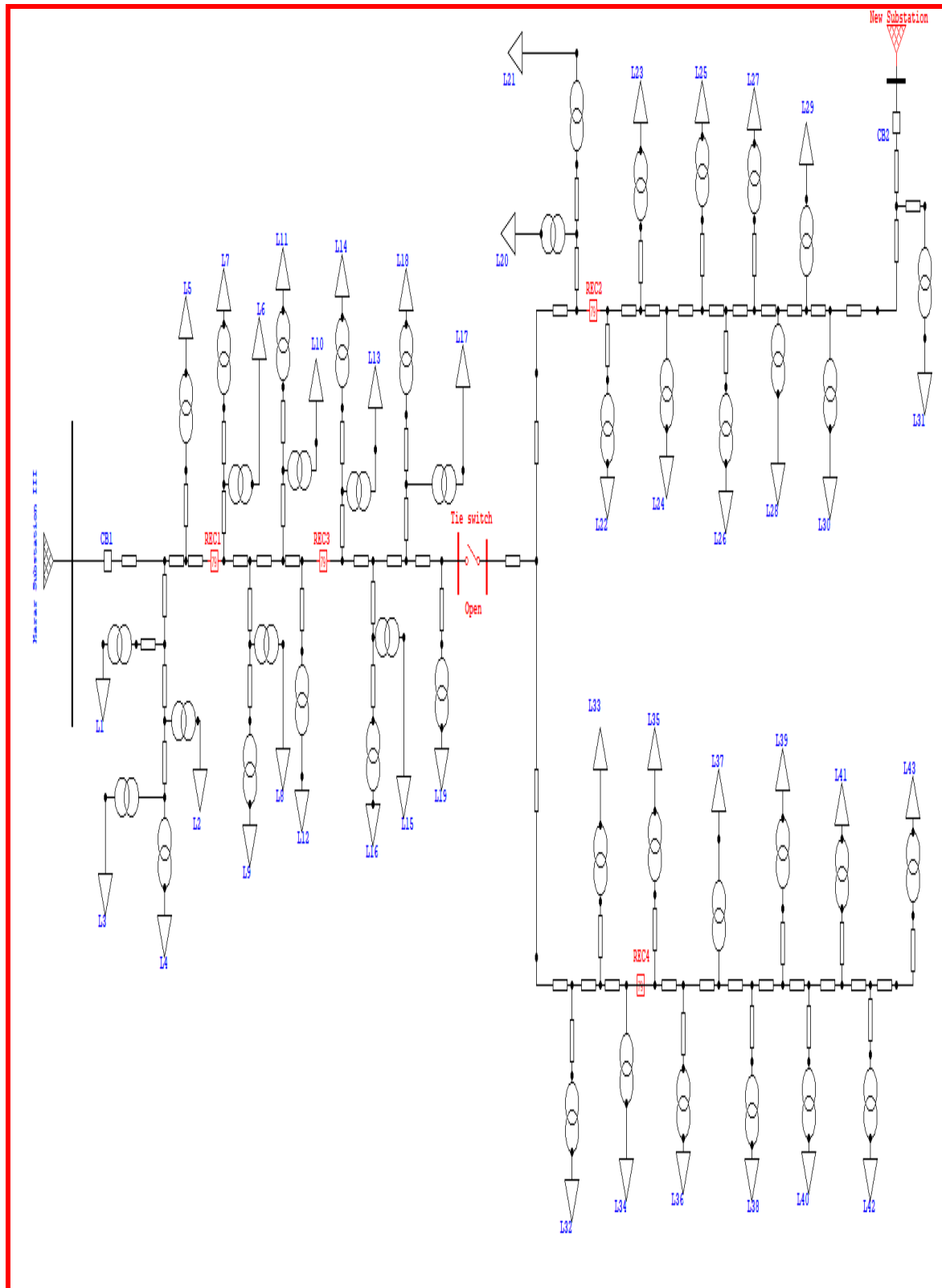


Figure 4.7: Single line diagram for Scenario- 4

Table 4.5: Simulation result reliability of indices for Scenario- 4

Project: Power Reliability Improvement	ETAP	Page: 1
Location: Harar, Ethiopia	12.6.0H	Date: 08-29-2019
Contract: 0910734320		SN:
Engineer: Mandefro Teshome Aseffa	Study Case: RA	Revision: Base
Filename: Senario 4		Config.: Normal
<u>System Indexes</u>		
SAIFI	94.9092 f / customer.yr	
SAIDI	63.4716 hr / customer.yr	
CAIDI	0.669 hr / customer interruption	
ASAI	0.9928 pu	
ASUI	0.00725 pu	
EENS	266.769 MW hr / yr	
SAIFI	System Average Interruption Frequency Index	
SAIDI	System Average Interruption Duration Index	
CAIDI	Customer Average Interruption Duration Index	
ASAI	Average service Availability Index	
ASUI	Average Service Unavailability Index	
EENS	Expected Energy Not Supplied	

Table 4.5 (Scenario- 4), the expected number of outages per year has been reduced from 521.00 to 94.91(81.8% system reliability has improved), the annual outage duration has been reduced from 446 to 63.4hours (85.8% reduction in outage duration) as compared with the existing system. In Scenario-4 the reliability of Harar feeder is improved by 81.8%, 85.8% and 94.55% for SAIFI, SAIDI and EENS respectively. And also the interruption energy cost for (Scenario- 4) can be calculated as,

$$\text{Interruption Cost} = 266.76\text{MWh} \times 1000 \times 0.4409 \text{ ETB/kWh} = 117,610.52\text{ETB}.$$

Therefore the interruption energy cost has been decreased from 2,159,060.846 to 117,610.52ETB per year.

4.4.5. Scenario- 5: Using Three Recloser, Tie Switch, Isolator and New Substation

In Scenario-5, three reclosers with a normally open tie switches are placed on the distribution line by considering the length of the feeder, the number of customers and criticality of the location. In this scenario (Figure 4.8) as clearly shown below, the long line runs into large area of Harar city and has been permanently isolated from the existing city feeder at the exit of the Harar city.

