Reliability Assessment and Enhancement of Distribution System (Case Study: Adama Mobile Substation Feeder M-1)

Ismael Awel Mohammed

A Thesis Submitted to the Department of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfilment of the Requirement for the Degree of Master's in Electrical Power and Control Engineering (Specialization in Power Engineering)

Office of Graduate Studies

Adama Science and Technology University

Sep, 2024

Adama, Ethiopia

Reliability Assessment and Enhancement of Distribution System (Case Study: Adama Mobile Substation Feeder M-1)

Ismael Awel Mohammed

Advisor: Prof. S Kim

A Thesis Submitted to the Department of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfilment of the Requirement for the Degree of Master's in Electrical Power and Control Engineering (Specialization in Power Engineering)

Office of Graduate Studies

Adama Science and Technology University

Sep, 2024

Adama, Ethiopia

Declaration

I hereby declare that this Master Thesis entitled “Reliability Assessment and Enhancement of Distribution System (Case Study: Adama Mobile Substation Feeder M-1)” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledge through citation.

Ismael Awel Mohammed	____________________	_______________
Name of the student	Signature	Date

Recommendation

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled “Reliability Assessment and Enhancement of Distribution System (Case Study: Adama Mobile Substation Feeder M-1)” prepared under my guidance by **Ismael Awel Mohammed** submitted in partial fulfillment of the requirements for the degree of Masters of Science in Power Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Prof. S Kim	____________________	01.09.2024
Major Advisor	Signature	Date

Approval Page of M.Sc. Thesis

I, the advisor of the thesis entitled "Reliability Assessment and Enhancement of Distribution System (Case Study: Adama Mobile Substation Feeder M-1)" and developed by **Ismael Awel Mohammed**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Prof. S Kim	____________________	01.09.2024
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Ismael Awel Mohammed** have read and evaluated the thesis entitled "Reliability Assessment and Enhancement of Distribution System (Case Study: Adama Mobile Substation Feeder M-1)" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Power Engineering.

____________________	____________________	____________
Chairperson	Signature	Date
____________________	____________________	____________
Internal Examiner	Signature	Date
Dr. Yeshitela Shiferaw	____________________	29/09/2024
External Examiner	Signature	Date

Final approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

____________________	____________________	____________
Department Head	Signature	Date
____________________	____________________	____________
School Dean	Signature	Date
____________________	____________________	____________
Office of Postgraduate Studies, Dean	Signature	Date

ACKNOWLEDGEMENT

I want to sincerely thank Almighty Allah for giving me the courage, wisdom, and persistence I needed to do this research. I will always be grateful for His heavenly direction and gifts.

I also want to express my sincere gratitude to Prof. S Kim, my adviser, for all of his help, advice, and knowledge during this process. His constructive criticism and support have been invaluable in helping to shape this thesis.

In addition, I am appreciative of my mother Alfiya Beyene and father Awel Mohammed for their constant belief in my potential, sacrifices, and unconditional love. Their steadfast encouragement has motivated me to continue learning.

In addition, I want to sincerely thank Shukria Hamda, my wife, for her continuous support, understanding, and love. Her unwavering faith in my abilities and support have inspired me.

Finally, I want to express my sincere gratitude to every one of my relatives and friends for their unwavering support during this trip. Your comments of support, inspiration, and faith in me have been quite helpful.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

AAC	All Aluminum Conductor
ACCI	System Average Customer Curtailment Index
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
CB	Circuit Breaker
CSC	Customer Service Center
CT	Current Transformer
DN	Distribution Network
DPEF	Distribution Permanent Earth Fault
DPSC	Distribution Permanent Short Circuit Fault
DT	Distribution Transformer
DTEF	Distribution Temporary Earth Fault
DTSC	Distribution Temporary Short Circuit Fault
DLOL	Distribution Line Overload
EC	Ethiopian Calendar

ECOST	Expected Interruption Cost
EEA	Ethiopian Electric Agency
EEP	Ethiopia Electric Power
EEU	Ethiopia Electric Utility
EENS	Expected Energy Not Supplied
EIC	Expected Interruption Cost
ETAP	Electrical Transient Analyzer Program
ETB	Ethiopian Birr
HLI	Hierarchical Level I
HLII	Hierarchical Level II
HLIII	Hierarchical Level III
IDMT	Inverse Definite Minimum Time Relay
IEEE	Institute of Electrical and Electronics Engineers
KM	Kilo meter
KV	Kilo Volt
KVA	Kilo Volt Ampere
KW	Kilo Watt
MAIFI	Momentary Average Interruption Frequency Index
MFP	Main Feeding Point
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair

MVA	Mega Volt Ampere
MV	Mega Volt
OP	Operational Interruption
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
USD	United States Dollar

Abstract

The study evaluates the current state of the distribution system, identifies its vulnerabilities, and proposes improvement strategies. It starts with a thorough reliability assessment using historical data from 2013 to 2015 E.C., load profiles, and system performance metrics. The assessment reveals that feeder M-1 experiences an average of 220 interruptions per customer per year, with an average duration of 306.12 hours per customer per year. These figures are substantially higher than the Ethiopian Electric Agency (EEA) standards, which set the SAIFI (System Average Interruption Frequency Index) at 20 interruptions per customer per year and the SAIDI (System Average Interruption Duration Index) at around 25 hours per customer per year. Key indicators such as outage frequency, duration, and customer impact are analyzed to evaluate the system's current reliability. Upon identifying critical areas of concern, the study proposes targeted enhancements, focusing primarily on the integration of advanced technologies. These include the strategic deployment of automatic outdoor reclosers, sectionalizers, and the integration of tie-switches into the system. These technologies aim to optimize fault isolation, facilitate rapid system reconfiguration, and improve overall resilience. The case study involves simulations using Electrical Transient Analysis Program (ETAP 19.0.1) software and real-world data analysis to demonstrate that the system's reliability can be significantly improved with economically and technically justified solutions. Four different mitigation cases are evaluated to improve system reliability. The case with the lowest SAIDI, SAIFI, and Expected Energy Not Supplied (EENS) at a reasonable cost is selected. The results show that the reliability of Adama city's feeder M-1 has improved by 74.09% for SAIFI, 74.13% for SAIDI, and 74.16% for EENS compared to the existing system under the simulated best option. The economic feasibility analysis indicates that the selected solution results in annual cost savings of 4,658,760.04 ETB from the unsold energy of feeder M-1, with a payback period of 0.77 years for the investment. Additionally, the societal satisfaction derived from these improvements is considered an invaluable benefit.

Keyword: ***Distribution System, ETAB Software, Power Reliability, Reliability Indices.***

CHAPTER 1. INTRODUCTION

1.1 Background

The reliability of a distribution system is of paramount importance to ensure the uninterrupted delivery of electricity to end-users. In rapidly evolving urban environments, such as the Adama mobile substation feeder M-1, the need for a robust and resilient distribution system becomes crucial. This background provides context for the case study on the reliability assessment and enhancement of the Adama mobile substation feeder M-1 distribution system (Arya et al., 2019).

Electric power distribution systems play a critical role in providing reliable and uninterrupted electricity supply to end-users. However, these systems are susceptible to various challenges, including equipment failures, environmental factors, and increasing demand. The reliability assessment and enhancement of distribution systems are essential components of ensuring a dependable power supply to consumers (Abrha et al., 2020).

The distribution of electrical power is a critical component of modern infrastructure, directly impacting the quality and reliability of electricity supply to end-users. Ensuring the reliability of distribution systems is paramount for minimizing downtime, improving customer satisfaction, and supporting economic activities (Yadav, 2018). The Adama mobile substation feeder M-1 serves as a case study to assess and enhance the reliability of a specific distribution system.

Adama, a city in Ethiopia, relies on its electrical distribution infrastructure to meet the growing demands of residential, commercial, and industrial consumers. Feeder M-1 from the Adama Mobile Substation plays a crucial role in supplying power to a designated area. Understanding the dynamics and challenges faced by this feeder is essential for optimizing its performance.

The power quality of the electric distribution system is a significant problem these days. More sophisticated electrical and technological technology means that customers demand greater quality service. Service quality in terms of voltage profile and stability, power distribution system performance, and efficiency are the metrics used to assess the efficacy of a power distribution system. The unreliable power at customer end causes early failure of equipment's, decreased efficiency and performance of high-power appliances (Adefarati & Bansal, 2018).

1.2 Statement of the Problem

The reliability of the electrical distribution system is a critical concern for the sustainable functioning of modern cities. Adama, Ethiopia, is no exception, and the Adama mobile substation feeder M-1, as a crucial component of the distribution network, faces specific challenges that necessitate a focused assessment and enhancement effort.

The infrastructure supporting feeder M-1 has aged, potentially leading to increased failure rates and prolonged downtime. Aging components, if not addressed, can compromise the overall reliability of the distribution system. Feeder M-1 has experienced a notable frequency of outages, causing inconvenience to residential, commercial and industrial consumers. These interruptions may stem from various factors, such as equipment failures, environmental conditions, or inadequate fault response mechanisms. In addition to slowing down or damaging production or forcing the plant to shut down, an unstable power supply can also cause equipment damage, necessitate more maintenance, and harm the industry's reputation for high-quality products like durability, effectiveness, and customer satisfaction in the distribution system (Sonwane, 2024). For the past few years, achieving power supply stability in Adama city has been a significant difficulty. If a peaceful solution to the issue is not found, it will remain so in the future. The fundamental topic this study attempts to answer is how a dependable distribution system might be adjusted for optimal power reliability enhancement of the study area.

In order to address this public issue, research is being done on the automatic outdoor recloser, tie-switch coordination, and sectionalizers in conjunction with distribution system reliability improvement.

1.3 Objectives

1.3.1 General Objective

The general objective of this thesis is to comprehensively evaluate the existing reliability of feeder M-1 within the Adama mobile substation and to propose strategic enhancements that will optimize the performance, resilience, and efficiency of the distribution system.

1.3.2 Specific Objectives

To achieve the main goals, the study has the following specific objective

- Identify the major causes of power interruptions and vulnerabilities in the existing system based on historical outage data.
- Evaluate system performance metrics based on selected base year's interruption data of the feeder using an available reliability analysis tool ETAP software.
- Assess feeder M-1 power distribution system in terms of its reliability problems.
- Evaluate the cost-benefit analysis of both the current and proposed systems, and draw relevant conclusions from the comparison

1.4 Significance of the Study

The significance of the study lies in its potential to address critical issues, such as identifying the major factors contributing to feeder interruptions, analyzing the current performance of the system, and exploring ways to improve the existing system through the integration of advanced technologies into the distribution network.

1.5 Expected Outcome of the Study

The study is expected to yield several key outcomes that will contribute to improving the overall performance, efficiency, and reliability of the feeder and the power distribution system. The anticipated results include: identification of key causes of feeder interruptions, quantitative reliability metrics, analysis of system weaknesses, improvement of system reliability, cost-effective solutions and recommendations for future maintenance and upgrades. By achieving these outcomes, the study will contribute to a more resilient, efficient, and sustainable power distribution network.

1.6 Scope and Limitation of the Study

The scope of this case study is defined within a specific time frame, focusing on historical data and performance records relevant to the Adama mobile substation feeder M-1. The analysis encompasses a retrospective evaluation and provides recommendations for future improvements. However, the computation of energy-oriented and customer-based reliability indices is limited in scope. To address time constraints, the study employed various strategies to optimize efficiency without compromising research quality. These strategies included prioritizing critical areas of analysis, utilizing ETAP simulation tools, and implementing efficient data collection methods.

CHAPTER 2. LITERATURE REVIEW

2.1 Theoretical Background

The two main factors that affect distribution dependability are equipment failures and customer interruption. Every material and every customer is energized under typical operating conditions. Normal working circumstances are disrupted by scheduled and unscheduled events, which can cause interruptions and outages. Electrical material failures or human error are the two main causes of the unplanned scenario. Customers will be informed in advance of the scheduled events, which are intended for periodic maintenance of the equipment. The transmission and distribution systems' dependability is assessed using a variety of metrics. Regulations may seek to maintain control over restoration times, provide compensation to customers for extended outages, and establish incentives for reducing the overall frequency and length of outages (R. Billinton and R. N. Allan, 1996).

Distribution system reliability is the ability to deliver electricity to all point of power utilization with acceptable limits of power flow constraints. The degree of performance of the bulk electric system's components that leads to the delivery of energy to customers in the intended quantity and within acceptable criteria is known as reliability. Distribution system dependability is crucial for achieving electricity supply targets, bringing about customer satisfaction. It also boosts public productivity and generates utility profit by minimizing the frequency and duration of interruptions. The distribution system's dependability needs to be assessed in order to maintain linked load energization and complete customer power access. There are numerous methods to define reliability in an electrical distribution system. These include the power system's availability and the services' capacity to continue fulfilling consumer demand (Makarov & Moharari, 2010).

The power system comprises three primary functional zones: generation, transmission, and distribution facilities. Figure 2.1 illustrates how reliability assessment can occur at various hierarchical levels, integrating these functional zones.

At hierarchical level I (HLI), the focus is on assessing the adequacy of generation facilities to match the system load, excluding transmission and distribution considerations. This evaluation is termed "generation capacity reliability evaluation."

Moving to hierarchical level II (HLII), both generation and transmission facilities are considered. Here, the analysis encompasses factors like transmission line constraints and the geographical placement of generation facilities, impacting supply reliability across transmission nodes and the entire system. This assessment is labeled "bulk system or composite system reliability evaluation" (Ahmad & Asar, 2021).

Hierarchical level III (HLIII) widens the scope to include all three functional zones, evaluating reliability at individual load points. Typically, reliability analysis occurs at the distribution system level, incorporating input from HLII evaluation. This approach acknowledges the complexities of practical power systems, including size, composition diversity, and ownership issues, which can make HLIII assessment challenging.

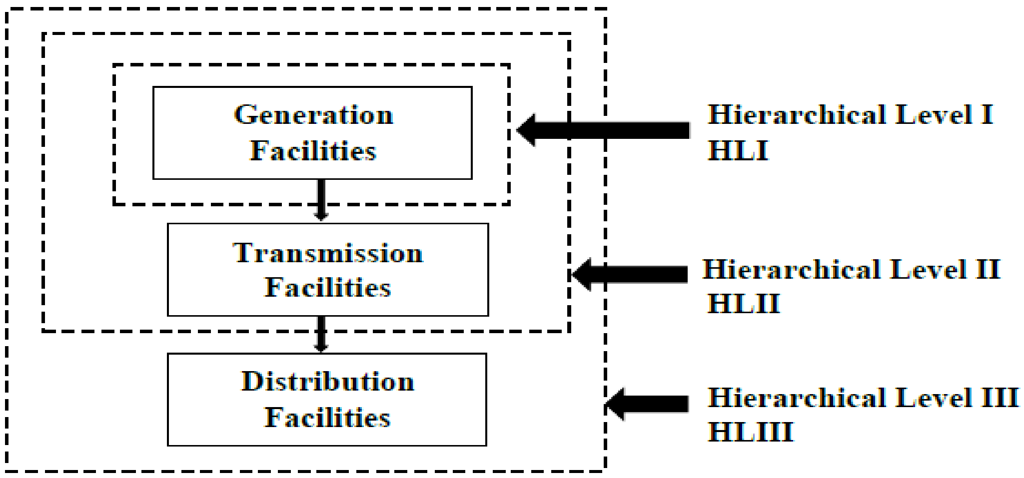

Figure 2. 1 Functional zones and hierarchical levels in reliability assessment

Concepts of electrical system reliability can be addressed by taking into account two fundamental and functional features of electrical systems.

- Adequacy
- Security

Adequacy: is the ability of the electrical system to meet all of the customers' combined energy needs and electrical demand, even in the event of planned system element outages.

To guarantee system sufficiency, the following three requirements must be fulfilled:

- Its generation capacity must be more than the system losses plus the demand load.
- It must have the capacity to deliver this power to its clients without overloading any equipment's.
- It needs to provide an appropriate voltage level to its load.

Each generator in the system is assigned a probability of availability, a probability of availability with a decreased capacity, and a probability of unavailable when it comes to the probabilistic nature of system adequacy assessment (Timalsena, 2020).

Security: is the electric system's capacity to withstand an unexpected loss of system element or an electric short circuit. In other words, security is the system's ability to keep supplying power to its load or customers in the event of one or more contingencies or an unforeseen event that disturbs the system. Whether a power system can meet peak demand if one or more pieces of equipment are disconnected is determined by a system security assessment.

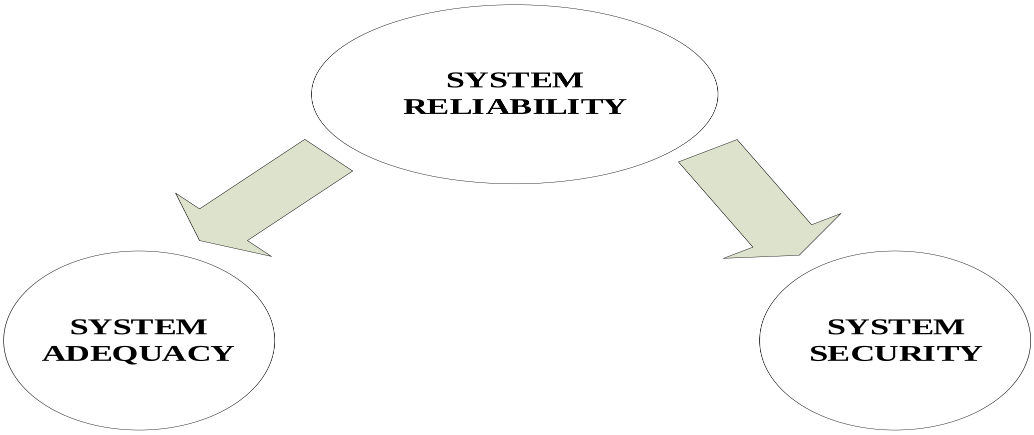

Figure 2. 2 System reliability subdivision

Reliability, to put it briefly, has to do with total power outages and voltage loss, not only sine wave distortions. Power reliability does not account for harmonics, swells, sags, or impulses (Pradhan et al., 2020).

Typically, reliability indices take into account factors like:

- The quantity of customers
- How long the interruption lasted in terms of seconds, minutes, hours, or days
- How much power (KVA) was disrupted
- How frequently the disruptions occurred

Reliability engineering uses a lot of terminology and definitions. Below are some definitions and terminology that are commonly used.

Reliability R (t): It is the probability that an item will carry out its assigned mission satisfactorily for the stated time period when used under the specified conditions. In short, reliability refers to the probability that a component experiences no failure during a time period (Sucita et al., 2018).

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

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

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

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

Useful life: It is the length of the time an item operates on an acceptable level of failure rate.

Failure Frequency (f): It 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.

$$f = \frac{number\ of\ failures}{Studied\ Period\ x\ Circut\ length\ of\ Transmission\ lines\ or\ Cables} \quad \text{……………..…………eq 2.1}$$

Mean Time to Failure (MTTF): The average time it takes to the occurrence of the component or system failure measured from t=0. The relationship between the failure frequency and the mean time to failure is given by;

$$\text{f} = \frac{1}{MTTF+MMTR} \quad \text{………………………………………………………................eq 2.2}$$

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

Failure Probability Q (t): It 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) …..eq 2.3

Availability (A): It is the probability that the component is normal at an arbitrary time t, given that it was good at a time zero (R. Billinton and R. N. Allan, 1996).

$$A = \frac{MTTR}{MTTF+MTTR} \quad \text{......eq 2.4}$$

Unavailability (U): It is the probability that the component is down at any arbitrary time t and unable to operate (Sonwane, 2024).

$$U = \frac{f*MTTR}{8760} \quad \text{......eq 2.5}$$

In the above equation, 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…………………………………………………………………………..eq 2.6

2.2 Electricity Service Faults

Transient Faults: A transient fault is one that doesn't need to be fixed right away and goes away on its own or when the faulty circuit is de-energized. Transient faults account for the majority of the problems on the overhead feeders. Temporary tree contacts with conductors and flashovers caused by lights or conductors momentarily swinging together are common causes of transient faults. According to this concept, reclosing the circuit breaker in question in the event of a transitory fault is always successful, even though it might not be on the first or second try.

Permanent Forced Outage Duration: The average amount of time it takes to return affected components to service after an automatic component outage caused by a permanent defect has occurred is the definition of duration (Jaleel & Abd, 2021).

Transient Forced Outage Duration: describes the period of time that an electrical system or component goes without power for a limited amount of time. Usually brought on by transitory defects like lightning strikes, short circuits, or brief system disruptions, these outages are frequently automatically resolved by circuit breakers or reclosers, among other safety mechanisms. Since these defects are typically transient and easily repaired without human assistance, the duration is typically brief. The fault-clearing apparatus and response mechanisms of the system, however, can affect how long the outage lasts.

2.3 Types of Power Interruption

There are various kinds of interruptions, which are covered in the sections that follow.

2.3.1 Momentary Interruption

In this instance, the customer's utility supply of electricity is interrupted for a few of minutes or less. Per IEEE 1366-2003 standard, a client is considered to have suffered a brief interruption if the power supply is interrupted and restored within five minutes. This interruption is caused by the functioning of a circuit breaker or reclosers, which briefly open the circuit to remove faults before closing it again. Interruptions of brief duration can occasionally cause voltage dips and impact the quality of power (Ololade et al., 2020).

2.3.2 Temporary Interruption

This is typically classified as a few-hour-long disruption. It often lasts longer than a brief interruption and less than a prolonged one. Usually, an operator must manually restart the system after this disruption. Because of this, the length of time is typically dictated by the operator's unavailability to complete the switching action right away. It is anticipated that this disruption will pass in less than two hours. Interruptions that are both brief and long-lasting may arise from lightning strikes, two conductors coming into touch in a windstorm, and so on (Ahmad & Asar, 2021).

2.3.3 Sustained Interruption

This is a supply interruption that typically lasts for several hours but occasionally persists for days for the consumer. If a transient problem is not fixed right away, it may result in a prolonged disruption. However, a broken transformer, an insulator, damaged cables, etc. could be the cause of the prolonged outage.

2.3.4 Planned Interruption

This is what happens when a component is purposefully pulled out of service to perform construction or maintenance. Usually, a planned outage is accompanied by this disruption. Customers are usually aware of the impending interruption of supply and it is frequently planned for.

2.4 Distribution System Reliability Indices

The assessment of a distribution system's reliability is linked to the uninterrupted flow of energy from the supply points to each load point of a single customer. Reliability indices are often used by utilities to maintain a tray of customer reliability in order to measure the performance of the distribution system. Every customer is given equal weight in the most widely used reliability metrics. This implies that the influence of a small residential client and a large industrial customer on computed indices will be equivalent. According to IEEE-P1366 2003, these dependability indices include measurements of outage duration, frequency, and availability as well as reaction time. System reliability and power quality are not the same thing because an interruption lasting longer than five minutes is typically regarded as a reliability index, while an interruption lasting less than five minutes is regarded as a power quality concern. Power quality relates to transient interruptions, whereas system reliability deals with prolonged ones. This study solely takes into account sustained interruptions, not any interruptions at all (Kovalev & Lebedeva, 2019).

To compare the dependability of different electric utility companies or to measure the reliability of a particular system, a variety of reliability indices can be used. Statistics aggregating reliability data for a group of loads, components, or customers are called reliability indices. The established reliability indices are used to evaluate the power supply's dependability. The majority of reliability indices are averages of a specific reliability characteristic throughout the whole system, feeder, or operational region. According to IEEE Standard 1366, customer-oriented and energy-oriented indices are among the indices used for distribution system analysis. The majority of nations utilize the following widely-used distribution system dependability indices to evaluate past performance and forecast a power system's future performance:

2.4.1 Customer Oriented Indices

- **System average interruption frequency indices /SAIFI/:** measures how frequently a system client encounters an outage on average each year. It is the mean number of continuous disruptions per client over a specified period of time. This indicator indicates the frequency with which a client encounters a continuous disruption over a given duration in their designated area. The improvement of SAIFI's index requires a fixed number of customers in addition to a reduction in the number of systemic interruptions in order to yield an accurate result (Nazaruddin et al., 2020).

$$\text{SAIFI} = \frac{\sum TOTAL\ NUMBER\ OF\ CUSTOMER\ INTERUPTION}{TOTAL\ NUMBER\ OF\ CUSTOMER\ SERVED} = \frac{\sum \lambda_i N_i}{\sum N_i} = \frac{\sum Ni}{NT} \quad \text{………………….eq.2.7}$$

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

- **System average interruption duration indices /SAIDI/:** is used for performance measurement of sustained interruption which measures the total duration of an interruption for the average customer during the given time period. This index is responsible for the average service interruption in the system. SAIDI's purpose is to indicate the total duration of an outage when continuous interruption occurs that result in power loss (Karimi et al., 2021).

It gives information on the average amount of time a customer is interrupted and is sometimes referred to as customer minutes of interruption or customer hour.

$$\text{SAIDI} = \frac{SUM\ OF\ CUSTOMER\ INTERUPTION\ DURATION}{TOTAL\ NUMBER\ OF\ CUSTOMER\ SERVED} = \frac{\sum U_i N_i}{\sum NT} \text{ ....eq 2.8}$$

Where, NT is the total number of customers served in the area, is the outage length for event i, and Ni is the number of affected consumers for each interruption event i during the reporting period.

- **Customer Average interruption frequency indices /CAIFI/:** indicates the mean frequency of prolonged disruptions for the customers who are undergoing such incidents. It calculates the typical annual number of disruptions experienced by each customer. It can be calculated by dividing the total number of disruptions by the total number of consumers impacted by the disruption.

$$\text{CAIFI} = \frac{TOTAL\ NUMBER\ OF\ INTERUPTION}{TOTAL\ NUMBER\ OF\ CUSTOMER\ INTERUPTED} = \frac{\sum No}{\sum N_i} \text{ No.....................................eq 2.9}$$

- **Customer Average Interruption Duration indices /CAIDI/:** these indices are used to determine the average time it takes to restore service following an outage. It is the typical amount of time required to get service back to a typical customer after a prolonged outage. This represents the mean length of interruption experienced by those clients over the course of a year. It is calculated by taking the total number of client interruptions during a one-year period and dividing it by the total number of customers who experienced one or more disruptions.

$$\text{CAIDI} = \frac{SUM\ OF\ CUSTOMER\ INTERUPTION\ DURATION}{TOTAL\ NUMBER\ OF\ CUSTOMER\ INTERUPTION} = \frac{\sum U_i N_i}{\sum N_i} = \frac{SAIDI}{SAIFI} \text{.....................eq 2.10}$$

❖ **Average Service Availability Index (ASAI):** shows how much of a customer's time, usually expressed as a percentage, is spent with power during a given reporting period or a year.

$$ASAI = \frac{CUSTOMER\ HOURS\ SERVICE\ AVAILABILITY}{CUSTOMER\ HOURS\ SERVICE\ DEMAND} = \frac{Ni*8760-\sum r_i N_i}{N_i*8760} \text{ ....eq 2.11}$$

❖ **Average Service Unavailability Index (ASUI):** This index is the complementary value of the average service availability index (R. Billinton and R. N. Allan, 1996).

ASUI = 1 – ASAI ....eq 2.12

2.4.2 Load or Energy Oriented Indices

❖ **Expected Energy Not Supplied Index (EENS):** This index represents the total energy not supplied by the system (Abrha et al., 2020).

$$EENS = \Sigma_{k=0}^{n} ri.Li \text{ ....eq 2.13}$$

Where, *L*a (i) is given by:

$$La\ (i) = Lp\ (i)*Lf\ (i) = \frac{Ed(i)}{t} \text{ ....eq 2.14}$$

Where, Lp (i) is a peak load demand,

Lf (i) is the load factor and

Ed (i) is the total energy demanded in the period of interest t.

❖ **Average Energy Not Supplied Index (AENS):** shows the average amount of energy that the system does not supply.

$$AENS = \frac{Total\ Energy\ not\ suplied}{Total\ number\ of\ Customers\ served} = \frac{\sum La(i) U_i}{\sum N_i} \text{ ....eq 2.15}$$

❖ **Average Customer Curtailment Index (ACCI):** shows how much energy each impacted customer is not receiving from the system overall.

$$ACCI = \frac{Total\ Energy\ not\ suplied}{Total\ number\ of\ Customers\ served} = \frac{\sum La(i) U_i}{\sum No} \text{ ....eq 2.16}$$

Where, No is the number of impacted customers, La (i) and Ui, respectively, are the average connected load and the average yearly outage time at load point i.

The reliability performance of utilities is measured in this thesis work using the System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), and Expected Energy Not Supplied (EENS).

2.5 Causes of Power Interruptions

To understand the root causes of these interruptions, interviews were conducted with line technicians, technical and head managers from the utility, and experienced employees knowledgeable about the distribution system.

The interviews were structured to unveil common causes of interruptions in Adama 15KV feeder lines. Insights from these discussions highlighted various factors such as aging infrastructure (poles, equipment, and wires), tree interference, pole and tree failures, overloading, insulation issues, animal interference (including large birds), adverse weather conditions like winds, rain, and lightning-all contributing to power interruptions within Adama distribution system. Additionally, distribution lines are intentionally interrupted for maintenance purposes as part of regular upkeep.

2.5.1 Aging of Pole and Equipment

Information gathered from interviews and on-site visits reveals that the installation of the 15 KV mobile feeder M-1 features an aging distribution system, with most equipment and poles being very old.

- **Poles: -** Based on the site visit and interview findings, the majority of poles along the 15 KV mobile feeder M-1 are old wooden poles, with a few concrete ones. The wooden poles, being susceptible to aging, pose a significant challenge, particularly when they deteriorate and collapse, impacting the support structure. This degradation of the pole roots is particularly problematic in lower-lying areas where pole collapses occur frequently.
  The age of poles in a distribution line significantly impacts the system's reliability. As poles age, their structural integrity deteriorates, leading to increased risks of failures and outages. Wooden poles may rot or become infested with insects, while steel poles can corrode, and concrete poles may develop cracks. These issues make aged poles more susceptible to breaking, leaning, or tilting, especially under mechanical stress from environmental factors like wind and storms.

The discussions highlighted that power interruptions are primarily caused by failing poles in these areas, as the distribution system lacks feeder sections or zones that could divide customers based on geographical areas, customer numbers, or environmental considerations.

Figure 2. 3 Feeder M-1 aged wooden pole structure on the existing system

- **Equipment Aging: -** The aging of power distribution system equipment leads to significant interruptions for customers. According to interview responses, aging wires often break and fail to properly ground, connecting instead to the arm of the insulator or another phase line, causing grounding or short-circuit issues. Additionally, aging insulators on each pole develop cracks, contributing to grounding problems.

- **Tree: -** In the Adama city, there are numerous large trees near the feeders, some of which extend branches or grow to heights that lead to contact with phases or shorting between two or more phases. Falling trees during windy conditions or due to improper pruning by customers also interrupt power from the substation, causing feeder circuit breakers to trip as trees create short circuits or grounding issues.
- **Animals: -** As per information from utility workers, animals can significantly affect the reliability of distribution lines, often causing interruptions and damage. Birds,

squirrels, and other wildlife frequently come into contact with power lines and equipment, leading to short circuits and outages. Birds can perch on power lines and nest on poles, sometimes bridging the gap between live wires and causing faults.

2.6 Types of Faults Recorded at Adama Mobile Substation

- **Distribution Permanent Earth Fault [DPEF]:-** A type of fault, arises when one of the three-phase lines makes direct or indirect contact with grounding, persisting for a significant period after its occurrence. As revealed in interviews, this fault commonly stems from trees touching the phase lines, broken conductors failing to ground, contact with nearby low voltage or telecommunication poles, phase lines loosening and slipping from insulator arms, insulators cracking or being broken by children, and weather conditions like rain and wind causing contact with trees.

- **Distribution Permanent Short Circuit Fault [DPSC]:-** A permanent short circuit fault occurs when two or more different feeder phase lines make contact with each other. This results in an excess of current traveling along an unintended path in the electrical circuit, potentially causing circuit damage, fires, or explosions. Short circuits are a common cause of power failures.

  According to interviews, the causes of DPSC in Adama city distribution systems include aging pole failures, strong winds, broken wires failing on phase lines due to aging, loose distribution lines contacting nearby lines, the loss of fixation of two or more insulations due to deteriorated pole edges, careless tree cutting leading to failures on lines, broken tree branches, and animals rubbing against aging poles.

- **Distribution Temporary Earth Fault [DTEF]:-** The term DTEF refers to a fault that is transient and doesn't persist for long periods, often causing circuit breakers to trip. DTEF incidents are common during the rainy season, where steel structures supporting the distribution lines come into contact with water, leading to old insulators cracking and resulting in interruptions.

  Additionally, strong winds can push feeder lines against trees or nearby poles such as telecommunication or low-voltage poles. In certain areas of Adama city, high-voltage and medium-voltage lines are closely packed on towers, sometimes even on the same pole, increasing the risk of lines being pushed or pulled by wind forces. This close proximity can create forces of attraction or repulsion between the lines, leading to contact with trees, towers, etc., and ultimately causing an earth fault.

- **Distribution Temporary Short Circuit Fault [DTSC]:-** According to interview responses, DTSC incidents are short-lived and don't persist for long durations. They typically occur due to contacts between distribution lines during windy seasons, interactions with large birds, resulting in momentary short circuits involving two or more phases. These contacts cause the breaker to trip, but they are transient and don't remain connected for extended periods.

  Similar events happen when trees sway in the wind, creating brief contacts with distribution lines. When a tree simultaneously touches two lines, it can lead to a line-to-line fault. Additionally, interruptions can occur due to birds colliding with lines or during stormy rainy seasons.

- **Distribution Line Overload [DLOL]:-** Occurs when the current flowing through a line exceeds its rated capacity. This can lead to a rise in temperature, causing fuse elements to melt or blow, insulation to melt, and conductors to disconnect. In Adama city, many low-voltage sides of distribution transformers experience overload effects.

  In this context, many low-voltage sides of distribution transformers are directly connected to loads without fuses or protective devices, leading to frequent fuse blowouts due to overloading. According to information gathered from interviews, DLOL is a significant cause of power outages in Adama mobile substation. The demand for high electrical power can overload the existing power grid, resulting in excessive tension on distribution lines and eventual disconnection of power networks.

  The central areas of towns, particularly around distribution transformers, have a high concentration of business centers, small to medium-sized micro-enterprises, and residential customers. These customers collectively consume electric power, often simultaneously, and the extent of their power consumption is often unknown, contributing to distribution line overloads.

- **Operational Interruption [OP]:-** When working on radial distribution systems, it's essential to temporarily interrupt customer service. According to explanations from Adama substation workers, interruptions in feeder lines are carried out voluntarily when requested by utility technicians for maintenance, load transfer, erecting new transformers, or installing new feeder lines for additional areas. This is necessary because the feeder lacks section divisions or zones, and in some cases, transformers are directly connected to the 15KV feeder and low-voltage side without isolators and fuses.

Based on site visits and interview responses, low-voltage lines are directly linked to transformers due to overload effects, leading to situations where fuses are absent. Consequently, for maintenance and installation on the low-voltage side, line technicians request substation operators to interrupt power for the entire feeder without prior notification to customers.

2.7 Distribution System Protection

Power system protection is a vital aspect of electrical power management, focused on safeguarding power systems against faults by isolating faulty components from the broader electrical network. It's crucial to ensure seamless coordination among protection devices to minimize customer disruptions during faults, thereby enhancing the reliability of the distribution system. Essentially, power system protection aims to maximize the safety and resilience of electrical energy distribution in the face of potential failures and risks (Kuphaldt, 2022).

The following is the primary goal of power system protections:

- To minimize the number of consumers affected by the fault,
- To minimize the duration of a fault and the outage.

The following are the distribution system protection's secondary goals:

- To disconnect faulted lines, transformers, or other apparatus.
- To get rid of safety risks as quickly as possible.
- To protect the system from unnecessary service interruptions and disturbances.
- To restrict systemic service disruptions to the smallest feasible area.
- To safeguard users' equipment.

Overhead distribution systems can experience two types of electrical faults: transient (temporary) faults and permanent faults. Typically, around 75-90% of all faults are temporary. Transient faults occur when phase conductors momentarily contact each other or the ground due to factors like trees, birds, high winds, lightning, or flashovers. These faults are resolved by temporarily interrupting the service to extinguish the power arc. To minimize fault duration, high-speed tripping and automatic reclosing mechanisms are employed, controlled by relays or circuit breakers. The settings for breaker speed, relay operation, and recloser characteristics are carefully chosen to halt the fault current before it becomes a permanent fault due to a series fuse.

The following are examples of permanent faults that need to be fixed by the repair team:

- Trimming tree limbs off the line.
- Restoring service by manually shutting off a circuit breaker or recloser.
- Replacing blown fuses, burned-out conductors, and any other damaged equipment.

To minimize the impact of faults on customers, protective apparatus is strategically placed along the feeder main, at branch tap points, and critical locations on branch circuits. Permanent faults are addressed using fuse cutouts installed at sub-main and lateral tap points, reducing the number of affected customers and aiding in pinpointing the fault location. Typically, only the main feeder and feeder tie line lack fuse protection; instead, circuit breakers and reclosers within the substation safeguard against faults on feeder and tie lines (Chandhra Sekhar et al., 2017).

2.7.1 Distribution System Protection Devices

Various equipment is employed for safeguarding distribution networks, with the choice of protection contingent on factors such as the system element and voltage level. While there aren't specific standards for overall distribution network protection, we can provide a general overview of how these systems operate.

The most popular devices for safeguarding distribution systems are: -

- Reclosers
- Fuses
- Sectionalizers
- Overcurrent Relays

Reclosers: - A recloser is a device that can detect phase and phase-to-ground overcurrent conditions, interrupting the circuit if the overcurrent persists beyond a set time, and then automatically reclosing to restore power to the line. If the fault persists, the recloser will remain open after a preset number of operations, isolating the faulty section from the rest of the system. In overhead distribution systems, where the majority of faults are temporary and short-lived, reclosers play a crucial role in preventing unnecessary service interruptions. Before shutting out the sequence with a final open operation, they are usually made to complete up to three open-close operations. Manual closure is also an option if necessary. The counting mechanisms track operations of the phase or ground-fault units, which can also be triggered by externally controlled devices with appropriate communication capabilities. Reclosers typically have three characteristic curves for operating time and current: two delayed and one fast. A typical set of time/current curves for reclosers is displayed in Figure 2.4. New reclosers, however, might incorporate keyboard-selectable time/current curves that let an engineer to create any curve to meet phase and ground fault coordination criteria. This eliminates the need to replace components by enabling the features to be reprogrammed to meet the unique needs of a customer (Timalsena, 2020).

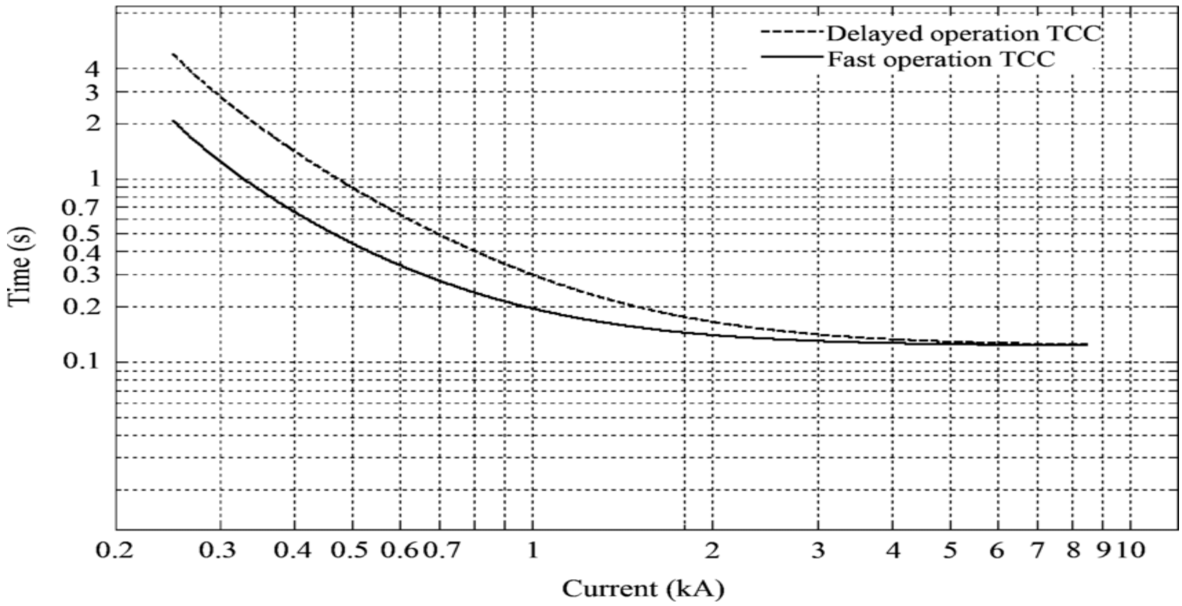

Figure 2. 4 Typical set of time/current curves for recloser

It's crucial to have well-coordinated protection devices to swiftly disconnect the smallest section of a circuit during a fault, minimizing disruptions to customer supplies. Typically, the time characteristics and operation sequence of a recloser are chosen to align with upstream mechanisms toward the power source. Once the recloser's size and operation sequence are set, downstream devices are adjusted for proper coordination. A typical recloser operation for a permanent fault is illustrated in Figure 2.4. The initial action is instantaneous to clear temporary faults before any damage occurs. Subsequent operations are timed with preset settings. If the fault is permanent, the time-delayed operation ensures that other protection devices closer to the fault open, reducing the amount of network disconnected (Bhugwandeen & Saha, 2018).

Ground faults are typically less critical than phase faults, highlighting the importance of ensuring that the recloser has sufficient sensitivity to detect them. One approach is to utilize current transformers (CTs) connected in a way that cancels out normal residual current, resulting in an almost zero residual current under normal conditions. The recloser should be set to trigger when the residual current surpasses a specific threshold, which typically happens during ground faults.

Reclosers fall into the following categories: -

- Single phase and three phase;
- Electronic or hydraulic operation mechanisms;
- Oil, vacuum or SF6.