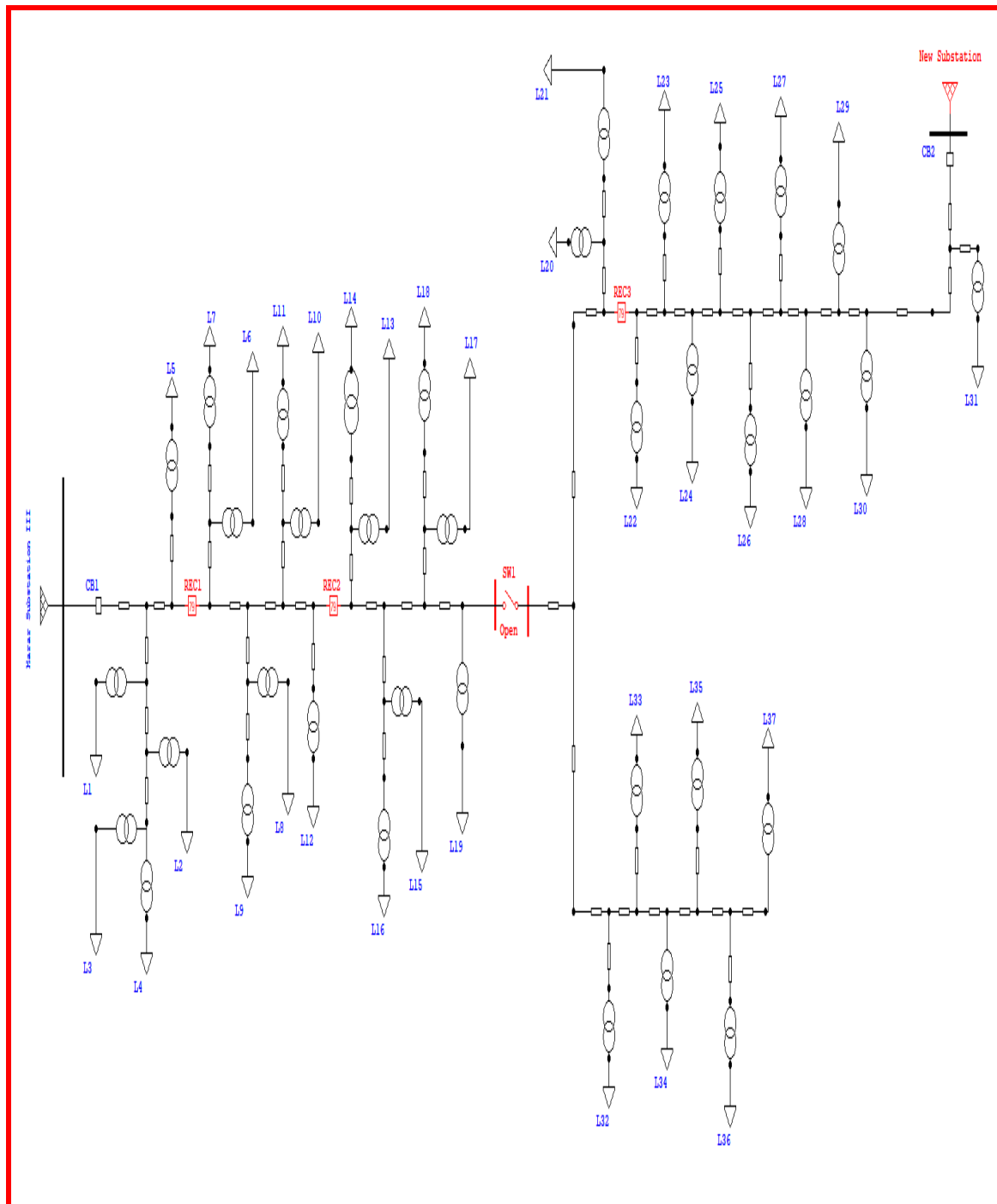


Figure 4.8: Single line diagram for Scenario- 5

Table 4.6: Simulation result reliability of indices for Scenario- 5

Project: Power Reliability Improvement	ETAP	Page: 1
Location: Harar, Ethiopia	12.6.0H	Date: 08-30-2019
Contract: 0910734320		SN:
Engineer: Mandefro Teshome Aseffa	Study Case: RA	Revision: Base
Filename: Senario 5		Config.: Normal
<u>System Indexes</u>		
SAIFI	87.0831 f / customer.yr	
SAIDI	46.9144 hr / customer.yr	
CAIDI	0.539 hr / customer interruption	
ASAI	0.9946 pu	
ASUI	0.00536 pu	
EENS	121.581 MW hr / yr	
SAIFI	System Average Interruption Frequency Index	
SAIDI	System Average Interruption Duration Index	
CAIDI	Customer Average Interruption Duration Index	
ASAI	Average service Availability Index	
ASUI	Average Service Unavailability Index	
EENS	Expected Energy Not Supplied	

In scenario-5, very important thing is isolating the 15 kV power line of Harar substation III which goes to Nursing school area line from the existing system and replacing it with 33kV power line of Fedis feeder. Isolating the Nursing school area line increases the reliability of the feeder in Harar city. Nursing school area Line consists' currently six transformers (1 with 315KVA, 4 with 100KVA and 1 with 630KVA ratings) and covers about 6km inside of Harar city.

The Fedis 33 kV line is one of the four outgoing 33 kV lines from Harar substation III. Its capacity is 4.0 MW, but the actual peak load of the feeder is 2.0 MW, which is only about 50% of its capacity. It extends from Harar city to Kombolcha town in the same direction.

Table 4.6 (Scenario- 5), the expected number of outages per year has been reduced from 521.00 to 87.1743(83.23% system reliability has improved), the annual outage duration has been reduced from 446 to 46.92hours (89.48% reduction in outage duration) as compared with the existing system. In Scenario-5 the reliability of Harar feeder is improved by 83.23%, 89.48% and 97.51% for SAIFI, SAIDI and EENS respectively. And also the interruption energy cost for (Scenario- 5) can be calculated as,

$$\text{Interruption Cost} = 121.6\text{MWh} \times 1000 \times 0.4409 \text{ ETB/kWh} = 53,613.44\text{ETB}.$$

Therefore the interruption energy cost has been decreased from 2,159,060.846 to 53,613.44ETB per year.