Single-phase reclosers are employed in situations where the load predominantly involves a single phase. In such scenarios, if a single-phase fault occurs, the recloser is designed to permanently disconnect the faulty phase, ensuring continued power supply on the unaffected phases. On the other hand, three-phase reclosers are utilized when it's necessary to disconnect all three phases to prevent unbalanced loading on the system.

A disconnecting coil is incorporated into reels with hydraulic operating mechanisms in series with the line. The coil triggers a piston, which opens the recloser's primary contacts and breaks the circuit, when the current reaches a preset threshold. The oil flow in various chambers controls the time characteristic and operating sequence of these reclosers.

On the other hand, reclosers that use electronic-type control mechanisms are usually found outside and obtain their current signals from a CT-type bushing. A delayed shot is started when the current exceeds the predetermined threshold, and finally the reclosers control mechanism receives a tripping signal. Based on its setup, the control circuit subsequently controls the mechanism's successive opening and closing. A coil or motor mechanism is used by reclosers with electronic operating systems to shut the connections.

Oil is used in oil reclosers as the main insulation material as well as to put out the arc. This oil can be used in the control mechanism as well. Conversely, hoover and SF6 reclosers have the benefit of requiring less upkeep.

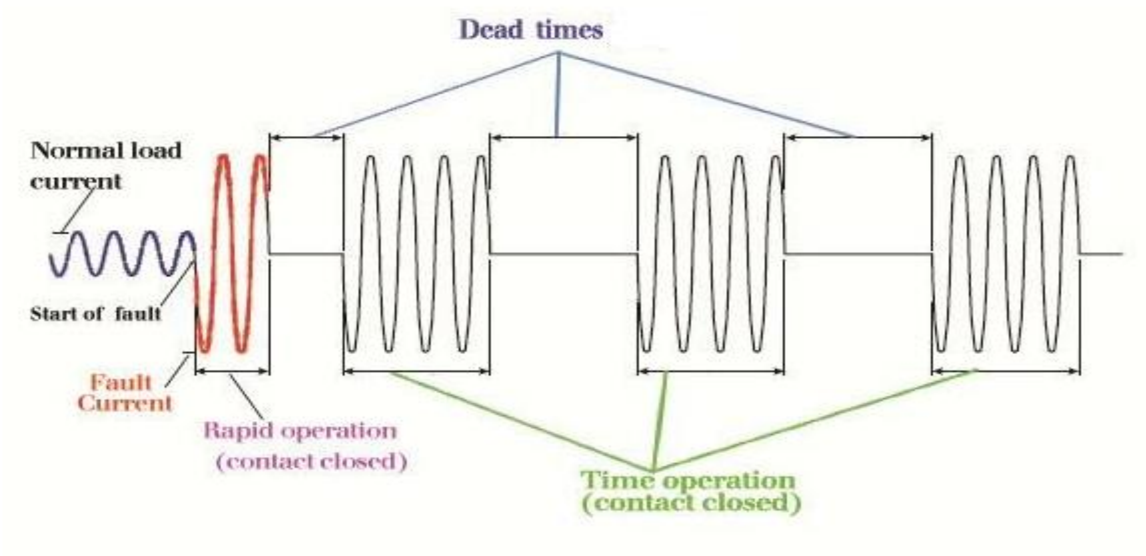

Figure 2. 5 Typical sequence for recloser operation

Reclosers are utilized in a power distribution system in the following locations:

- To offer a circuit's primary protection in substations.
- In main feeder circuits, to enable the sectioning of lengthy lines and avert the loss of the entire circuit in the case of a fault near the circuit's terminus.
- In branches or spurs, to stop the main circuit from tripping as a result of spur faults.

The following considerations must be made while installing reclosers:

- System voltage
- Short circuit level
- Maximum load current
- Minimum short-circuit current within the zone to be protected by the recloser
- The sensitivity of operation for ground faults

The recloser's voltage rating and short circuit capacity must match or exceed the values at the installation point. Similarly, the current capability of the recloser should be in line with the maximum load current of the circuit. Additionally, it's crucial to verify that the fault current at the protected line's end is sufficiently high to trigger the recloser's operation.

Fuses: - A fuse acts as an overcurrent protection device, containing an element that heats up when current passes through it and is destroyed if the current surpasses a set value. A properly chosen fuse should break the circuit by destroying its element, extinguish any arc formed during this process, and maintain an open circuit with nominal voltage across its terminals, ensuring no arcing occurs across the fuse element (Chandhra Sekhar et al., 2017).

The ejection principle governs how the majority of fuses used in distribution systems work. Their components are a fusible element and a de-ionizing fiber-lined tube that is intended to contain the arc. During a fault, the fusible element melts, heating the interior fiber and generating de-ionizing gases that collect within the tube. As a result, the arc is compressed and expelled from the tube, and the gas escaping from the tube ends causes the particles sustaining the arc to be expelled as well. This process extinguishes the arc as the current reaches zero.

After the current passes through zero, the turbulence in the tube and the presence of de-ionizing gases prevent the fault current from re-establishing. The operational zone is defined by two factors: the minimum melting time required for the element to fuse (lower limit) and the maximum total time for the fuse to clear the fault (upper limit).

The following information is required in order to select a suitable fuse for use on the distribution system:-

- Voltage and insulation level.
- Type of system.
- Maximum short-circuit level.
- Load current.

The above four factors determine the fuse nominal current, voltage and short circuit capability characteristics (Kumar et al., 2020).

Sectionalizes: - A sectionalizer is an automatic device that, when the fault current has been blocked by an upstream breaker or recloser, isolates the defective parts of a distribution circuit. Sectionalizers are usually put after a recloser. Since they are unable to break fault current on their own, they need a backup device that can do so.

These devices monitor the number of recloser operations during fault conditions. Once a preselected number of recloser openings is reached and the recloser remains open, the sectionalizer activates, isolating the faulty section of the line. This allows the recloser to close and restore power to areas unaffected by faults. In cases of temporary faults, the sectionalizers operating mechanism resets after isolation.

Sectionalizers are available in single or three-phase configurations and feature hydraulic or electronic operating mechanisms. Unlike protective devices with current/time operating characteristics, sectionalizers are used in situations where the operating curves of two protective devices are closely aligned, and adding an extra coordination step is not feasible.

In sectionalizers with hydraulic operating mechanisms, the line is connected in series with an operational coil. The coil drives a piston in the case of an overcurrent event, and the displacement of oil across the sectionalizer chambers causes the circuit to open and the current to drop to zero, activating a counting mechanism. The sectionalizer connections are opened by pretension springs following a set number of circuit openings. Sectionalizers of this kind can be manually closed.

On the other hand, sectionalizers with electronic operating mechanisms offer more operational flexibility and easier configuration. They measure load current via CTs, with the secondary current directed to a control circuit that tallies recloser or interrupter operations. Subsequently, a tripping signal is sent to the opening mechanism. These sectionalizers can be constructed with manual or motorized closing capabilities.

When choosing a sectionalizer, the following elements need to be taken into account:

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

The maximum voltage or load values at the installation point should be equal to or greater than the nominal voltage and current ratings of the sectionalizer. Furthermore, at the installation location, the sectionalizer short circuit capacity (momentary rating) must match or exceed the fault level. Making sure the connected interrupter's maximum clearing time doesn't go above the sectionalizer short-circuit rating is vital.

Coordination factors to consider include the starting current setting and the number of operations of the associated interrupter before it opens.

Overcurrent Relays: - The overcurrent relay is a type of relay that triggers only when the current exceeds its predetermined setting. It safeguards power system equipment from fault currents.

The following types of overcurrent relays are distinguished based on their operating time:

- Instantaneous Overcurrent Relay: - The relay lacks intentional time delay for activation. Its contacts close immediately when the current surpasses the set operational value, with a very short time interval between pick-up and contact closure.

  The primary advantage of the instantaneous relay is its swift response time. It triggers instantly when the current exceeds the relay setting, operating only when the impedance between the source and relay is lower than specified.

  Its key feature is rapid operation, providing protection against earth faults and circulating currents. The instantaneous overcurrent relay is typically installed in outgoing feeders.

- Inverse time Overcurrent Relay: - The relay activates based on an inverse relationship between its operating current magnitude and the energized quantities' magnitude. As current increases, the relay's operating time decreases. The relay's operation is contingent upon current magnitude.

  The characteristic curve depicting the relay's behavior is illustrated in the Figure 2.6. It remains inactive when current values are below the pick value. This type of relay is commonly employed to safeguard distribution lines. Inverse time relays are categorized into three types.

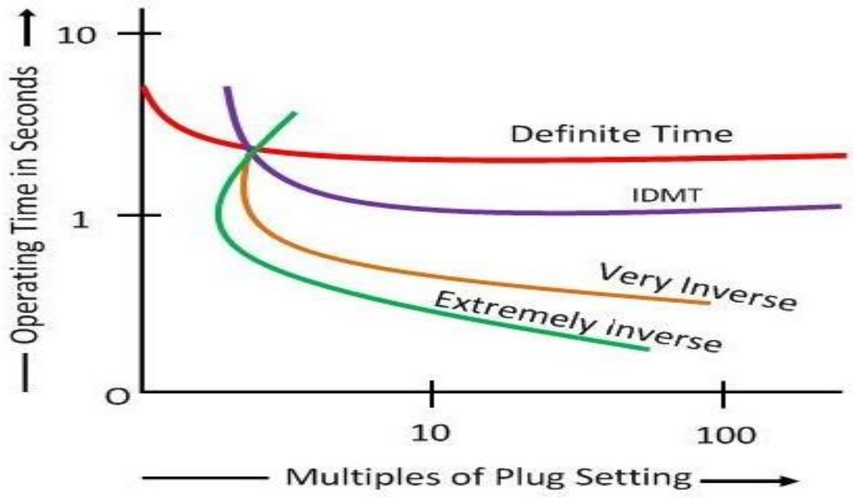

Figure 2. 6 Characteristics of varies overcurrent relays

- Definite Time Overcurrent Relay: **-** Definite time overcurrent relay is used as a backup protection of distance relay of transmission line with time delay, backup protection to differential relay of power transformer with time delay and main protection to outgoing feeders and bus couplers with adjustable time delay setting (Brown, 2017).

  The settings of this relay type can be customized at various points within the network to ensure that the breaker nearest to the fault is tripped with the shortest delay. Subsequently, the other breakers in the direction toward the upstream network are tripped successively with longer time delays.

- Inverse Definite Minimum Time Relay: **-** The relay that exhibits an operating time roughly proportional to the fault current is called an Inverse Definite Minimum Time (IDMT) relay. Its operating time is regulated by adjusting the time delay setting. The IDMT relay utilizes an electromagnetic core, as it can readily saturate for currents larger than the pickup current. It is commonly employed for protecting distribution lines.

- Very Inverse Relay: - The relay with an inverse characteristic greater than IDMT is commonly employed in feeders and long transmission lines. It is specifically used in locations where the short circuit current magnitude decreases rapidly due to the considerable distance from the power source. This relay type is designed to detect fault currents regardless of the fault location (Eaton, 2017).

- Extremely Inverse Relay: - The characteristic time of this relay is significantly longer compared to IDMT and very inverse relays. It is primarily utilized for protecting cables, transformers, and other equipment. The relay can trigger instantaneously when the current exceeds the preset threshold, ensuring swift operation even during fault conditions. Its main purpose is to detect overheating in machinery.

  Inverse time relays find application in distribution networks and power plants, offering rapid operation during fault scenarios due to their fault time characteristic.

2.8 Reliability Cost/Worth

When there's a power interruption, both the utility and customers incur costs due to the interruption. Customers have a willingness to pay a certain amount of money to avoid such interruptions, known as the customer cost of reliability. These costs can be tangible or intangible, and there's also an opportunity cost involved. However, evaluating the interruption cost from the customer's perspective can be challenging.

To enhance reliability, utilities must strike a balance between the costs of reinforcing reliability and the costs incurred by customers due to poor reliability. The optimal level of reliability is achieved when the combined costs of the utility and customers are minimized (Kumar et al., 2020). Figure 2.7 illustrates the costs associated with both customers and utilities, and it indicates that high reliability is attained by making costly investments.

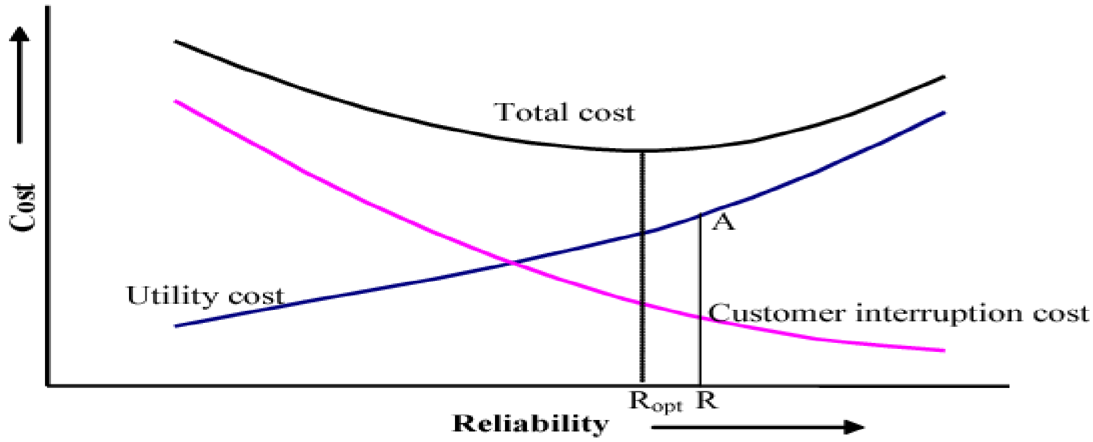

Figure 2. 7 Reliability worth and reliability cost

2.9 Related Works

In each modern economy, electricity is an essential component. For a nation to flourish economically and develop economically, it is essential that a dependable power supply be available at an affordable price. Therefore, electric power utilities over the globe strive to provide customers with a reliable and affordable service while meeting their needs as economically as feasible. The electricity utility must change in order to satisfy consumer needs, and the distribution substation system must be updated, run, and maintained appropriately (Joshi et al., 2018).

The following studies on the electric power distribution substation system are presently being conducted in order to satisfy and meet consumer needs; some of these are mentioned below:

A paper presented by (Makarov & Moharari, 2010) describe the creation of a new dependability and security index that takes into account both direct and indirect qualities. Direct characteristics address the possibility of undersupplying a load in a variety of situations. Unwanted situations including circuit overloads, voltage issues, poor stability margins, area interchange violations, inadequate generation reserves, impractical power flows, etc. are addressed by indirect characteristics. Even while indirect traits don't always result in load losses, they nonetheless indicate a narrowing security/reliability margin. This reduced margin could result in severe system failures (voltage collapse), unanticipated events (cascading outages), and occasionally even barely measurable and predicted load losses (by corrective actions, islanding, and instability). The new index uses a fuzzy logic-like technique to combine many contributing aspects to provide a more thorough answer regarding the overall level of security and reliability in the system. It is made to adapt to different power companies' goals and admittance policies with relation to specific features that are incorporated into the index. The general index can be used to relate to or generate various existing indices, such as unexpected lost energy, system minutes, stability margins, and others. The security and dependability index is practical, adaptable, and efficient, and it satisfies this purpose.

(Kim, 2019) delivered a paper on ageing power systems. When evaluating the reliability of a power system, component ageing is a crucial factor. It arises from a variety of causes, including equipment damage, erosion, and degeneration. For whatever reason, most equipment may eventually exhibit an ageing trend. Ageing may therefore lead to load reductions due to an increased likelihood of system failure. Therefore, ageing features must be considered while evaluating system dependability or economic feasibility. High-reliability power systems at a reasonable price could be advantageous in a competitive market. The impact of ageing on the assessment of composite power system reliability is demonstrated in this thesis.

The application of reliability enhancement solutions to test systems has been assessed from a socio-economic perspective, according to a paper presented by (Ahmad & Asar, 2021). The average annual supply interruption cost to the customers served by the test system has been estimated for each of the alternative options applied in the test system. Additionally, an estimate of the highest yearly capital cost related to each solution's deployment has been provided. Then, if the capital cost of implementing a reliability enhancement solution is less than the reduction in the cost of disruption to the consumers as a result, the solution is seen to be justified socioeconomically.

A paper presented by (Kovalev & Lebedeva, 2019), discussed that a distribution recloser is intended to stop fault current. In an effort to clear the problem, it is made to "reclose" on the fault multiple times in a predetermined order. Increasing reliability is one of the guiding principles behind the use of reclosers.

A comparative analysis of the gains in distribution reliability that can be obtained by utilizing different outside distribution equipment is described in a work by (Goodin et al., 2004). The use of the most popular kinds of equipment, such as manual switches, automatic sectionalizers, and line reclosers, is covered first. Additionally, quantify the dependability gains that can be attained by utilizing any one of these devices alone or in combination. The study comes to the conclusion that all gadgets provide increased reliability. SAIDI will increase with switches. In tie-point situations where feeder ties are feasible, midpoint switches are also quite valuable. With the exception of the reclosers' greater improvement for MAIFI, sectionalizes and reclosers function reasonably similarly for the different setups.

A paper presented by (F. R. Islam and K. A. Mamun, 2019), has discussed the possible application of reclosers to increase power reliability. According to their discussion, in the event that a failure is transient in nature, the recloser aids in the prompt restoration of service, hence allowing the outage period to be reduced.

It is well known that the length of the feeder directly and significantly affects the value of reliability indices; that is, variations in the feeder's length (resulting from the use of new substations) alter the failure rate, which in turn affects variations in the reliability indices' value. Nevertheless, the impact of feeder length variation on reliability index values has not received much attention in the research studies or review papers published thus far on power reliability enhancement.

The reviewed literature highlights significant advancements in understanding distribution system issues, particularly through reliability indexes like SAIFI, SAIDI, and EENS. However, a notable research gap exists in enhancing the reliability of Adama city's distribution system, specifically for the Adama mobile substation feeder M-1. This study addresses the gap by proposing an integrated approach that combines sectionalizers, reclosers, and tie-switch strategies to improve the feeder’s reliability, thereby enhancing the overall distribution system performance.

CHAPTER 3. MATERIALS AND METHODS

3.1 Introduction

This study employs both measurement and simulation techniques. All necessary distribution system parameters, including transformer rating (KVA), feeder length, feeder impedance per kilometer, feeder resistance per kilometer, and feeder reactance per kilometer, were collected from Ethiopian electric authority organizations EEU and EEP.

The research followed the methodology outlined below:

- **Literature survey**: A number of journals, article and to be familiar with the concepts of reliability assessment and enhancement of a distribution system and other related works have been reviewed. Most of the papers gives clear indication of how an electrical distribution system reliability can be improved and the reduction of down-time of the feeders in the system.
- **Data collection**: Primary data has been collected by the direct involvement of the researcher, staffs of EEU from Adama District, EEP from Adama substation and customers for the purpose that is intended to be done. During the site visit, the primary data necessary for this study were the length of the feeder, rating and type of distribution transformer, topology and layout of the system, conductor type, number of customer connected in each nodes. Assessment of the physical system in the case study area, understanding and adopting the system as a whole. The feeder length, number of poles, conductor size, conductor type and ratings of transformers has been collected from the existing system and the Adama district. Questioners were prepared to identify causes of the unreliability of the distribution system and discussions with assigned workers and consumers. The collected data has been used to clearly analyze the problems of the feeder M-1. In this thesis work, the data can be collected through various methods like surveys, observations, personal interviews and case study.
    - Three years (2013 - 2015 E.C) the interruption, data has been collected from EEP Adama substation which helps to carry out reliability analysis.
    - The rating of transformers, number of customers and feeder length is collected from EEU Adama district.
    - Load of the existing system has been gathered from EEP Adama substation.
    - The collected data is used to clearly analyze the problems of the M-1 feeder.

❖ **Data Analysis:** To perform data analysis on this thesis the data generated analyzed by using different methods like:-

- Representation of the primary distribution system using single line diagram
- Developed a model for the simulation of reliability analysis
- Analysis of the reliability indexes by ETAB
- Based on the result of this analysis and assessment, different alternatives are going to be demonstrated.

When analyzing power reliability, key factors such as interruption frequency, interruption duration, connected loads, total number of interrupted customers, and total number of customers served are examined. This chapter presents the collected failure data and essential electrical information of power system equipment necessary for reliability analysis. These data are analyzed to evaluate the current reliability status of the Adama substation feeder M-1 and identify the primary issues causing interruptions.

3.2 Description of Site Location

The study is being conducted at Adama town, a city located in Ethiopia's central Oromia region. Adama is surrounded by East Shewa Zone and forms a unique zone within Oromia. Situated 99 miles southeast of Addis Ababa, at a height of 1712 meters, it is located at 8.54°N 39.27°E. The city is situated between the Great Rift Valley to the east and the foot of an escarpment to the west.

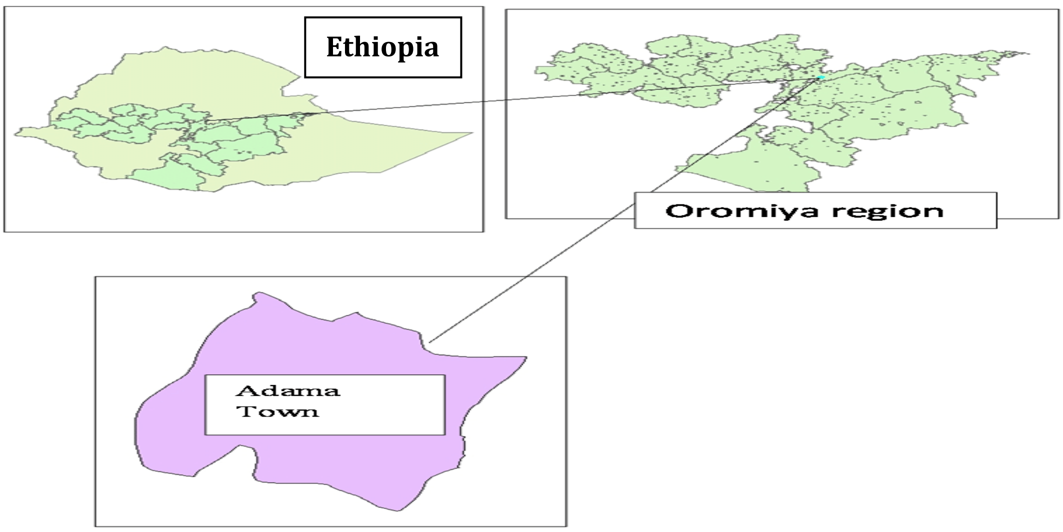

Figure 3. 1 Map of study area

3.2.1 Adama Substation

The Adama substation receives electrical power from the Koka hydro power plant, Adama Wind Farm 1 & 2, and Awash Melaksa hydro power plant, supplying 132 kV via transmission lines to three power transformers. The first two power transformers are 25 MVA 132 kV/15 kV units, which take 132 kV as input and output to seven outgoing 15 kV feeder lines: Line-1, Line-2, Line-3, Line-4, Line-5, Line-6, and Line-7. The third unit is a 50 MVA 132 kV/15 kV mobile power transformer, which also takes 132 kV as input and outputs to six outgoing 15 kV feeder lines: Mobile-1, Mobile-2, Mobile-3, Mobile-4, Mobile-5, and Mobile-6.

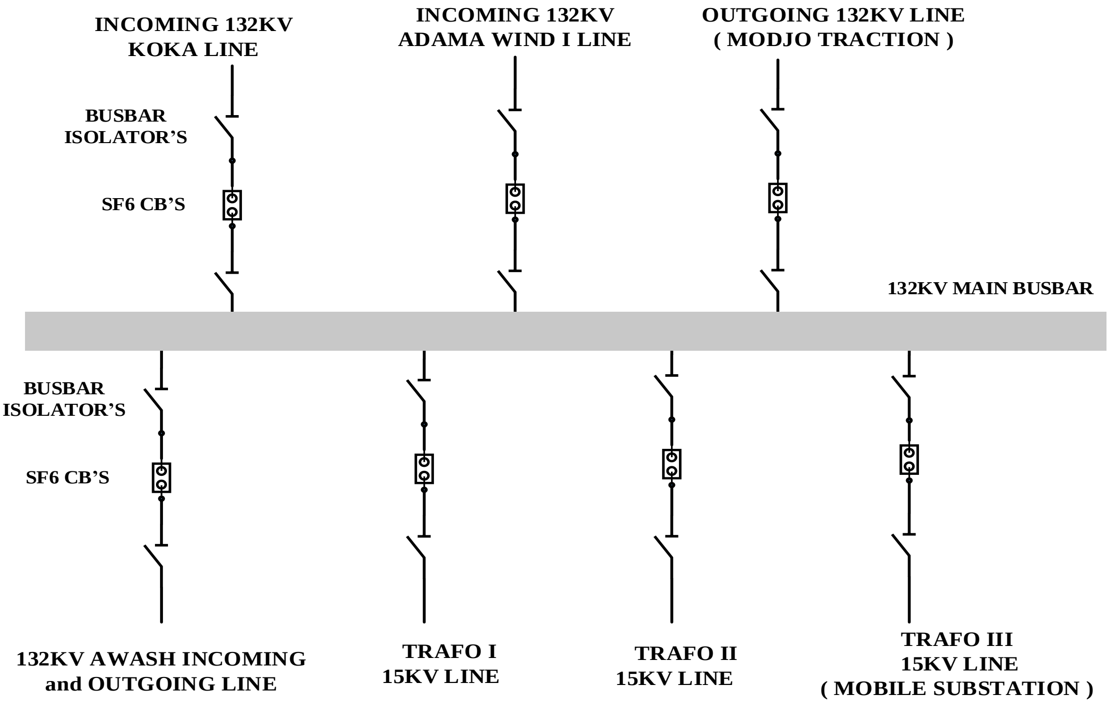

Figure 3. 2 Single line diagram of Adama substation

3.2.2 Adama Old Substation

The Adama old substation is equipped with two 25 MVA 132 kV/15 kV power transformers. These transformers receive 132 kV as input and distribute power through seven outgoing 15 kV feeder lines: Line-1, Line-2, Line-3, Line-4, Line-5, Line-6, and Line-7.

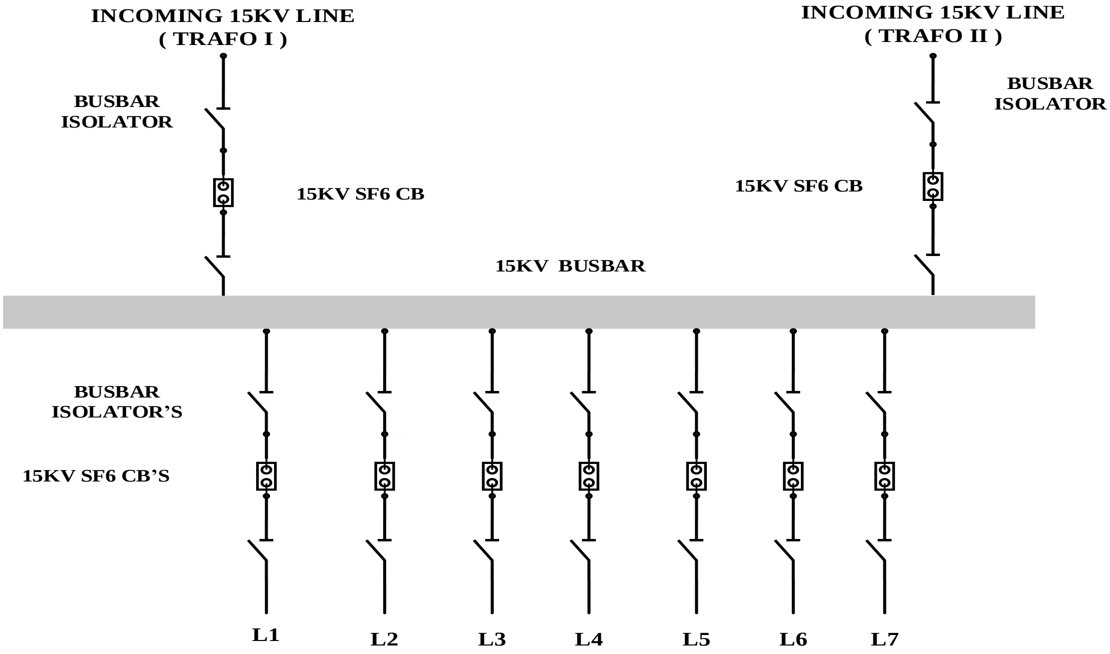

Figure 3. 3 Single line diagram of Adama old substation

3.2.3 Adama Mobile Substation

The Adama mobile substation is equipped with a single 50 MVA 132 kV/15 kV power transformer. This transformer receives 132 kV as input and distributes power through six outgoing 15 kV feeder lines: Mobile-1, Mobile-2, Mobile-3, Mobile-4, Mobile-5, and Mobile-6.

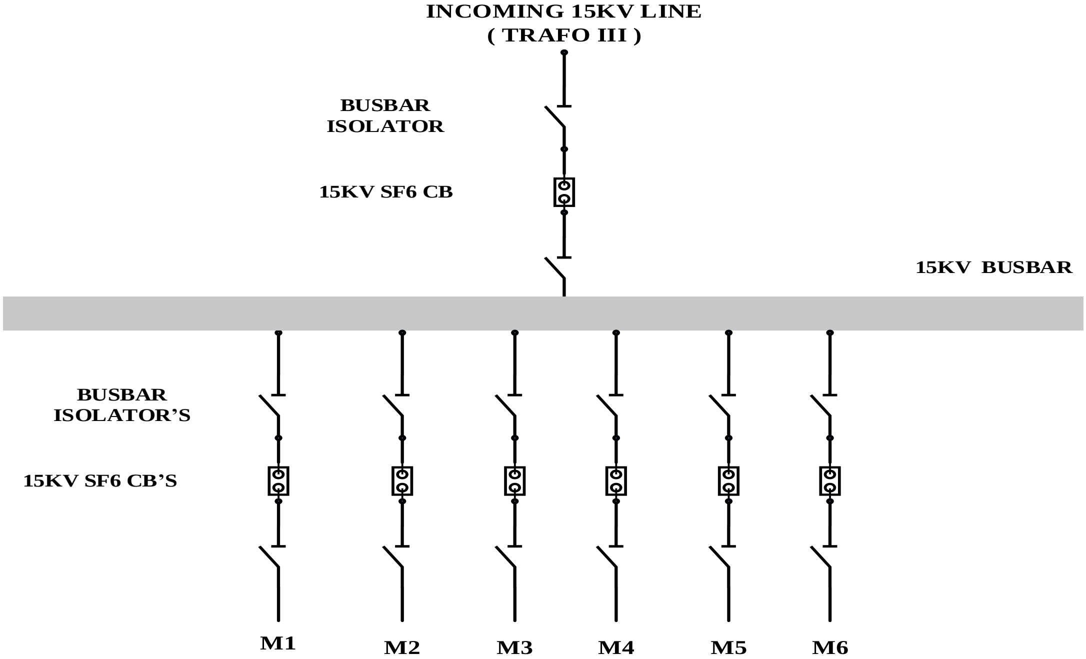

Figure 3. 4 Single line diagram of Adama mobile substation

3.2.4 The Case Study of Mobile Feeder M-1

This thesis focuses on Adama mobile feeder M-1 as its case study, a radial distribution system that efficiently delivers electrical power from the Adama substation to customers. The service center managed by Adama 01 CSC serves approximately 40,000 customers, with 17,425 of them connected to the mobile feeder M-1. These customers include owners of large hotels, small restaurants, micro-industries, government administrative offices, schools, colleges, hospitals, clinics, and some factories.

Mobile feeder M-1 is structured into various laterals, each further subdivided into several sub-laterals supplying feeders to distribution transformers. The primary feeders leading to distribution transformers are three-phase, three-wire systems operating at 15KV. On the low-voltage side after the distribution transformers, the setup consists of three-phase, four-wire circuits or single-phase, two-wire circuits.

3.3 Data Collection

Data collection is a critical component of this study, involving the systematic gathering of information necessary for analyzing and improving the reliability of the distribution system.

3.3.1 Primary Data

The primary data for this study was gathered directly by the researcher and employees of the Adama district electric utility, Adama substation and Adama 01 customer service center, ensuring the reliability of the evaluation. This involved on-site surveys to collect essential information such as feeder length, total number of transformers, transformer rating and type, total number of customers, system topology and layout, conductor specifications, and considerations regarding topography and environmental conditions.

3.3.1.1 Feeder Length

A fundamental factor incorporated into the design of the current system using software (ETAP 19.0.1) is the length of the line. The entire feeder, spanning up to 44.04 km, is divided into segments according to the placement of tap points and transformers.

Table 3. 1 Line data for feeder M-1

No.	Feeder Name	Network Name	Line Specific Name	Primary Voltage (KV)	Conductor Type (mm^2)	Line Distance (KM)
1	Mobile-1	Network 1	National Defense	15 KV	AAC 50mm^2	9.26 KM
2	Mobile-1	Network 2	Industry			5.86 KM
3	Mobile-1	Network 3	18 Kebele			9.08 KM
4	Mobile-1	Network 4	40 Meter			4.18 KM
5	Mobile-1	Network 5	Gende-Hara			6.31 KM
6	Mobile-1	Network 6	Muslim Cemetery			9.35 KM
Total						44.04 KM

3.3.1.2 Transformer and Load

The second set of data needed for ETAP 19.0.1 for distribution system analysis includes transformer ratings, their capacity, and the load they carry. Information on the total number of transformers along with their respective loads is gathered specifically for mobile feeder M-1.

Table 3. 2 Partial transformer data with its load rating

No.	Transformer Name	Rated Power (KVA)	Rated Load (KW)	Remark
1	DT-010599	200 KVA	160 KW	All transformers have primary side voltage of 15KV and secondary side voltage of 0.4KV.
2	DT-010620	200 KVA	160 KW	
3	DT-010617	200 KVA	160 KW	
4	DT-010614	100 KVA	80 KW	
5	DT-010610	100 KVA	80 KW	
6	DT-010607	50 KVA	40 KW	
7	DT-010604	25 KVA	20 KW	
8	DT-010601	200 KVA	160 KW	
9	DT-010594	315 KVA	252 KW	
10	DT-010591	200 KVA	160 KW	
11	DT-010588	50 kVA	40 KW	
12	DT-010586	315 KVA	252 KW	
13	DT-010597	200 KVA	160 KW	
14	DT-010595	200 KVA	160 KW	
15	DT-010592	25 KVA	20 KW	

3.3.1.3 Outgoing Feeder Breaker

The current transformer (CT) rating refers to the maximum current that a CT can handle safely without causing saturation or distortion in its output signal. This rating is typically expressed in amperes (A) and is crucial for ensuring accurate measurement and protection within electrical systems.

Table 3. 3 CT rating of mobile substation outgoing feeders

Feeder Name	Voltage Level	CT Rating	CB Type
Mobile M-1	15 KV	800/1 A	SF6 Gas
Mobile M-2			
Mobile M-3			
Mobile M-4			
Mobile M-5			
Mobile M-6			

3.3.2 Secondary Data

Secondary data was gathered from the Adama substation, covering a three-year period from 2013 to 2015 E.C., focusing on interruption data from six outgoing 15 KV feeder lines (M-1, M-2, M-3, M-4, M-5, and M-6) associated with the 50 MVA, 132/15 KV mobile power transformer. The data includes the frequency and duration of interruptions for each feeder line, as detailed in Tables 3.4 and 3.5, which present the total frequency and duration of sustained interruptions at the Adama substation.

Table 3. 4 Total frequency interruption of Adama mobile substation from 2013-2015 E.C.

Feeder Name	2013 E.C	2014 E.C	2015 E.C
Mobile M-1	262	203	194
Mobile M-2	172	164	19
Mobile M-3	144	44	19
Mobile M-4	158	130	118
Mobile M-5	71	76	41
Mobile M-6	33	27	17

Table 3. 5 Total duration interruption of Adama mobile substation from 2013-2015 E.C

Feeder Name	2013 E.C	2014 E.C	2015 E.C
Mobile M-1	368.33	264.42	285.61
Mobile M-2	325.07	264.16	18.83
Mobile M-3	243.41	34.17	18.01
Mobile M-4	364.00	179.97	188.41
Mobile M-5	131.77	93.62	35.11
Mobile M-6	131.20	74.24	12.15

3.3.2.1 Types of Faults Recorded Based on Outgoing Feeders

The data collected for this study are secondary data recorded over the past three years, from 2013 E.C. to 2015 E.C., at the Adama substation. During this period, various types of power system faults were frequently observed at the substation. Table 3.6 and 3.7 details the duration and frequency of these faults over the three-year span. An average assessment of the frequency and duration of interruptions was conducted based on the number of occurrences.

Tables 3.6 and 3.7 below illustrate the percentage calculation for both the frequency and duration of interruptions, considering the contribution of each type of fault and their total sum.

Table 3. 6 Analysis of three years' average interruption frequency of faults

No.	Feeder		Fault Type						
			DPEF	DPSC	DTEF	DTSC	DLOL(LDC)	OP	Total
1	MOBILE 1	Avg. Freq.	43	58	26	22	5	65	219
		Avg. Freq. %	19.63	26.48	11.87	10.05	2.28	29.68	100%
2	MOBILE 2	Avg. Freq.	25	36	7	1	11	39	119
		Avg. Freq. %	21.01	30.25	5.88	0.84	9.24	32.77	100%
3	MOBILE 3	Avg. Freq.	23	10	7	3	12	13	68
		Avg. Freq. %	33.82	14.71	10.29	4.41	17.65	19.12	100%
4	MOBILE 4	Avg. Freq.	36	42	9	1	12	36	136
		Avg. Freq. %	26.47	30.88	6.62	0.74	8.82	26.47	100%
5	MOBILE 5	Avg. Freq.	4	5	1	0	9	44	63
		Avg. Freq. %	6.35	7.94	1.59	0.00	14.29	69.84	100%
6	MOBILE 6	Avg. Freq.	2	1	2	0	8	12	25
		Avg. Freq. %	8.00	4.00	8.00	0.00	32.00	48.00	100%

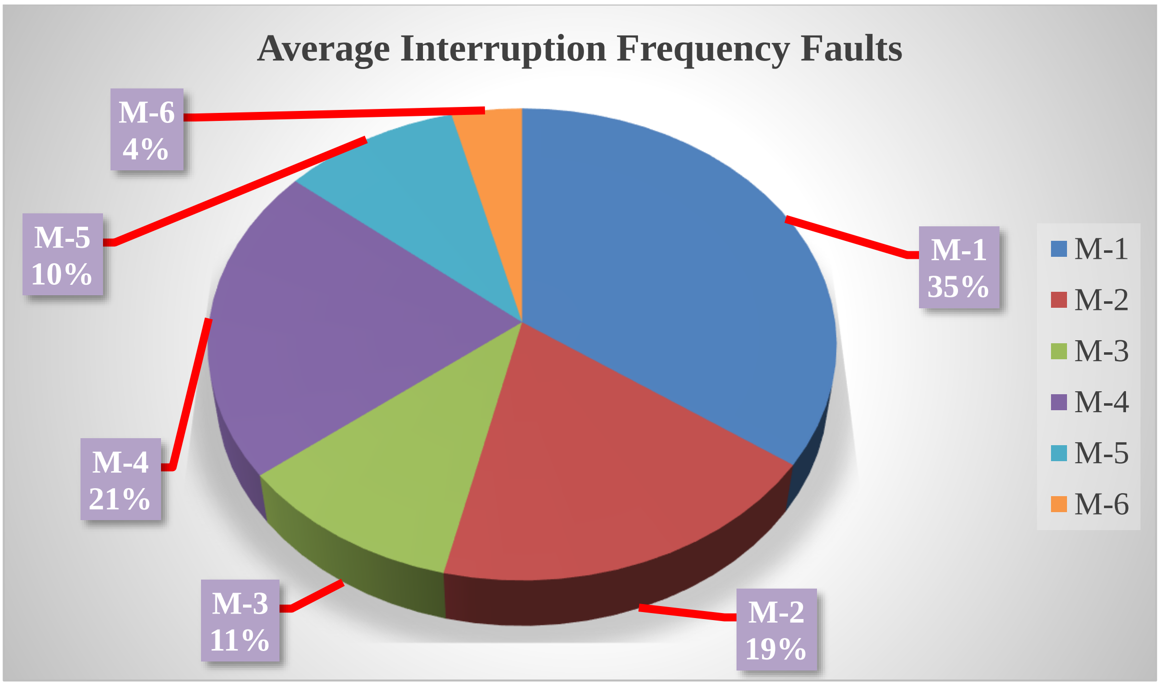

Figure 3. 5 Comparing average interruption frequency of faults on mobile feeders

As illustrated in Figure 3.5, feeder M-1 is clearly the most frequently interrupted feeder when considering interruption frequency.