Table 4.7: Summary of the results of reliability improvement for all Scenarios

Customer Oriented Reliability Indices	Scenarios					
	Existing System	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
SAIFI (f/customer/yr)	521	275.42	190.19	99.421	94.914	86.174
SAIDI (hr/customer/yr)	446	215.62	139.40	72.689	63.433	46.917
CAIDI(hr/customer/Int.)	0.855	0.783	0.733	0.731	0.668	0.538
ASAI (Pu)	0.9491	0.9754	0.9841	0.9917	0.9928	0.9946
ASUI (Pu)	0.5089	0.0246	0.0159	0.0083	0.0072	0.0054
% Reduction in SAIFI	0	47.22	63.526	80.9	81.8	83.23
% Reduction in SAIDI	0	51.79	68.74	83.7	85.8	89.48

From the above Table 4.7, it was concluded that the most effective alternative (Scenario- 5) for improving the power reliability of the study area was installing three Reclosers, tie switch and sectionalizer at critically selected locations.

Table 4.8: Summary of the result of system energy oriented reliability improvement for all Scenarios.

Energy-Oriented Reliability Indices	Scenarios					
	Existing System	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
EENS(MWhr/yr)	4897.12	2271.131	1123.71	364.897	266.75	121.59
ECOST(USD/yr)	76,233.6	35,358.11	17,494.5	5,680.36	4,152.5	1,893
%Reduction in EENS	0	53.62%	77.053%	92.55%	94.55%	97.5%
%Reduction in ECOST	0	53.62%	77.053%	92.55%	94.55%	97.51%

In addition to the system configuration upgrading, scheduled preventive maintenance, additional rehabilitation works on the entire of the system, enhancing manpower problems, control strategy and other related problems will have a great role in the system reliability improvement.

4.5. Interlocking and Switching Sequence Operation of Protective Devices

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

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

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

Table 4.9: Interlocking between CB1, CB2 and Tie switch

Single-Throw Switch Editor - Tie Switch ×

Info Reliability **Interlock** Remarks Comment

Pre-Switching Logic							
Active	Action		Type	ID/Tag		Status	
☐	On		HVCB	CB1	=	Open	AND
			HVCB	CB2	=	Closed	
☐	Cl		HVCB	CB1	=	Open	OR
>>			HVCB	CB2	=	Open	

Add Delete

Post Switching Logic							
Active	Action	Delay		Type	ID/Tag		Status
☐	Op...		IF	HVCB	CB1		
				HVCB	CB2		
☐	Cl...		IF	HVCB	CB1	=	Open
		0	THEN	HVCB	CB1	->	Close END
			IF	HVCB	CB1	=	Closed
		0	T...	HVCB	CB2	->	Trip END

Logic Description

Pre Switching logic Close:
IF CB1 = Open OR CB2 = Open

From Table 4.9, it is clearly observed that the interlocking among the two substation circuit breakers (CB-1 and CB-2) and the Tie switch; so that the tie switch should not close unless one of the two breakers are open. This implies that the three switches never be closed at the same time as the two substations are not synchronized to feed the same load at the same time.

Table 4.10: Switching sequence for different operation of CB1, CB2 and Tie switch

Switch Sequence

ID ☒ Save Last Config

			Device/Logic		Operation					Modification		
Action #	Group #	Active	Type	ID	Delay T (MMSS)	Action	Crew	Remarks	Cost (\$)	Name	Date	Time
1	1	☒	HV CB	CB1	0:00:00.000	Open			0.00	0000	04/01/20	3:57:13
>> 2	2	☒	Switch	Tie Switch	0:00:00.000	Close			0.00	0000	04/01/20	3:57:17

Switch Sequence

ID ☒ Save Last Config

			Device/Logic		Operation					Modification		
Action #	Group #	Active	Type	ID	Delay T (MMSS)	Action	Crew	Remarks	Cost (\$)	Name	Date	Time
1	1	☒	HV CB	CB2	0:00:00.000	Open			0.00	0000	04/01/20	4:01:01
>> 2	2	☒	Switch	Tie Switch	0:00:00.000	Close			0.00	0000	04/01/20	4:01:03