Table 3. 7 Analysis of three years' average interruption duration of faults

No.	Feeder		Fault Type						
			DPEF	DPSC	DTEF	DTSC	DLOL(LDC)	OP	Total
1	MOBILE 1	Avg. Dur.	73.63	142.15	3.62	4.43	4.89	77.39	306.12
		Avg. Dur. %	24.05	46.44	1.18	1.45	1.60	25.28	100%
2	MOBILE 2	Avg. Dur.	55.95	87.54	2.86	0.18	21.32	34.84	202.69
		Avg. Dur. %	27.61	43.19	1.41	0.09	10.52	17.19	100%
3	MOBILE 3	Avg. Dur.	35.13	24.27	2.60	1.69	22.33	12.52	98.53
		Avg. Dur. %	35.65	24.63	2.63	1.71	22.66	12.71	100%
4	MOBILE 4	Avg. Dur.	81.96	104.87	3.25	0.87	21.78	31.38	244.13
		Avg. Dur. %	33.57	42.96	1.33	0.36	8.92	12.85	100%
5	MOBILE 5	Avg. Dur.	11.54	18.32	0.39	0.00	18.67	37.92	86.84
		Avg. Dur. %	13.29	21.10	0.45	0.00	21.51	43.66	100%
6	MOBILE 6	Avg. Dur.	3.14	4.36	1.86	0.15	16.04	46.99	72.53
		Avg. Dur. %	4.33	6.01	2.56	0.21	22.11	64.78	100%

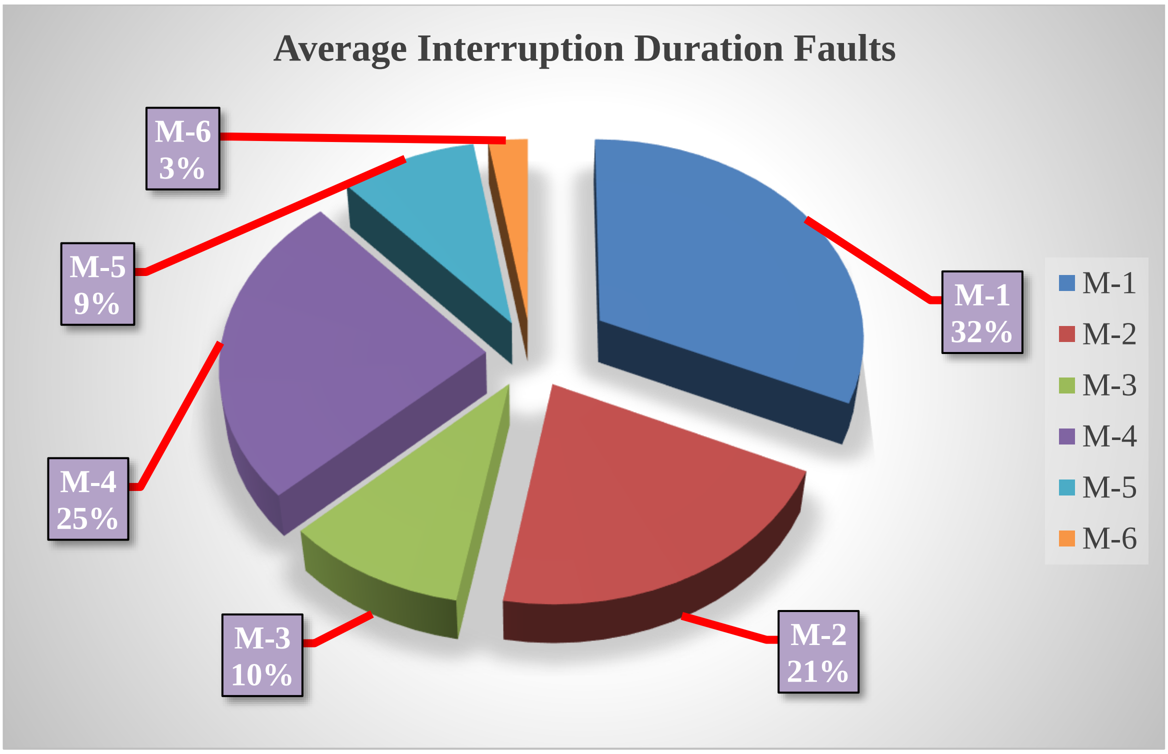

Figure 3. 6 Comparing average interruption durations of faults on mobile feeders

3.4 Reliability Evaluation and Analysis Methods

The assessment of a distribution system's reliability is tied to the consistent delivery of energy from supply points to individual customer load points. Reliability is gauged through indices that consider interruption duration, frequency, the customer base served, interruptions experienced, and connected loads. This chapter presents gathered failure and essential electrical data crucial for reliability analysis. Analyzing this data reveals the current reliability standing of the substation and helps pinpoint the primary interruption issues.

Distribution system reliability is assessed using two primary methods.

- Simulation techniques derived from statistical distribution drawings.
- Methods of analysis based on solving mathematical models.

Monte Carlo techniques are typically time-consuming because they require numerous iterations to achieve precise results. These techniques involve statistical distributions of failure rates and outage times for each component's fault distribution.

In contrast, analytical approaches rely on assumptions about the statistical distribution of failure rates and repair times. Common evaluation methods involve using a set of approximate equations for failure mode analysis.

3.4.1 ETAP (Electrical Transient Analyzer Program)

ETAP is a comprehensive software solution used for the design, analysis, and management of electrical power systems. It offers a wide range of tools for engineers and professionals in the electrical industry to model, simulate, and optimize electrical networks, ensuring reliability and efficiency. Key features of ETAP 19.0.1 include:

- Advanced Simulation Capabilities
- User-Friendly Interface
- Enhanced Reporting Tools
- Compliance with Standards
- Modular Architecture
- Integration with Other Systems

3.5 Data Analysis

The analytical approach employs mathematical equations to compute average reliability indices. This method is straightforward and consumes a relatively small amount of computer resources. It relies on assumptions regarding the statistical distributions of failure rates and repair times (Pradhan et al., 2020).

This thesis collected both primary and secondary data from Adama district utility and Adama substation, respectively. The secondary data, including the frequency and duration of power interruptions in the feeder M-1 distribution system from 2013 to 2015 E.C., were analyzed and interpreted. Additionally, primary data on the total length of the feeder (44.04 KM) were used for load point indices interpretation. By combining the frequency of interruptions, duration of interruptions, feeder length, failure rate and mean time to repair for each failure were calculated (Goodin et al., 2004). Data from the Adama district utility were crucial for computing the failure rate and mean time to repair, and these findings were used to analyze the reliability indices of the feeder M-1, which served as the case study for this thesis.

This study assesses the performance of feeder M-1 using standard reliability indices, which offer insights into customer risk. The results of these indices, obtained through analytical means, are presented exclusively for the feeder M-1 distribution system. The reliability analysis focuses on the electrical distribution system within this feeder line, evaluating its performance through various indices. Specifically, the reliability of the systems feeder M-1 load point is evaluated, considering only sustained interruptions in the calculations. Secondary data from Adama district utility, regarding sustained interruptions in frequency and duration, form the basis of the analysis, focusing solely on system average indices of sustained interruption. Momentary indices are not included, and the interruption recording method extends beyond customer impact to monitor fault resolution across multiple delivery points.

The reliability indices for the feeder M-1 in the distribution system were computed using the ETAP 19.0.1 software package. This software was employed to forecast the reliability indices, requiring values for failure rates and mean time to repair for each component.

3.5.1 Failure Rate

The failure rate of the line per kilometer can be estimated by dividing the total number of outages by the feeder length (km), as shown in the equation below (F. R. Islam and K. A. Mamun, 2019).

$$\mu A = \frac{\text{Total number of interruption}}{\text{Total feeder length (km)} * \text{year}} \quad \frac{int}{km * yr} \text{ ……………………………………………eq 3.1}$$

Table 3. 8 M-1 frequency of power interruption

Feeder	2013 E.C	2014 E.C	2015 E.C
Mobile-1	262	203	194

Average of frequency interruption = $\frac{(262+203+194)}{3}$ = 220 int/customer/yr

Total length of feeder M-1 is 44.04 KM.

$\mu A = \frac{220}{44.04}$ = 4.5 interruption/ km.year

3.5.2 Repair Times

The amount of time required to restore a system, equipment, or component to its normal operating condition after a failure or malfunction. And can be calculated by:-

$$\text{MTTR} = \frac{Total\ repair\ time}{Total\ number\ of\ interruption} \text{ ……………………………………………………eq 3.2}$$

Table 3. 9 M-1 duration of power interruption

Feeder	2013 E.C	2014 E.C	2015 E.C
Mobile-1	368.33	264.42	285.61

Average of duration interruption = $\frac{(368.33+264.42+285.61)}{3}$ = 306.12 hr/customer/yr

MTTR = $\frac{306.12}{220}$ = 1.39 hr/interruptions

Based on equation 3.1 and 3.2, the average calculated failure rate of the line and repair times per kilometer of the existing feeder are 4.5 interruptions per kilometer per year and 1.39 hours per interruption, respectively.

3.5.3 Modeling and Analysis of Existing System

ETAP 19.0.1 software utilizes the µA and MTTR equations to forecast fundamental reliability parameters for reliability analysis. To estimate a component's failure rate, it combines passive µp and active µA failure rates. The number of failures per year per unit length is measured by the active failure rate, or µA. The primary protective zone surrounding the failed component is triggered by this rate of failure, which may result in the removal of other healthy components and branches from service. Service can be restored to part or all of the load points after the actively failing component is separated and the protection breakers are closed again. But take note that only after repair or replacement can the defective component itself—as well as components that are directly connected to it—be put back into operation.

Conversely, µp stands for the passive failure rate, which is expressed in terms of failures per year per unit length. This rate is linked to a type of component failure where the remaining functional components are unaffected and protection breakers are not triggered. Service can be resumed by fixing or replacing the malfunctioning part. µp is taken to be zero in the model.

The reliability indices for the Adama feeder M-1 are calculated using ETAP 19.0.1 software, and these values are detailed in Table 3.10 of the software library.

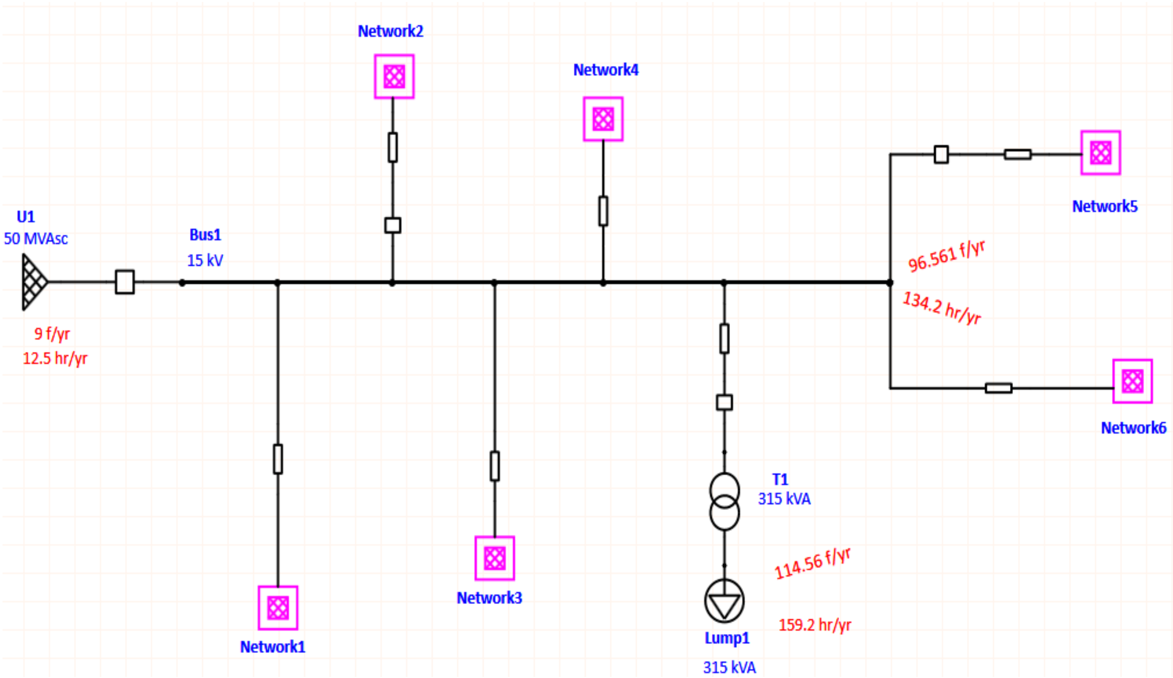

Figure 3. 7 Single line diagram of the existing system of feeder M-1

Table 3. 10 Reliability indexes for existing system

SUMMARY	
System Indexes	
ACCI	40476.60 kVA / customer
AENS	45.0100 MW hr / customer.yr
ASAI	0.9651 pu
ASUI	0.03495 pu
CAIDI	1.390 hr / customer interruption
EENS	3690.819 MW hr / yr
SAIDI	306.1256 hr / customer.yr
SAIFI	220.2343 f / customer.yr

The analysis of the existing system data covered both availability metrics and metrics related to unreliability. When comparing the reliability indices derived from the data analysis of the current system to the benchmarked reliability indices of various countries, it is evident from Table 3.10 that feeder M-1 distribution system performs poorly. This indicates a need for improvement to enhance its reliability indices. The calculated reliability indices are used to measure the performance of the feeder distribution system, particularly in terms of sustained interruptions.

The results of the reliability indices are explained as follows:

- ACCI: This index represents the total energy not supplied per affected customer by the system. The overall system has an ACCI value of 40,476.60 KVA per customer.
- AENS: This index represents the average energy not supplied per customer by the system. The overall system has an AENS value of 45.0100 MW hr per customer per year.
- ASAI: The average service availability index measures the proportion of time that power was available to customers during a given period relative to the total customer hours demanded. It indicates the fraction of time customers received power during the reporting period. For feeder M-1, the power supply availability is 0.9651 pu (96.51%), as shown in the table.

- ❖ ASUI: The average service unavailability index measures the proportion of time that power was unavailable to customers during a given period relative to the total customer hours demanded. It indicates the fraction of time customers did not receive power during the reporting period. For feeder M-1, the power supply unavailability is 0.03495 pu (3.495%), as shown in the table.
- ❖ CAIDI: The customer average interruption duration index measures the average time to restore service once an outage occurs. For feeder M-1, the CAIDI value is 1.390 hours per customer interruption. This means that, on average, any customer who experienced an outage during the year was without service for 1.390 hours.
- ❖ EENS: This index indicates the unserved or unsold energy for each feeder. For the overall system, the total unsold energy was 3690.819 MW hr per year.
- ❖ SAIDI measures the total duration of interruptions for the average customer during a given time period, which amounts to 306.12 hours per customer per year. This index indicates that each customer experiences 306.12 hours per year without power, suggesting a significant reliability issue in the existing feeder M-1 when compared to benchmarking data.
- ❖ SAIFI represents the average number of times that customers on feeder M-1 experience an outage during the year. In this context, the SAIFI result is 220 outages per customer per year, meaning customers on the feeder have a 220 probability of experiencing a power outage each year. When comparing this SAIFI value with benchmarking data, it significantly exceeds the maximum benchmark value. This clearly highlights a serious reliability issue in the feeder M-1.

From the data analysis, the following conclusions can be drawn:

- ✓ The reliability of the mobile feeder M-1 falls short of the benchmarking standards set by other countries, and it also lags behind the international reliability indices of top-performing nations.
- ✓ The current power grid of the feeder experiences significant losses of unsupplied energy, attributed to both planned and unplanned outages.
- ✓ The network experiences a notable lack of service availability.

3.6 Bench Marking for Distribution System Reliability Indices

The benchmark against which the reliability of a distribution system is evaluated is known as a reliability benchmark. These standards are established to provide a justification and an acceptable margin for the reliability performance of the distribution network. The IEEE guide conducted benchmarking across ten countries to evaluate power distribution reliability, as outlined in Table 3.11. This table provides annual SAIFI and SAIDI values for each participating country, reflecting their emphasis on power quality and reliability. Notably, Germany stands out for its highly reliable power delivery among developed nations, as evidenced by its lower SAIDI value. This indicates shorter sustained interruption durations or fewer power outages per year compared to the other countries in the study. However, when compared to the other nine countries, the USA is considered unreliable. The concept of power reliability is extensive, encompassing the system's ability to meet customer requirements without excessively burdening tariffs (Joshi et al., 2018). Commonly used reliability indices for distribution systems are crucial for assessing past performance and predicting future power system performance.

Table 3. 11 International comparison of reliability indices (Dauda, 2017).

Countries	SAIFI [frequency/customer/year]	SAIDI [duration/customer/year]
Netherland	0.3	0.55
Germany	0.5	0.383
Denmark	0.5	0.4
United Kingdom	0.8	1.5
Australia	0.9	1.2
France	1.0	1.03
United States of America	1.5	4.0
Italy	2.2	0.967
Spain	2.2	1.73
Canada	3.4	6.9
Ethiopia	20	25
Feeder M-1	220	306.12

From the data analysis of the existing system

- Compared to the reliability standards set by Ethiopian Electric Agency, the reliability indices of the mobile feeder M-1 system fall significantly short of the required values.
- The feeder requires significant reliability improvements to meet best practices. An effective and sustainable reliability solution is needed to achieve the standard and ensure optimal power reliability.

3.7 Reliability Cost and Worth

The concept of reliability cost and worth refers to the balance between the expenses incurred to maintain a reliable system and the value derived from having that reliability. In essence, it involves assessing the cost of ensuring a certain level of reliability against the benefits or worth that reliability provides.

Reliability cost encompasses various expenses such as maintenance, upgrades, equipment replacements, and workforce training aimed at achieving and sustaining a reliable system. These costs are essential for minimizing downtime, reducing disruptions, and meeting customer expectations regarding service quality and continuity.

On the other hand, reliability worth relates to the value or benefits derived from having a reliable system. This includes factors such as improved customer satisfaction, increased productivity, reduced losses due to downtime, enhanced safety, and regulatory compliance. A reliable system contributes to operational efficiency, customer trust, and overall economic stability.

The balance between reliability cost and worth is crucial for organizations to make informed decisions regarding investments in reliability enhancement measures. It involves analyzing the trade-offs between spending on reliability improvements and the tangible and intangible benefits gained from a more dependable system. Achieving an optimal balance ensures that the costs associated with reliability are justified by the value and advantages it brings to stakeholders and the overall operation of the system.

3.7.1 Assessing the Cost of Power Interruptions in the Distribution System

Assessing the cost of power interruptions in the distribution system is a critical aspect of ensuring reliable and efficient electrical supply. This assessment involves a comprehensive analysis of both the direct and indirect costs associated with interruptions. Direct costs typically include expenses such as lost revenue for businesses, productivity declines, repair and restoration costs, and compensation to affected customers. On the other hand, indirect costs encompass broader impacts like reputational damage, customer dissatisfaction, potential loss of contracts or business opportunities, and increased insurance premiums. Moreover, the duration and frequency of interruptions play a crucial role in cost assessment, with longer or more frequent interruptions generally leading to higher overall costs. To effectively manage these costs, utilities and stakeholders often conduct detailed risk assessments, invest in infrastructure upgrades and backup systems, and implement proactive maintenance practices. By understanding and quantifying the various financial and operational impacts of power interruptions, organizations can make informed decisions regarding investment priorities, regulatory compliance, and customer satisfaction initiatives within the distribution system.

3.7.2 Analyzing the Cost of Power Interruptions from the Utility's Perspective

Analyzing the cost of power interruptions from the utility's perspective involves a thorough examination of the financial implications and operational challenges associated with disruptions in electrical supply. From a financial standpoint, power interruptions incur direct costs such as revenue losses, expenses for repair and restoration efforts, and potential compensation to affected customers. Indirect costs may also arise, including reputational damage, customer dissatisfaction, and increased regulatory scrutiny.

Operationally, power interruptions require resources for emergency response, maintenance, and contingency planning. Utilities must invest in infrastructure upgrades, implement robust monitoring and control systems, and develop resilient backup mechanisms to minimize the impact of interruptions. Additionally, assessing the duration and frequency of interruptions helps utilities prioritize investment in reliability enhancement projects and optimize outage management strategies.

Furthermore, analyzing the cost of power interruptions enables utilities to make informed decisions regarding risk management, regulatory compliance, and customer service improvements. By understanding the full spectrum of costs and impacts associated with interruptions, utilities can implement proactive measures to enhance system reliability, minimize downtime, and ultimately deliver a more reliable and resilient electrical supply to customers.

The Expected Interruption Cost (EIC) is calculated for each delivery point in the area by determining the contribution to the Expected Energy Not Supplied (EENS) and EIC for every anticipated interruption throughout the year. The calculation considers the expected frequency and duration of each failure that causes an interruption at the delivery point, along with the expected load and the specific interruption cost for each duration. This process yields the EIC for each delivery point.

EIC = EENS * Tariff per KWH

The utility's average equivalent flat rate is calculated at 1.7021 ETB per kWh. This figure is derived from the average of the first block tariffs applicable to domestic and commercial customers, as detailed in Appendix III.

The electrical energy not supplied (EENS) is 3690.819 MW hr/yr

ECOST= EIC = 3,690,819 KWH/yr * 1.7021 per KWH = 6,282,143.02 birr

On average, the EEU Adama district branch incurs a yearly loss of 6,282,143.02 ETB due to power outages in the mobile feeder M-1 systems.

3.8 Mitigation Techniques for Power Distribution Systems

3.8.1 Interruption Mitigation

Mitigation techniques for power distribution systems are essential strategies implemented to minimize the impact of disruptions and enhance system reliability. These techniques encompass various measures aimed at preventing, detecting, and mitigating potential faults or failures within the distribution network.

One key mitigation technique is the deployment of protective devices such as circuit breakers, fuses, and relays. These devices act as safety mechanisms, automatically isolating faulty sections of the network to prevent cascading failures and minimize downtime. Advanced protective relays can provide selective fault detection and rapid response, improving overall system reliability.

The main goals for improving reliability and power quality for customers are to eliminate faults and minimize their impact when they occur. According to responses from Adama district utility employees, the causes of power interruptions include aging poles, equipment, and wires; tree contact or trees falling on lines; pole failures; overloading;

insulator cracking; animals; wind; rain; and lightning. Additionally, distribution lines are sometimes interrupted for maintenance operations. Identifying the root causes of these outages is the first step in maximizing the reliability of the distribution system.

Distribution power outage mitigation techniques can be classified into two basic categories.

- **Electrical Mitigation Technique: -** This has a direct impact on the analysis of the distribution system. Techniques to improve system reliability include:
  - Placement of protective devices such as reclosers, fuses, and circuit breakers
  - Installation of switching devices (manual or automatic switches)
  - System reconfiguration and feeder upgrading

This thesis focuses on the addition of reclosers as protective devices in the distribution feeder line due to their reliability and overcurrent protection capabilities, primarily for enhancing system reliability.

The distribution system can be reconfigured by changing the location of normally open switches, effectively reallocating customers and altering the power flow for optimal feeder performance. This not only improves reliability but also reduces losses, operational costs, and the effects of overloading.

Automated service restoration aims to activate tie switches in order to restore the electricity supply to the greatest region that can be impacted by a problem. In essence, this is moving clients who are now unreliable to a neighboring, healthier feeder that is more reliable, increasing the system's overall efficacy.

- **Non-Electrical Mitigation Technique: -** Non-electric mitigation techniques do not impact other engineering analysis tools and can be evaluated solely through reliability studies. Types of non-electric mitigation techniques include:
  - Vegetation management and installation of lightning arresters
  - Animal protection guards
  - Strategic placement of crews and consideration of human factors

3.8.2 Strategies to Mitigate Power Outages through Maintenance

Implementing robust maintenance strategies is essential to mitigate power outages effectively. Regular inspections, testing, and servicing of critical equipment such as transformers, circuit breakers, and switches are fundamental preventive measures.

The primary objective of maintenance is to prolong equipment lifespan and minimize the risk of failure. Regular maintenance activities result in reduced frequency and duration of interruptions. Maintenance can be classified into two main categories:

- **Preventive Maintenance: -** Is a proactive approach aimed at improving the condition of components that may have deteriorated. Utility experts should assess key distribution system equipment, such as transformer oil, deteriorated poles, and loose insulators, which can cause power outages. Predictive and planned maintenance can be performed based on the system's criticality.
- **Corrective Maintenance: -** Involves repairing or replacing failed components. Electrical equipment deteriorates due to aging factors such as insulation degradation, heating from current flow, mechanical damage, and corrosion. Life extension and repair practices are preferable to replacing equipment with new ones. Damage should be addressed through timely life extension programs. Repairing equipment is generally more cost-effective and durable than replacement. Replacement should be considered only after confirming frequent failures and operational incapability.

3.9 Selecting Strategies for Placement of Automatic Outdoor Reclosers

In this thesis, a Nu-Lec 15 KV outdoor pole-mounted automatic circuit recloser has been selected for the simulation purposes based on the capacity of the Adama mobile feeder line. The placement and number of automatic reclosers were determined by considering the number of customers, feeder length, area sensitivity, and economic benefits. The reliability indices SAIFI, SAIDI, and cost benefits are the main criteria for comparing the alternatives using a heuristic technique.

3.9.1 Criteria for Placing Reclosers

- **Sensitivity and Economic Benefits**: The primary consideration is the significance of the feeder line to Adama town's activities. The feeder line supports critical infrastructures such as hotels, small restaurants, micro-industries, governmental offices, schools, colleges, universities, hospitals, clinics, private hospitals, banks, and various governmental finance offices. Additionally, a few industries and nearly all service providers depend on this feeder line. The feeder line also supplies electricity to a large number of residential customers.

- ❖ **Topology and Landscape**: The second consideration involves the landscape through which the lateral feeder line passes and frequently affected by wind, tree branches, and farming animals, which cause power failures. These challenges complicate fault identification and resolution for repair crews. Faults in these lateral feeder lines result in outages for the entire mobile feeder M-1.
- ❖ **Environmental Factors**: The third consideration is environmental. Lateral feeder lines passing through straight green areas which are prone to faults caused by tree failing on the line and birds which can interfere with the lines.

3.9.2 Switch Placement Techniques

- ✓ STEP 1: Determine the feeder line and the number of switches to be installed.
- ✓ STEP 2: Divide the main feeder line into sections, with each section containing approximately the same number of customers. Alternatively, sections can be randomly determined if the technique is repeated multiple times. This step includes the initial placement of switches and calculation of the objective function.
- ✓ STEP 3: Randomly determine a sequence of switches, and verify the location of each switch.
- ✓ STEP 4: Create two new switch placements (in the order determined in STEP 3): one moving towards the main feeding point (MFP) and the other in the opposite direction, but not beyond any existing switch location.
- ✓ STEP 5: Calculate the objective function values for the new switch placements and choose the most advantageous one compared to the original placement. If the objective function values improve, the switch is moved to the new position; otherwise, it remains at its original location.
- ✓ STEP 6: If not all switches have been verified in the determined sequence (as per STEP 3), return to STEP 4 or STEP 3 and repeat the procedure until the specified number of cycles (a parameter of the technique) is completed.
- ✓ STEP 7: Once the process is complete, the switch placements are considered optimal.

3.10 Procedure for Reliability Analysis by ETAP Software

The reliability analysis is conducted using ETAP 19.0.1 software through the following procedures:

- Model the one-line diagram of the existing system using the software.
- Identify and input relevant parameters for the simulation.
- Specify the types and operational characteristics of the protection devices.
- Perform load flow, short circuit, and reliability assessment simulations.

To estimate the failure rate of a component, ETAP 19.0.1 combines active (μA) and passive (μP) failure rates. The active failure rate, measured as the number of failures per year per unit length, is associated with a component failure mode that triggers the operation of the primary protection zone around the failed component. This leads to the removal of other healthy components and branches from service until the failed component is isolated and the protection breakers are reclosed, allowing service restoration to some or all load points. However, the failed component itself, along with those directly connected to it, can only be restored after repair or replacement.

The passive failure rate, also measured as the number of failures per year per unit length of the feeder, pertains to failure modes that do not activate protection breakers and thus do not impact other healthy components. Service is restored upon repairing or replacing the failed component. In this model, the passive failure rate (μP) is assumed to be zero, as there is no means of isolating specific faulty areas in the system (ETAP Software Library).

The Adama city feeder (15 KV) is constructed using a 50 mm^2, All Aluminum Conductor (ALC). This specification is nearly equivalent to the ICEA three-phase AL Conductor or Code AL 50 mm^2, available in the ETAP Library. To model the existing city distribution line and analyze the current distribution reliability, the following assumptions have been considered as inputs in ETAP 19.0.1 software:

- City line data
- Cable length
- Number of customers
- Connected load
- Number and rating of transformers for each load point

- Active failure rate
- Duration of interruptions in hours
- Frequency of interruptions

The mobile feeder M-1 is protected by an 800/1A CT circuit breaker located at the transformer's outgoing side at the substation. This feeder line lacks sectional divisions and protective devices apart from the substation circuit breaker. Consequently, when a fault occurs at a distant point from the substation or on a lateral feeder line, the entire feeder line is affected, causing power interruptions for all customers connected to it. These interruptions persist until the faulted lateral line is manually located and isolated.

This thesis proposes dividing the feeder M-1 into six different zones. The zone concept involves a systematic method of segmenting the distribution network into manageable areas based on load, load criticality, and disturbance vulnerability. The proposal includes implementing automatic reclosers to enhance reliability by making the distribution system more automatic. Each division zone will be equipped with automatic electronic control reclosers and tie-switching technology. The placement and number of automatic reclosers on different points of the feeder M-1 are determined based on criteria such as the utility's challenges in fault identification and manual restoration, as well as the economic benefits for Adama town.

3.10.1 Interlocking and Switching Sequence Operation of Protective Devices

Protection devices can be made to interlock mechanically, electrically, or by other means. The main purposes of these interlocks are to guarantee system safety and service continuity.

Due to differing sensitivities and tolerances, each circuit breaker that detects a problem may measure a different amount of fault current when the fault occurs anywhere in the system. In order to isolate and halt the faulty circuit, the protection device nearest to the problem should be the first to activate.

A sequence of status changes in switching devices, like switches and circuit breakers, is called a switching sequence. These devices are used to accomplish a variety of tasks, such as transferring loads between sources, energizing and de-energizing loads, and de-energizing equipment, like transformers or buses, for maintenance. With the help of this program, you may examine the impacts of the switching sequence and mimic system behavior before putting it into practice.

3.10.1.1 Interlocking Operation of Protective devices

Interlocking refers to a system of safeguards that ensures protective devices operate in a specific sequence to avoid conflicts or dangerous conditions. It prevents the simultaneous operation of devices that could lead to faults, equipment damage, or unsafe situations. Interlocking can be mechanical, electrical, or software-based, depending on the system configuration.

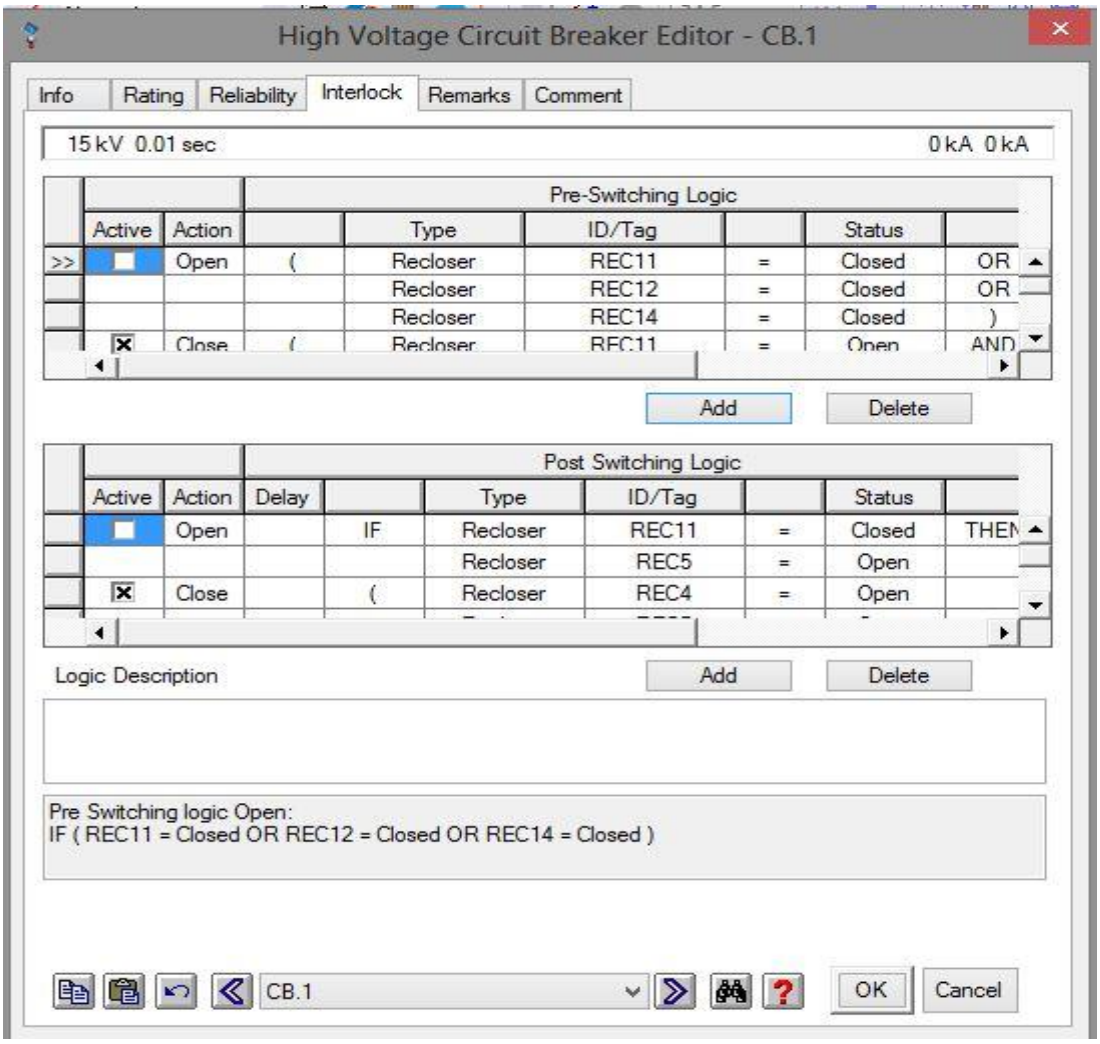

Figure 3. 8 Sample of interlocking between tie switch and recloser

3.10.1.2 Switching Sequence Operation of Protective devices

The switching sequence refers to the specific order in which switching operations are performed during normal operation, maintenance, or fault conditions. Correct switching sequences are critical to maintaining system stability and preventing dangerous situations like live equipment exposure or unintentional energization.

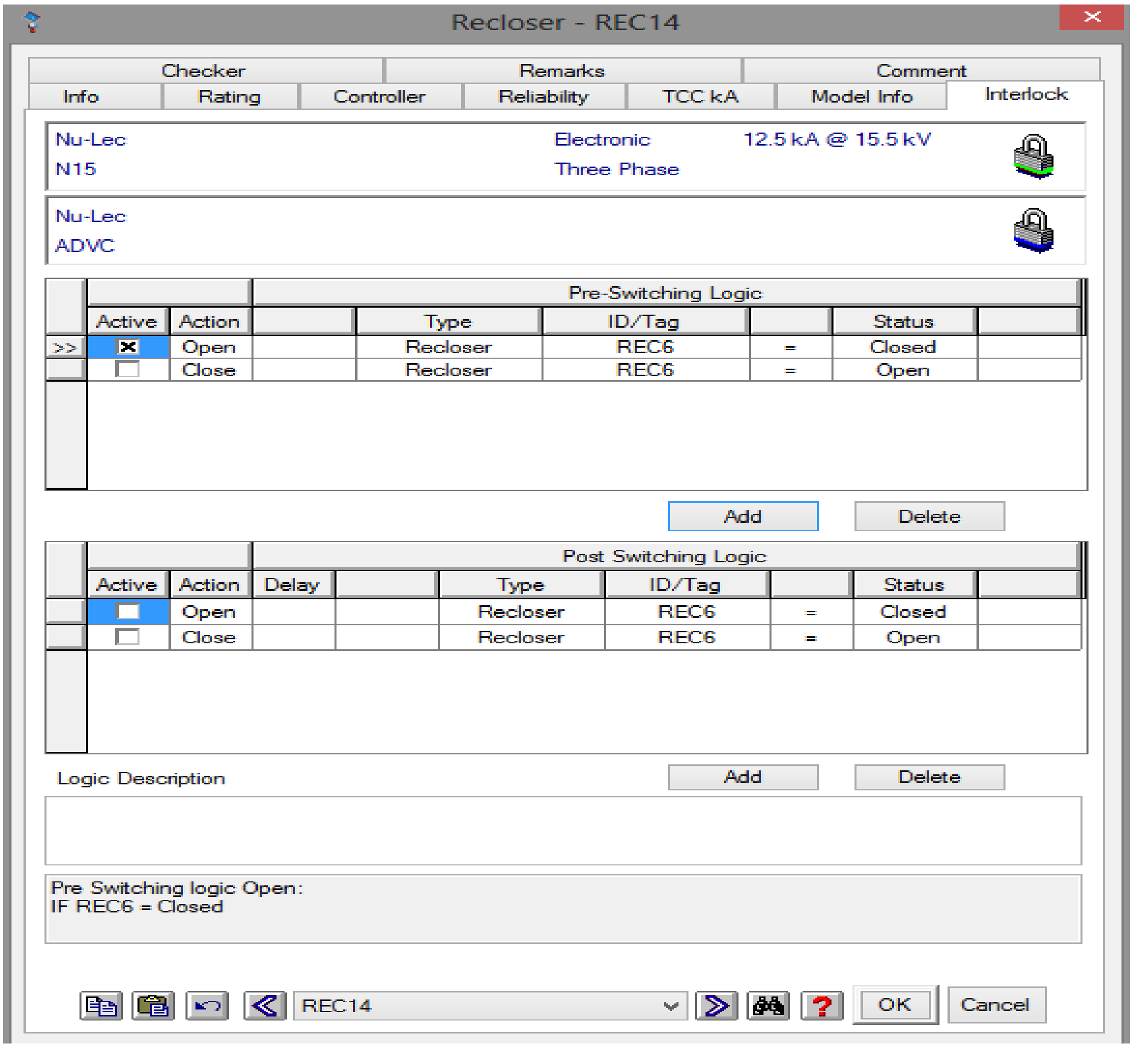

Figure 3. 9 Sample of switching operation between tie switch and recloser

It is evident from Figures 3.8 and 3.9 that the tie switch and the substation circuit breakers are interlocked, preventing the tie switch from closing unless one of the two breakers is open. Given that the two substations are not synchronized to serve the same load at the same time, it follows that the three switches are never closed simultaneously.

CHAPTER 4. RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter explains the modeling and simulation of the existing system and explores various mitigation techniques to enhance the reliability of the Adama city feeder line cost-effectively. Using ETAP 19.0.1 software, different methods such as reclosers, sectionalizing, circuit breakers, and other techniques have been analyzed. The simulations assess the impact of these techniques on system performance.

A recloser is a device used in overhead distribution systems to interrupt the circuit and clear faults. Automatic reclosers are equipped with electronic control sensors and vacuum interrupters that can automatically reclose to restore service if the fault is temporary. If the fault persists, the recloser locks out after several attempts to clear and energize the circuit. In this thesis, three-phase reclosers are used to enhance power distribution reliability. These reclosers, incorporating protective relaying equipment, are set to trip under specific overcurrent conditions and reclose at predetermined intervals. After a circuit trip and a set time delay, the recloser automatically re-energizes the circuit. Typically, reclosers are set to trip and reclose two or three times before a lockout condition occurs, requiring manual reset by personnel to restore power. If the fault condition clears before lockout, the protective relaying resets to the start of the sequence. Reclosers can also be manually tripped, allowing them to function as load-break switches.

Reclosers enable utilities to implement automatic back feed restoration (loop automation) and fault detection. Designed for overhead distribution lines and distribution substations, automatic circuit reclosers are available for various voltage classes, including 15 KV, 27 KV, and 38 KV. In this thesis, a 15 KV recloser has been selected to match the capacity of the Adama city feeder line. The placement and quantity of automatic reclosers were determined by considering factors such as the number of customers, feeder length, area sensitivity, and economic benefits.

All necessary parameters, including connected load, number of customers, cable length, and active failure rate, are entered into the ETAP software for the reliability analysis of the distribution system. Interruption data from the years 2013 to 2015 E.C. are used as the base year. According to data from the customer service center, the total number of customers currently connected to the Adama city mobile feeder M-1 is approximately around 17,425.

4.2 Case Study-1 [Placement of reclosers in feeder M-1]

Reclosers function similarly to station breakers and are equipped with protective relaying equipment that can be programmed to trip under specific overcurrent conditions and reclose at designated time intervals. Typically installed on the main feeder of a circuit, they are also commonly used on lateral branches. In the case of feeder M-1, it has been divided into six zones/areas to facilitate easier management during utility fault scenarios, with six automatic reclosers protecting each zone downstream. The simulation aims to assess the system's reliability when all reclosers are activated simultaneously.

The results from Table 4.1 indicate significant improvements in reliability indices. For instance, SAIDI decreases from 306.12 to 257.24 hours per customer per year, marking a 15.97% improvement from the current state. Similarly, SAIFI decreases from 220 to 185 failures per customer per year, representing a 15.91% improvement. Additionally, EENS decreases from 3,690.819 to 3,080.486 kWh per year. Consequently, the utility's loss of earnings due to EENS also reduces from 6,282,143.02 birr to 5,243,295.22 birr, translating to an annual profit increase of approximately 1,038,847.80 birr, on top of the ordinary profits from electricity sales, if this methodology is implemented.