Switch Sequence

ID ☒ Save Last Config

			Device/Logic		Operation					Modification		
Action #	Group #	Active	Type	ID	Delay T (MMSS)	Action	Crew	Remarks	Cost (\$)	Name	Date	Time
1	1	☒	Switch	Tie Switch	0:00:00.000	Open			0.00	0000	04/01/20	4:06:59
>> 2	2	☒	HV CB	CB1	0:00:00.000	Close			0.00	0000	04/01/20	4:06:01

Switch Sequence

ID ☒ Save Last Config

			Device/Logic		Operation					Modification		
Action #	Group #	Active	Type	ID	Delay T (MMSS)	Action	Crew	Remarks	Cost (\$)	Name	Date	Time
1	1	☒	Switch	Tie Switch	0:00:00.000	Open			0.00	0000	04/01/20	4:07:35
>> 2	2	☒	HV CB	CB2	0:00:00.000	Close			0.00	0000	04/01/20	4:07:38

Table 4.10 explains the switching sequences intended to be experienced by the three devices (CB-01, CB-02 and the Tie switch) under different situations. Four different

conditions have been demonstrated as shown in sequences of 1, 2, 3 and 4 in the Table. In Sequence-1, it is assumed that CB-01 has been opened by any case, and then needs to close Tie switch to transfer a power from the other sources to the interrupted load. Here the tie switch should be closed the circuit after checking CB-01 is opened, mean that it is must checking as if CB-01 is opened first to close the tie switch.

After maintenance or other works made on CB-01, to close CB-01, tie switch must be opened first. The same procedure has been followed in relation with CB-01 and the Tie switch (Sequences 2, 3 and 4).

4.6. Economical Cost Analysis

In this thesis, an economical cost analysis has been done based on the interruption cost only related to the utility side by using Expected Energy Not Supplied (EENS) of each Scenario. For Scenario-1, annual average unsold energy is reduced from 4897.123 to 2271.131 MWh per year as shown in Table 4.10. Therefore, the revenue saved due to reliability improvement can be estimated as follows.

The Revenue loss before improvement due to unsold energy is:

$$4,897,123 \text{ KWh/year} \times 0.4409 \text{ ETB/KWh} = 2,159,141.53 \text{ ETB/year}$$

For Scenario-1; The Revenue saved after improvement due to unsold energy is: -

$$[4,897,123 - 2,271,131] \text{ KWh/year} \times 0.4409 \text{ ETB/KWh} = 1,157,799.87 \text{ ETB}$$

The investment cost can be calculated by using the cost of one recloser used to design the system in Scenario-1.

Average cost of one Recloser is \$15,000 (USD) [22]. (Based on the currency exchange rate found from Commercial Bank of Ethiopia on Saturday, 8 In May, 2019), One US Dollar (USD) is sold by 28.23 Ethiopian Birr (ETB). And hence, the cost of one 15kV, 800A pole mounted out door Recloser is: $15,000 \times 28.88 = 433,200$ Birr.

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 investment option.

Thus, for Scenario-1 the payback period is:

$$\text{Payback Period} = 433,200\text{Birr} / 1,157,799 = 0.4\text{year}.$$

Hence, the payback period indicates that it takes 0.4 years to get back the investment cost. In this Scenario-1, the reliability indices SAIFI and SAIDI have been reduced by about 47.22% and 51.79% respectively.

For Scenario-2; The Revenue saved after improvement due to unsold energy is:

$$[4,897,123 - 1123,710] \text{ KWh/year} \times 0.4409 \text{ ETB/KWh} = 1,663,697.79\text{ETB}$$

Thus, for scenario-2 the payback period is:

$$\text{Payback Period} = (433,200 \times 2)\text{Birr} / 1,663,697.79 = 0.52\text{year}$$

Hence, the payback period indicates that it takes 0.52 years to get back the investment cost. In this Scenario-2, the reliability indices SAIFI and SAIDI have been reduced by about 63.526%and 68.74% respectively.