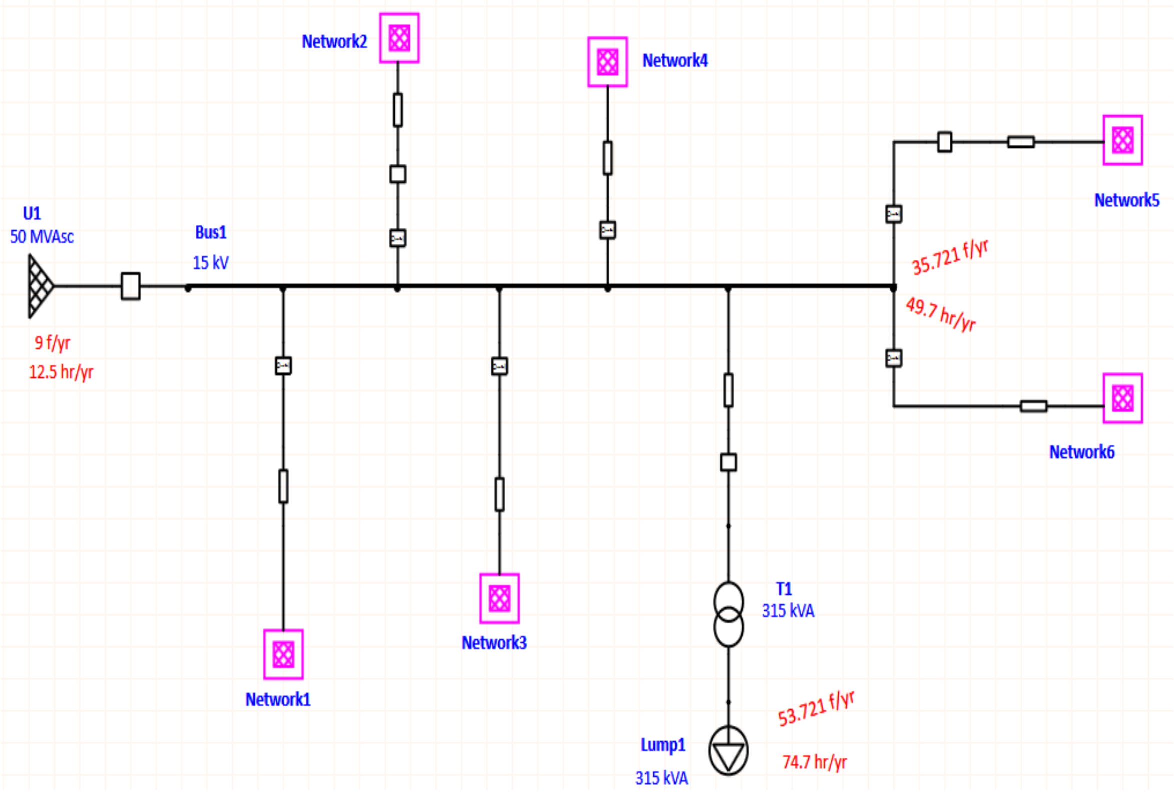

Figure 4. 1 Single line diagram of the of feeder M-1 with each zone protected reclosers

Table 4. 1 Reliability indexes for case study-1

SUMMARY	
System Indexes	
ACCI	33783.18 kVA / customer
AENS	37.5669 MW hr / customer.yr
ASAI	0.9706 pu
ASUI	0.02936 pu
CAIDI	1.390 hr / customer interruption
EENS	3080.486 MW hr / yr
SAIDI	257.2354 hr / customer.yr
SAIFI	185.0613 f / customer.yr

Generally, while distribution reliability has improved, it still falls short when compared to other countries in benchmarking studies. Despite the enhancements in reliability indices, they do not meet the standards set by benchmark countries. Consequently, the reliability of this feeder is still below the international indices of top-performing countries. As a case study, we applied an alternative supply through tie switching from an adjacent unloaded feeder line.

4.3 Case Study-2 [Tie circuit added on the network-4]

By employing a tie recloser switching system to execute an automatic source transfer strategy, system reliability is further increased.

The feeder M-1 in case study 1 was zoned into six sections according to the town topology, environmental considerations, feeder length, sensitivity, and financial gains. To maximize customer satisfaction and prevent a complete power outage on the feeder M-1, each zone has automatic reclosers connected with a tie switch system to identify and isolate problems within that zone.

Furthermore, in order to improve distribution dependability in the case of a defect or main supply interruption from the substation, this thesis suggests giving each feeder zone a backup power source. By altering the normally open switches, the distribution system may efficiently reallocate consumers and optimize power supply to the feeders. This method minimizes operational expenses, overloading impacts, and losses while simultaneously increasing reliability. In order to prevent network overloading during back-feed restoration, a healthy load zone's boundary tie switching devices will return power to it when it loses it. The feeder's separated zones are rearranged with nearby healthy feeders by means of standard tie reclosers, which shut off when the main supply loses power when instructed.

In general, tie reclosers make it easier to shift a zone's load during a power loss from the primary source to a backup supply. The main tactic is to move clients who are unreliable to a nearby feeder who is more reliable; the efficiency of this system configuration technology is mostly dependent on the quantity of tie-switches in the system. The case study that follows shows how feeder dependability has improved.

As shown in Table 4.2, the reliability indices have significantly improved. SAIDI is reduced to 217.87 hours per customer per year, an improvement of 28.83% from the existing status. Similarly, SAIFI is reduced to 156.74 interruptions per customer per year, marking 28.75% improvement. Furthermore, EENS is reduced to 2,630.574 MWh per year, also showing 28.73% improvement.

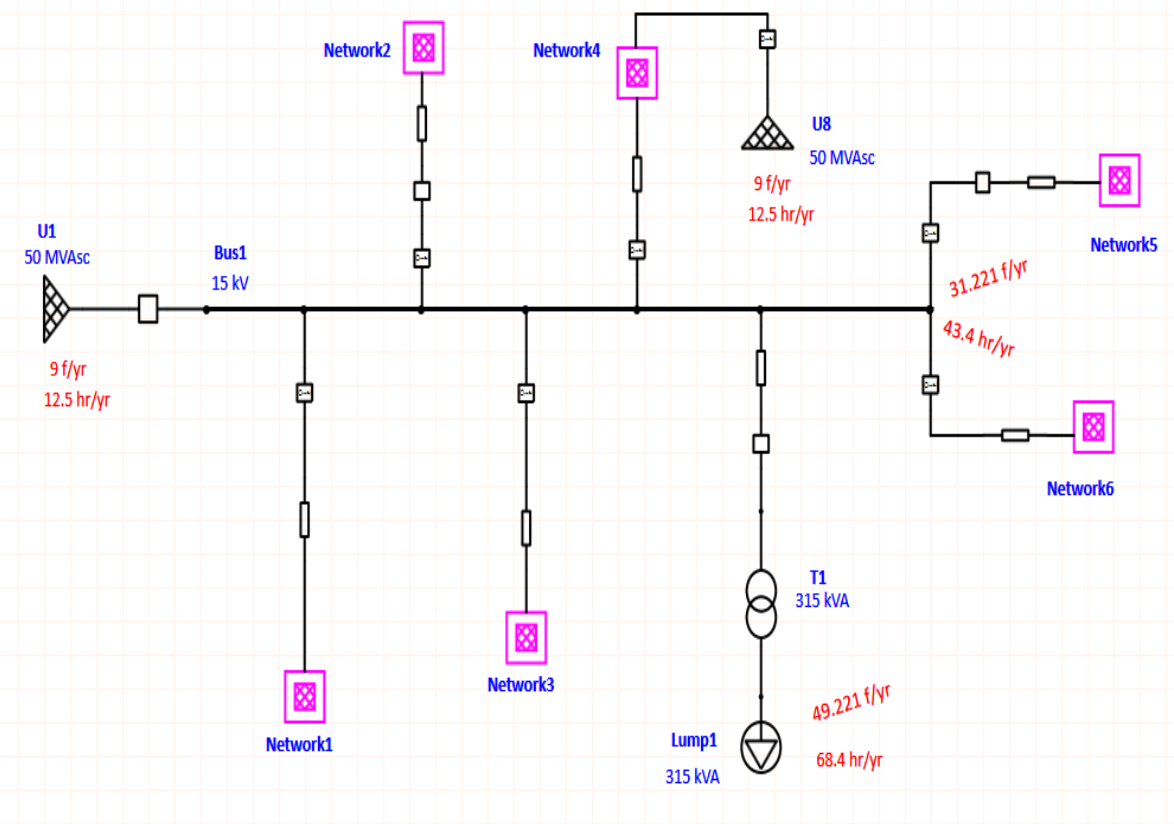

Figure 4. 2 Single line diagram of feeder M-1 with tie-switch for network-4

Table 4. 2 Reliability indices for case study-2

SUMMARY	
System Indexes	
ACCI	28849.07 kVA / customer
AENS	32.0802 MW hr / customer.yr
ASAI	0.9751 pu
ASUI	0.02487 pu
CAIDI	1.390 hr / customer interruption
EENS	2630.574 MW hr / yr
SAIDI	217.8707 hr / customer.yr
SAIFI	156.7415 f / customer.yr

4.4 Case Study-3 [Tie circuit added on the network-4 and 6]

Situated on the other side of the town, this division zone provides services to a range of small businesses, health centers, and production centers. The feeder is more dependable since it has an automated recloser to protect it and a generally open tie recloser to provide backup power.

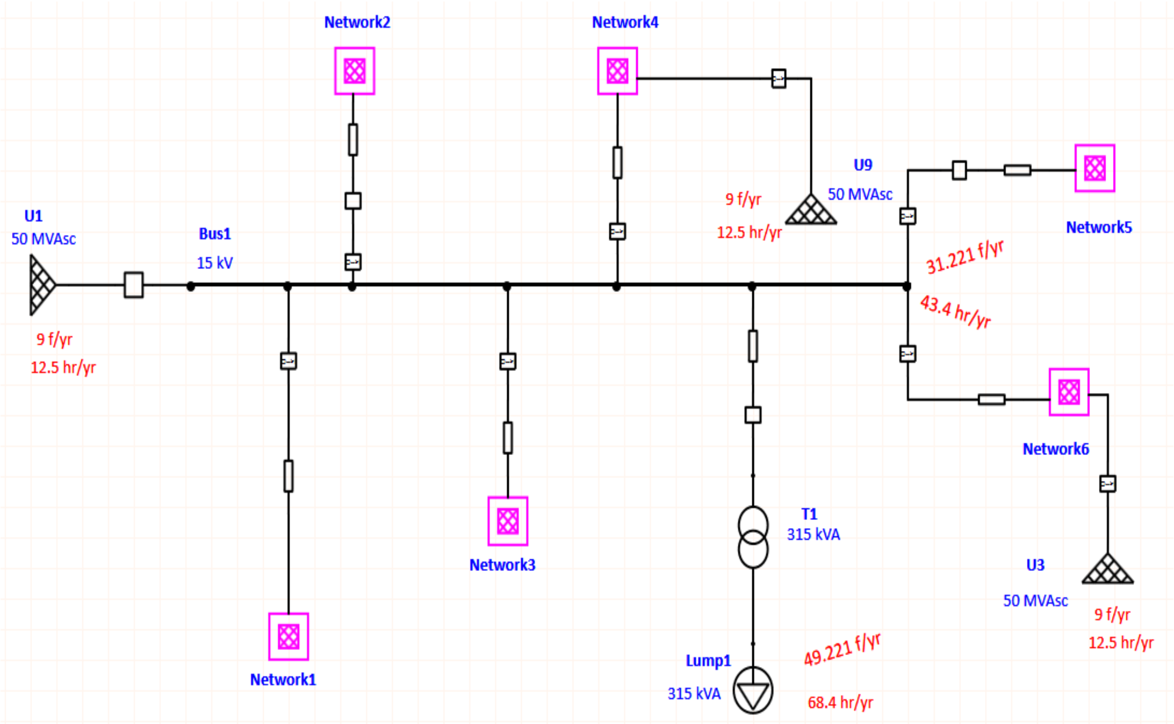

Figure 4. 3 Single line diagram of feeder M-1 with tie-switch for network-4 and 6

The overall reliability indices for the feeder M-1 have improved significantly. As shown in Table 4.3, the SAIDI has decreased to 139.36 hours per customer per year, an improvement of 54.48% from the existing status. The SAIFI has decreased to 100.26 interruptions per customer per year, making 54.43% improvement. Additionally, the EENS has been reduced to 1,736.80 MWh per year, an improvement of 52.94%.

Table 4. 3 Reliability indices for case study-3

SUMMARY	
System Indexes	
ACCI	19047.19 kVA / customer
AENS	21.1805 MW hr / customer.yr
ASAI	0.9841 pu
ASUI	0.01591 pu
CAIDI	1.390 hr / customer interruption
EENS	1736.799 MW hr / yr
SAIDI	139.3573 hr / customer.yr
SAIFI	100.2570 f / customer.yr

4.5 Case Study-4 [Tie circuit added on the network-4, 5 and 6]

Six zones or portions make up the feeder M-1, and each is safeguarded and managed by electronically controlled reclosers. Instead of creating a complete power loss, the thoughtful positioning of switches on the downhill lateral feeder within each zone helps lessen the impact of power outages for customers in that particular zone.

The selection of networks 4, 5, and 6 for tie connections reflects a combination of load balancing, geographical proximity, network performance, redundancy, cost, and regulatory considerations. These factors are intended to optimize network performance, reduce latency, enhance reliability, and ensure cost-effective operations.

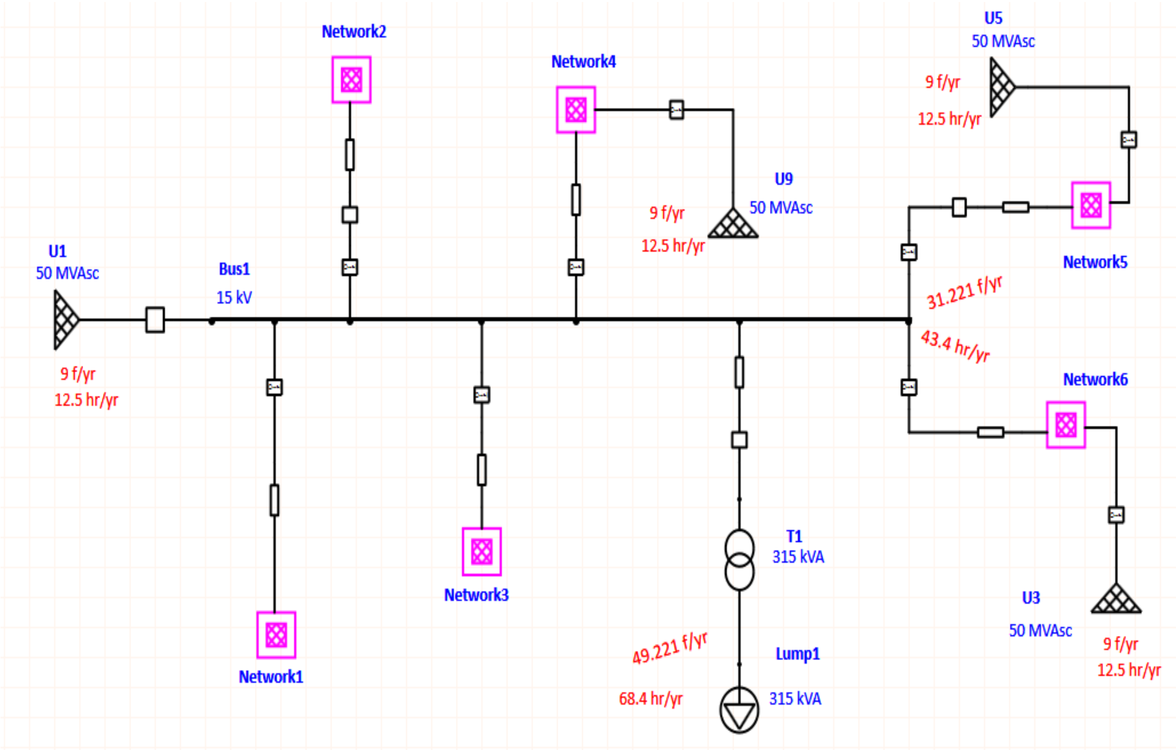

Figure 4. 4 Single line diagram of feeder M-1 with tie-switch for network-4, 5 and 6

As shown in Table 4.4, the SAIDI has decreased to 79.18 hours per customer per year, an improvement of 74.13% from the existing status. Additionally, the SAIFI has decreased to 56.97 interruptions per customer per year, making 74.11% improvement. Additionally, the EENS has been reduced to 953.753 MWh per year, an improvement of 74.16%.

Table 4. 4 Reliability indices for case study-4

SUMMARY	
System Indexes	
ACCI	10459.65 kVA / customer
AENS	11.6311 MW hr / customer.yr
ASAI	0.9910 pu
ASUI	0.00904 pu
CAIDI	1.390 hr / customer interruption
EENS	953.753 MW hr / yr
SAIDI	79.1836 hr / customer.yr
SAIFI	56.9666 f / customer.yr

4.6 Comparison of Reliability Indexes of Proposed and Existing Systems

4.6.1 Customer Oriented Reliability Indexes

Customer-oriented reliability indexes are critical metrics used by utilities to assess the quality of service provided to customers by measuring the frequency, duration, and impact of power outages. These indexes focus on how outages affect end-users, providing a direct evaluation of reliability from the customer's perspective. The most widely used indexes include SAIFI (System Average Interruption Frequency Index), which measures the average number of interruptions a customer experiences within a given timeframe, and SAIDI (System Average Interruption Duration Index), which calculates the total duration of interruptions that the average customer faces over the same period. Together, these indexes offer a clear view of both how often outages occur and how long they last, giving utilities a holistic understanding of their system's performance.

Table 4. 5 Summary of the customer oriented reliability indices for all cases

Customer Oriented Reliability Indices	Cases				
	Existing System	Case-1	Case-2	Case-3	Case-4
ASAI [pu]	0.9651	0.9706	0.9751	0.9841	0.9910
ASUI [pu]	0.03495	0.02936	0.02487	0.01591	0.00904
SAIDI [hr / customer.yr]	306.1256	257.2354	217.8707	139.3573	79.1836
SAIFI [f / customer.yr]	220.2343	185.0613	156.7415	100.2570	56.9666
% Reduction in SAIDI	0	15.97	28.83	54.48	74.13
% Reduction in SAIFI	0	15.97	28.83	54.48	74.09

4.6.2 Energy Oriented Reliability Indexes

Energy-oriented reliability indexes are metrics used to assess the reliability of electrical distribution systems by focusing on the amount of energy lost or not delivered due to system interruptions. These indexes provide insights into how much energy customers are deprived of during outages, offering a broader view of the impact beyond just the duration or frequency of interruptions.

Table 4. 6 Summary of the energy oriented reliability indices for all cases

Energy Oriented Reliability Indices	Cases				
	Existing System	Case-1	Case-2	Case-3	Case-4
ACCI [kVA / customer]	40476.60	33783.18	28849.07	19047.19	10459.65
AENS [MW hr / customer.yr]	45.01	37.5669	32.0802	21.1805	11.6311
EENS [MW hr / yr]	3690.819	3080.486	2630.574	1736.799	953.753
ECOST [ETB/ yr]	6,282,143.02	5,243,295.22	4,477,500.01	2,956,205.58	1,623,382.98
% Reduction in ACCI	0	16.53	28.73	52.94	74.16
% Reduction in AENS	0	16.54	28.73	52.94	74.16
Reduction in EENS [MW hr / yr]	0	610.333	1060.245	1954.02	2737.07
Revenue saved [ETB/ yr]	0	1,038,847.80	1,804,643.01	3,325937.44	4,658,760.04

Based on Table 4.5 and 4.6, the most effective solution is case 4 for enhancing power reliability in the study area involves installing reclosers with a tie switch at critical locations.

Enhancing system reliability would involve not only setting up the system for scheduled preventive protection but also carrying out rehabilitation work on all system components, dealing with personnel challenges, enhancing control techniques, and fixing related concerns.

4.7 Economical Cost Benefit Analysis

In this thesis, an economic cost analysis was conducted based solely on the interruption cost related to the utility side, using EENS for each case.

The price of an outdoor automatic recloser can vary based on several factors such as the manufacturer, specific features, and the region of purchase. However, as of recent data, the typical cost for a standard outdoor automatic recloser for a 15kV system approximately around $7,000. Based on the exchange rate of the Commercial Bank of Ethiopia (CBE) on May 3, 2024, 1 USD is equivalent to 56.97 ETB. The cost of one pole mounted outdoor recloser is $7000 * 56.97 = 398,790 ETB

4.7.1 Payback Period

Payback period is a financial metric used to determine the amount of time it takes for an investment to generate enough cash flows to recover the initial cost. It is a straightforward and widely used method to assess the risk and liquidity of a project or investment. The payback period is particularly useful when investors or companies need to evaluate the time it will take to recoup their initial outlay and become cash-positive. This metric is calculated by dividing the investment cost by the annual savings generated through the investment.