For Scenario-3: The new 3.4 km feeder line cost mainly consists of material cost, labor cost, and transportation cost. The line should be 15 kV, 12 meter concrete pole, and three phase 95 mm² AAC conductor with overhead triangular configuration. By dividing the total length (3400 meter) to the span length (50 meters) the total number of concrete poles is estimated to be about 68 (68 Concrete poles for 12 meters).

For Scenario-3; The Revenue saved after improvement due to unsold energy is:

$$[4,897,123 - 3,64897] \text{ KWh/year} \times 0.4409 \text{ ETB/KWh} = 1,998,258.443\text{ETB}$$

Table 4.11: Labor and Transport cost of MV line construction (EEU price list, 2011 E.C)

Distance	Labor cost (ETB)	Transport cost (ETB)	Total (ETB)
for 1km line construction	10,725.12	1,643.76	12,368.88
for 3.4 km line construction	36,465.408	5,588.784	42,054.192

From the Table 4.11, the sum of labor and transport cost to construct 3.4 km medium voltage line is 54,423.072 ETB

Table 4.12: Summary of materials needed to construction the new line and their costs
(EEU price list, 2011 E.C).

Stock No	Materials	Unit	Unit Price	Amount	Total Cost
03-01-000	Insulator HT 18/5 mm ² 15 KV	Each	439.30	204	89,617.2
03-01-200	Insulator pin 18/5 for H.T 15 KV	Each	510.82	204	104,207.3
04-04-920	AAC. All Aluminum Conductor 95 mm ²	MT	50.31	10,200	513,162
09-01-680	Concrete Pole 12 M	Each	4,574.13	68	311,040.8
09-03-030	Cross arm Type 4-48/202	Each	142.54	68	9,692.72
09-03-430	Collars Big	Each	131.08	272	35,653.76
09-03-670	15kv Tie strap	Each	442.71	136	60,208.56
12-04-860	Long Bolt Galvanized 5/8" 40 cm	Each	185.37	4	741.48
Total Material Cost					1,124,324

As per the Ethiopian Electric Utility price List version 2011 E.C, the total materials cost needed to construct the new MV line (3.4 km) as shown in Table 4.13, is 1,124,324 ETB.

$$\text{Payback Period} = \frac{(1,124,324 + 54,423.072 + (433,200 * 2))\text{Birr}}{1,998,258.44} = 1.023\text{years}$$

Hence, the payback period indicates that it takes 1.023 years to get back the investment cost. In this Scenario-3, the reliability indices SAIFI and SAIDI have been reduced by about 80.9%and 83.69% respectively.

For Scenario-4

All material, labor and transport cost of scenario-4 is the same as to scenario-3, the only difference is in scenario-4 there is two additional reclosure. Based on this the payback period is calculated as follows.

The Revenue saved after improvement due to unsold energy is:

$$[4,897,123 - 266751] \text{ KWh/year} \times 0.4409 \text{ ETB/KWh} = 2,041,531.015\text{ETB}$$

$$\text{Payback Period} = \frac{(1,124,324 + 54,423.072 + (433,200 * 4))\text{Birr}}{2,041,531.015} = 1.43\text{years}$$

Hence, the payback period indicates that it takes 1.43 years to get back the investment cost. In this Scenario-4, the reliability indices SAIFI and SAIDI have been reduced by about 81.8%and 85.8% respectively.

For Scenario-5; The Revenue saved after improvement due to unsold energy is:

$$[4,897,123 - 121595] \text{ KWh/year} \times 0.4409 \text{ ETB/KWh} = 2,105,530.3 \text{ ETB}$$

Thus, for scenario-5 the payback period is:

$$\text{Payback Period} = \frac{(1,124,324 + 54,423.072 + (433,200 * 3)) \text{ Birr}}{2,105,530.3} = 1.18 \text{ years}$$

Hence, the payback period indicates that it takes 1.18 years to get back the investment cost. In this Scenario-5, the reliability indices SAIFI and SAIDI have been reduced by about 83.23%and 89.49% respectively.

Table 4.13: 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	4897.123	2,159,060.846	0		
Scenario – 1	2271.131	1,001,341.66	433,200	1,157,799	0.4
Scenario – 2	1123.710	495,443.739	753,350	1,663,697.79	0.52
Scenario – 3	364.897	160,883.1	2,045,147.072	1,998,258.44	1.023
Scenario – 4	266.751	117,610.52	2,911,547.07	2,041,531.04	1.43
Scenario – 5	121.595	53,613.44	2,478,347.07	2,105,530.3	1.18

Table 4.13 reveals that the payback period of scenario-1, 2, and 3 is small as compared with the scenario-5, but as clearly shown in Table 4.6, the percentage reduction for SAIFI and SAIDI compared with the selected base years is minimum.

When coming to scenario four the percentage reduction for SAIFI and SAIDI is about 80 percent as compared to the existing system, but the payback period is not good as scenario 5. Scenario-5 has enhanced the reliability of the system very well and the payback period is only 1.18 years.

Table 4.14: 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
Harar, City-Feeder	Existing	521.454	446.82
	Senario-1	275.418	215.6193
	Senario-2	190.6407	139.4736
	Senario-3	99.4212	72.6892
	Senario-4	94.914	63.4336
	Senario-5	86.1743	46.917

Table 4.14 shows the comparison of the most commonly used reliability indices (SAIFI and SAIDI) of Harar city feeder, with the requirements of the Ethiopian Electric Utility (EEU) and the best experienced countries.

As it is observed from Table 4.14, both the SAIFI value in interruptions per year per customer and the SAIDI value in hours per year per customer of the city feeder can be improved to 85% as compared with the base years values.

For the selected scenario (scenario-5), the reliability indices values of the case study area can be further improved by using scheduled preventive maintenance, strategic management system, keeping fit the workers, by further rehabilitating the system and by solving other related problems.

CHAPTER FIVE

5. CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK

5.1. Conclusions

In this thesis work, evaluation of power reliability and improvement techniques for Harar city feeder has been conducted.

In this thesis, System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) have been used as the main driver for evaluating each Scenario. Expected Energy Not Supplied (EENS) was also monitored during this process and cost-effectiveness have considered as the main constraint of any analysis in this thesis work.

The study clearly identified that the reliability of the Harar city feeder does not meet the requirements set by the Ethiopia Electric Utility (EEU). The average frequency of the interruptions the city feeder is 521.454 interruptions per customer per year (SAIFI). And also the average duration of the interruption is 446.5667 hours per customer per year (SAIDI). This shows that there is huge loss of unsupplied energy due to planned and unplanned outages. The average of unsupplied energy is 4,896.94 MWh per year. This results in a loss of around 2,159060.846 ETB per year from Ethiopia Electric Utility (EEU).

In this thesis, the system modeling and simulation studies are carried out on one of 15 kV Harar city feeder to evaluate its reliability performance for the existing feeder and also for predicting the reliability performance for the proposed improvement techniques.

In this thesis work, five different Scenarios have been proposed and analyzed for the implementation of reliability improvement in the study area. As the simulation result shows all Scenarios have different reliability improvement contribution on the city feeder with 0.4 to 1.43 years payback period investment cost. All Scenarios are tolerable in terms of the investment cost. But, to improve city power reliability indices more Scenario-5 is highly proposed.

The author of this thesis paper believes that reconfiguration of the system using tie switch, three auto reclosers and sectionalizer 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. By implementing Scenario-5 the overall reliability of Harar city feeder is improved by 83.23%, 89.48% and 97.51% for SAIFI, SAIDI and EENS respectively.

The proposed solution has the potential to save around 2,105,447.326ETB per year from the unsold energy of the city feeder with 1.18 years payback period for the technology investment made to improve the reliability. Satisfaction of the society has also been considered as the priceless advantage.

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 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 this thesis is conducted on one feeder, doing reliability assessment analysis for whole part of the city is recommended.
- It is highly recommended that EEU has to look at the various technologies evaluated in this research for improving the reliability of distribution systems.
- It is also important to give more attention to preventive maintenance to improve random power interruption, sustainability of equipment and to deliver reliable power to the customer.
- Harar substation III workers have little experience in the documentation of the performance data for the outgoing feeders. It is, therefore, strongly recommended that the data collection and documentation have to improved at EEU.

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