- For Case-1, the annual average unsold energy was reduced from 3,690.819 MWh to 3,080.486 MWh per year, as shown in the Table 4.6. Therefore, the revenue saved due to reliability improvements can be estimated as follows:-

  The revenue saved after enhancement = EENS*Tariff/Kwh

  $$= \frac{(3{,}690{,}819 - 3{,}080{,}486)\text{kWH}}{\text{year}} * \frac{1.7021\text{ birr}}{\text{kWH}} = 1{,}038{,}847.80\text{ ETB/year}$$

  The Investment Cost = 6 recloser * 398,790 ETB = 2,392,740 ETB

  $$\text{Payback Period} = \frac{\text{Investment Cost}}{\text{Annual Revenue Saved Cost}} = \frac{2{,}392{,}740.00}{1{,}038{,}847.80} = 2.303\text{ year}$$

  Payback Period = 2 years, 3 months and 19 days

- For Case-2, the annual average unsold energy was reduced from 3,690.819 MWh to 2,630.574 MWh per year. Therefore, the revenue saved due to reliability improvements can be estimated as follows:-

The revenue saved after enhancement = EENS*Tariff/Kwh

$$= \frac{(3{,}690{,}819 - 2{,}630{,}574)\text{kWH}}{\text{year}} * \frac{1.7021\ \text{birr}}{\text{kWH}} = 1{,}804{,}643.01\ \text{ETB/year}$$

The Investment Cost = 7 recloser * 398,790 ETB = 2,791,530.00 ETB

$$\text{Payback Period} = \frac{\text{Investment Cost}}{\text{Annual Revenue Saved Cost}} = \frac{2{,}791{,}530.00}{1{,}804{,}643.01} = 1.547\ \text{year}$$

Payback Period = 1 year, 6 Months and 17 days

- For Case-3, the annual average unsold energy was reduced from 3,690.819 MWh to 1,736.799 MWh per year. Therefore, the revenue saved due to reliability improvements can be estimated as follows:-

The revenue saved after enhancement = EENS*Tariff/Kwh

$$= \frac{(3{,}690{,}819 - 1{,}736{,}799)\text{kWH}}{\text{year}} * \frac{1.7021\ \text{birr}}{\text{kWH}} = 3{,}325{,}937.44\ \text{ETB/year}$$

The Investment Cost = 8 recloser * 398,790 ETB = 3,190,320.00 ETB

$$\text{Payback Period} = \frac{\text{Investment Cost}}{\text{Annual Revenue Saved Cost}} = \frac{3{,}190{,}320.00}{3{,}325{,}937.44} = 0.959\ \text{year}$$

Payback Period = 11 months and 15 days

- For Case-4, the annual average unsold energy was reduced from 3,690.819 MWh to 953.753 MWh per year. Therefore, the revenue saved due to reliability improvements can be estimated as follows:-

The revenue saved after enhancement = EENS*Tariff/Kwh

$$= \frac{(3{,}690{,}819 - 953{,}753)\text{kWH}}{\text{year}} * \frac{1.7021\ \text{birr}}{\text{kWH}} = 4{,}658{,}760.04\ \text{ETB/year}$$

The Investment Cost = 9 recloser * 398,790 ETB = 3,589,110.00 ETB

$$\text{Payback Period} = \frac{\text{Investment Cost}}{\text{Annual Revenue Saved Cost}} = \frac{3{,}589{,}110.00}{4{,}658{,}760.04} = 0.770 \text{ year}$$

Payback Period = 9 months and 7 days

Table 4. 7 Summary and comparison of payback periods for all the cases

Energy Oriented Reliability Indices	**Cases**				
	Existing System	Case-1	Case-2	Case-3	Case-4
EENS [MW hr/yr]	3690.819	3080.486	2630.574	1736.799	953.753
ECOST [ETB/ yr]	6,282,143.02	5,243,295.22	4,477,500.01	2,956,205.58	1,623,382.98
Investment Cost [ETB]	0	2,392,740.00	2,791,530.00	3,190,320.00	3,589,110.00
Annual Revenue Saved [ETB]	0	1,038,847.80	1,804,643.01	3,325,937.44	4,658,760.04
Payback Period [Year]	0	2.303	1.547	0.959	0.770

Table 4.7 shows that, out of the four scenarios, case 4's payback period is the shortest, taking just 0.77 years (9 months and 7 days) to return the initial expenditure. It is therefore the most economical choice. Apart from the brief payback period, case 4 attains notable enhancements in system reliability, as seen by reductions in SAIFI and SAIDI of 74.09% and 74.13%, respectively, in comparison to the base year values. Case 4 is very beneficial due to its combined benefits of a rapid financial return and a significant improvement in reliability.

The most widely used reliability indices (SAIFI and SAIDI) of the Adama city feeder are contrasted with the Ethiopian Electric Agency's (EEA) criteria as well as the world's top-performing nations in Table 4.8.

Table 4. 8 Summary and comparison of reliability indices with benchmark countries

Countries		SAIFI [frequency/customer/year]	SAIDI [duration/customer/year]
France		1.0	1.03
United States of America		1.5	4.0
Italy		2.2	0.967
Spain		2.2	1.73
Canada		3.4	6.9
Ethiopia		20	25
Adama City Mobile Feeder M-1	Existing System	220	306.12
	Case-1	185.06	257.24
	Case-2	156.74	217.87
	Case-3	100.26	139.36
	Case-4	56.97	79.18

The difference between the case study results and the Ethiopian standard index could be due to an extreme environmental factors such as high temperatures, humidity, or altitude that can have a significant impact on system performance. For example, higher temperatures increase resistance in conductors, leading to more distribution losses. Such external factors can cause the system to operate beyond the limits defined by the Ethiopian standard index.

Temperature Effects: In regions with high ambient temperatures, the system's efficiency may drop due to the increased resistance of electrical lines, leading to performance metrics that exceed standard allowances.

Environmental Stress: Dust, moisture, or other environmental challenges in Ethiopia’s specific geography may have an effect on components like transformers and lines, degrading their performance and causing system deviations.

Potential Solution: System designs should account for local environmental factors by using heat-resistant or insulated materials and adapting maintenance schedules to mitigate environmental impacts. By implementing these improvements, the system can be optimized to meet or even exceed Ethiopian standards in future assessments.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The Ethiopian Electric Agency's (EEA) standards for electricity distribution system reliability are not met by the Adama city system, according to the study's findings. For feeder M-1, there are 220 interruptions on average per customer annually, and the average length of an interruption is 306.12 hours. Furthermore, when compared to the global reliability requirements of high-performing nations like France and Italy, the Adama city power distribution system's dependability, as evaluated in this case study, is inadequate.

Ageing infrastructure (poles, equipment, and wires), overloading, insulation problems, animal interference (including large birds), and unfavorable weather conditions like wind, rain, and lightning are some of the major causes of the ongoing interruptions in the existing distribution system. Individuals, companies, and communities are negatively impacted by the current system. These include the negative financial effects of lower output, damaged equipment, and increased operating costs, as well as the negative social effects of reduced quality of life and disturbance of everyday life. Degradation of infrastructure and the environmental effects of increased emissions

The thesis evaluate system performance metrics and compare cost benefit analysis of four case studies and shows how to improve feeder M-1 dependability in the event of faults in the divided zones by using reclosers, tie-switching circuits, and load isolation techniques. As a result, improvements of 74.09% and 74.13%, respectively, were seen in SAIFI, which decreased from 220 interruptions per customer annually to 56.97 interruptions per customer annually, and SAIDI, which decreased from 306.12 hours per customer annually to 79.18 hours per customer annually. EENS was also decreased, improving by 74.16%, from 3,690.819 MWh annually to 953.753 MWh annually. As a result of these dependability improvements, the Ethiopian Electric Utility (EEU) gets an extra 2,737.07 MWh annually that may be sold, improving the utility's revenue.

According to the simulation results, all of the suggested models—whose payback times range from 0.77 to 2.3 years—contribute to improved reliability. With a payback period of just around 9 months and 7 days to repay the initial expenditure, case-4 is the most financially effective of the four scenarios. In addition to having a short payback period, case-4 improves system reliability significantly, as seen by reductions in SAIFI and SAIDI of 74.09% and 74.13%, respectively, when compared to base year values. Case-4 is especially beneficial and financially feasible in terms of investment cost due to its twin benefits of a rapid financial return and significant reliability improvement.

5.2 Recommendations

Encouraging the Adama city power distribution system's dependability must be the EEU’s top priority. To satisfy dependability criteria, the current distribution network has to be upgraded. The findings in this thesis demonstrate that the current power distribution system's dependability can be improved by using protective devices along the feeder lines. Still, this might not be enough to satisfy the EEA’s standards.

By addressing the underlying causes of this city's problems, we can ensure that these strict requirements are met. This can be accomplished in a number of ways, such as by trimming trees to remove any potential vegetation interference, scheduling inspections for poles and conductor clearance, performing routine preventive maintenance on poles and conductors, thoroughly inspecting distribution transformers, and changing transformer oil on a regular basis. By taking these preventative measures, the system satisfies the high criteria imposed by regulatory bodies such as the EEA, while also increasing its reliability.

5.3 Future Work

The thesis focused on enhancing the reliability of the Adama city M-1 feeder only. However, the scope of reliability assessment can be expanded to include:-

- The reliability assessment of the whole part of the outgoing feeders.
- Technical and non-technical losses.
- Maintenance optimization of the distribution system.

REFERENCE

Abrha, E. B., Worku, G. B., & Abose, T. A. (2020). Power distribution system reliability assessment and improvement case of Jimma Town, Ethiopia. In *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, LNICST: Vol. 308 LNICST*. Springer International Publishing. https://doi.org/10.1007/978-3-030-43690-2_28

Adefarati, T., & Bansal, R. C. (2018). Reliability assessment of distribution system with the integration of renewable distributed generation. *Applied Energy*, *185*, 158–171. https://doi.org/10.1016/j.apenergy.2016.10.087

Ahmad, S., & Asar, A. U. (2021). Reliability enhancement of electric distribution network using optimal placement of distributed generation. *Sustainability (Switzerland)*, *13*(20). https://doi.org/10.3390/su132011407

Arya, R., Choube, S. C., & Arya, L. D. (2019). Reliability evaluation and enhancement of distribution systems in the presence of distributed generation based on standby mode. *International Journal of Electrical Power and Energy Systems*, *43*(1), 607–616. https://doi.org/10.1016/j.ijepes.2012.05.045

Bhugwandeen, R., & Saha, A. K. (2018). Improving Reliability on Distribution Systems by Means of Network Reconfiguration. *2018 IEEE PES/IAS PowerAfrica, PowerAfrica 2018*, *November*, 220–225. https://doi.org/10.1109/PowerAfrica.2018.8520987

Brown, R. E. (2017). Electric power distribution reliability, second edition. In *Electric Power Distribution Reliability, Second Edition*. https://doi.org/10.1201/9780849375682

Chandhra Sekhar, P., Deshpande, R. A., & Sankar, V. (2017). Evaluation and improvement of reliability indices of electrical power distribution system. *2016 National Power Systems Conference, NPSC 2016*, *November 2001*. https://doi.org/10.1109/NPSC.2016.7858838

Dauda, F. (2017). Appraisal of Electric Power Distribution Feeders Reliability in the Region unit in Nigeria. *International Journal of Engineering Research and Technology*, *Vol. 6*, 99–107.

Eaton. (2017). *Overcurrent Protection Fundamentals. Fuseology*. *877*.

F. R. Islam and K. A. Mamun. (2019). Reliability Evaluation of Power Network; A case Study of Fuji Islands. *University of the South Pacific Electronic Research Repository*.

Goodin, R. E., Fahey, T. S., & Hanson, A. (2004). Distribution reliability using reclosers and sectionalisers. *ABB Inc, Lake Maryu*.

Jaleel, A. M., & Abd, M. K. (2021). Reliability Evaluation of Electric Distribution Network with Distributed Generation Integrated. *International Journal of Intelligent Engineering and Systems*, *14*(5), 306–319. https://doi.org/10.22266/ijies2021.1031.28

Joshi, D., Burada, S., & Mistry, K. D. (2018). Distribution system planning with optimal conductor selection. *2017 Recent Developments in Control, Automation & Power Engineering (RDCAPE)*, 263–268.

Karimi, H., Niknam, T., Aghaei, J., GhasemiGarpachi, M., & Dehghani, M. (2021). Switches optimal placement of automated distribution networks with probability customer interruption cost model: A case study. *International Journal of Electrical Power & Energy Systems*, *127*, 106708.

Kim, H. (2019). *Reliability Modeling and Evaluation in Aging Power Systems*. *August*.

Kovalev, G. F., & Lebedeva, L. M. (2019). *Reliability of power systems* (Vol. 1). Springer.

Kumar, S., Saket, R. K., Dheer, D. K., Holm-Nielsen, J. B., & Sanjeevikumar, P. (2020). Reliability enhancement of electrical power system including impacts of renewable energy sources: a comprehensive review. *IET Generation, Transmission & Distribution*, *14*(10), 1799–1815.

Kuphaldt, T. R. (2022). *Modular Electronics Learning (ModEL) project V = I R Kirchhoff ' s Voltage Law*. *September*.

Makarov, Y. V, & Moharari, N. S. (2010). A generalized power system reliability and security index. *IEEE Power Tech. Conference, Budapest*, *31*.

Nazaruddin, Mahalla, Fauzi, Maimun, Subhan, Abubakar, S., & Aiyub, S. (2020). Reliability Analysis of 20 KV Electric Power Distribution System. *IOP Conference Series: Materials Science and Engineering*, *854*(1). https://doi.org/10.1088/1757-899X/854/1/012007

Ololade, O. S., Tang, P., & Sinneh, S. (2020). *Reliability and Fault Analysis of Electrical Distribution System : A Case Study of Kafanchan Distribution Substation in Kaduna*. *1*, 180–188.

Pradhan, A. K., Kar, S. K., shill, P. K., & Dash, P. (2020). Implementation of Monte Carlo simulation to the distribution network for its reliability assessment. *Innovation in Electrical Power Engineering, Communication, and Computing Technology: Proceedings of IEPCCT 2019*, 219–228.

R. Billinton and R. N. Allan. (1996). Chapter 2: Generating Capacity-Basic Probability Methods, in Reliability Evaluation of Power Systems. *Plenum Press: New York and London*.

Sonwane, P. (2024). *Distribution System Reliability: An Overview*.

Sucita, T., Mulyadi, Y., & Timotius, C. (2018). Reliability Evaluation of Power Distribution System with Reliability Index Assessment (RIA). *IOP Conference Series: Materials Science and Engineering*, *384*(1). https://doi.org/10.1088/1757-899X/384/1/012072

Timalsena, K. R. (2020). *Reliability {{Assessment}} of {{Power Distribution Networks Incorporating Circuit Breaker Failure Modes}}*. *March*.

Yadav, A. C. (2018). *Reliability Assessment of Distribution System At Presence*. *May*.

APPENDIX

I. Adama Mobile Substation M-1 Feeder Length

No.	Feeder Name	Network Name	Line Specific Name	Primary Voltage (KV)	Conductor Type (mm2)	Line Distance (KM)
1	Mobile-1	Network 1	National Defense	15 KV	AAC 50mm2	9.26 KM
2	Mobile-1	Network 2	Industry	15 KV	AAC 50mm2	5.86 KM
3	Mobile-1	Network 3	18 Kebele	15 KV	AAC 50mm2	9.08 KM
4	Mobile-1	Network 4	40 Meter	15 KV	AAC 50mm2	4.18 KM
5	Mobile-1	Network 5	Gende-Hara	15 KV	AAC 50mm2	6.31 KM
6	Mobile-1	Network 6	Muslim Cemetery	15 KV	AAC 50mm2	9.35 KM
Total						44.04 KM

II. Adama Mobile Substation M-1 Feeder Transformer Rating

No.	Transformer Name	Primary Voltage (KV)	Secondary Voltage (KV)	Rated Power (KVA)	Rated Load (KW)
1	DT-010599	15 KV	0.4 KV	200 KVA	160 KW
2	DT-010620	15 KV	0.4 KV	200 KVA	160 KW
3	DT-010617	15 KV	0.4 KV	200 KVA	160 KW
4	DT-010614	15 KV	0.4 KV	100 KVA	80 KW
5	DT-010610	15 KV	0.4 KV	100 KVA	80 KW
6	DT-010607	15 KV	0.4 KV	50 KVA	40 KW
7	DT-010604	15 KV	0.4 KV	25 KVA	20 KW
8	DT-010601	15 KV	0.4 KV	200 KVA	160 KW
9	DT-010594	15 KV	0.4 KV	315 KVA	252 KW
10	DT-010591	15 KV	0.4 KV	200 KVA	160 KW
11	DT-010588	15 KV	0.4 KV	50 kVA	40 KW
12	DT-010586	15 KV	0.4 KV	315 KVA	252 KW
13	DT-010597	15 KV	0.4 KV	200 KVA	160 KW
14	DT-010595	15 KV	0.4 KV	200 KVA	160 KW
15	DT-010592	15 KV	0.4 KV	25 KVA	20 KW
16	DT-010589	15 KV	0.4 KV	200 KVA	160 KW
17	DT-010585	15 KV	0.4 KV	315 KVA	252 KW
18	DT-010582	15 KV	0.4 KV	100 KVA	80 KW
19	DT-010579	15 KV	0.4 KV	315 KVA	252 KW
20	DT-010576	15 KV	0.4 KV	25 KVA	20 KW
21	DT-010596	15 KV	0.4 KV	400 KVA	320 KW
22	DT-010573	15 KV	0.4 KV	100 KVA	80 KW
23	DT-010593	15 KV	0.4 KV	315 KVA	252 KW
24	DT-010590	15 KV	0.4 KV	100 KVA	80 KW
25	DT-010583	15 KV	0.4 KV	315 KVA	252 KW
26	DT-010587	15 KV	0.4 KV	200 KVA	160 KW
27	DT-010584	15 KV	0.4 KV	50 kVA	40 KW

28	DT-010581	15 KV	0.4 KV	25 KVA	20 KW
29	DT-010580	15 KV	0.4 KV	100 KVA	80 KW
30	DT-010578	15 KV	0.4 KV	200 KVA	160 KW
31	DT-010577	15 KV	0.4 KV	315 KVA	252 KW
32	DT-010575	15 KV	0.4 KV	315 KVA	252 KW
33	DT-010572	15 KV	0.4 KV	200 KVA	160 KW
34	DT-010574	15 KV	0.4 KV	200 KVA	160 KW
35	DT-010571	15 KV	0.4 KV	315 KVA	252 KW
36	DT-010568	15 KV	0.4 KV	315 KVA	252 KW
37	DT-010545	15 KV	0.4 KV	200 KVA	160 KW
38	DT-010565	15 KV	0.4 KV	100 KVA	80 KW
39	DT-010564	15 KV	0.4 KV	315 KVA	252 KW
40	DT-010561	15 KV	0.4 KV	200 KVA	160 KW
41	DT-010558	15 KV	0.4 KV	200 KVA	160 KW
42	DT-010553	15 KV	0.4 KV	100 KVA	80 KW
43	DT-010552	15 KV	0.4 KV	50 kVA	40 KW
44	DT-010548	15 KV	0.4 KV	200 KVA	160 KW
45	DT-010569	15 KV	0.4 KV	50 kVA	40 KW
46	DT-010567	15 KV	0.4 KV	200 KVA	160 KW
47	DT-010563	15 KV	0.4 KV	200 KVA	160 KW
48	DT-010556	15 KV	0.4 KV	315 KVA	252 KW
49	DT-010554	15 KV	0.4 KV	315 KVA	252 KW
50	DT-010551	15 KV	0.4 KV	200 KVA	160 KW
51	DT-010549	15 KV	0.4 KV	315 KVA	252 KW
52	DT-010544	15 KV	0.4 KV	50 kVA	40 KW
53	DT-010570	15 KV	0.4 KV	315 KVA	252 KW
54	DT-010566	15 KV	0.4 KV	200 KVA	160 KW
55	DT-010562	15 KV	0.4 KV	315 KVA	252 KW
56	DT-010560	15 KV	0.4 KV	50 kVA	40 KW
57	DT-010559	15 KV	0.4 KV	315 KVA	252 KW

58	DT-010557	15 KV	0.4 KV	100 KVA	80 KW
59	DT-010555	15 KV	0.4 KV	100 KVA	80 KW
60	DT-010550	15 KV	0.4 KV	200 KVA	160 KW
61	DT-010547	15 KV	0.4 KV	315 KVA	252 KW
62	DT-010543	15 KV	0.4 KV	200 KVA	160 KW
63	DT-010537	15 KV	0.4 KV	315 KVA	252 KW
64	DT-010535	15 KV	0.4 KV	50 kVA	40 KW
65	DT-010532	15 KV	0.4 KV	315 KVA	252 KW
66	DT-010529	15 KV	0.4 KV	50 kVA	40 KW
67	DT-010526	15 KV	0.4 KV	200 KVA	160 KW
68	DT-010523	15 KV	0.4 KV	200 KVA	160 KW
69	DT-010539	15 KV	0.4 KV	100 KVA	80 KW
70	DT-010536	15 KV	0.4 KV	315 KVA	252 KW
71	DT-010534	15 KV	0.4 KV	50 kVA	40 KW
72	DT-010531	15 KV	0.4 KV	25 KVA	20 KW
73	DT-010528	15 KV	0.4 KV	200 KVA	160 KW
74	DT-010524	15 KV	0.4 KV	315 KVA	252 KW
75	DT-010541	15 KV	0.4 KV	50 kVA	40 KW
76	DT-010542	15 KV	0.4 KV	315 KVA	252 KW
77	DT-010540	15 KV	0.4 KV	200 KVA	160 KW
78	DT-010538	15 KV	0.4 KV	200 KVA	160 KW
79	DT-010533	15 KV	0.4 KV	100 KVA	80 KW
80	DT-010530	15 KV	0.4 KV	25 KVA	20 KW
81	DT-010527	15 KV	0.4 KV	100 KVA	80 KW
82	DT-010525	15 KV	0.4 KV	100 KVA	80 KW

III. Ethiopian Electric Utility Tariff Board

EEU Consumption Tariff		
Category	**Sub-category / Monthly Consumption (KWH)**	**Price Per KWH (Birr)**
Domestic Tariff	1st Block (up to 50)	0.2730
	2nd Block (up to 100)	0.7670
	3rd Block (up to 200)	1.6250
	4th Block (up to 300)	2.0000
	5th Block (up to 400)	2.2000
	6th Block (up to 500)	2.4050
	7th Block (above 500)	2.4810
General Tariff	Single Tariff	2.1240
Low Voltage Industry	Single Tariff	1.5310
	Demand Charge	200.0000
Medium Voltage Industry (15KV)	Single Tariff	1.1930
	Demand Charge	147.5400
High Voltage Industry (Above 66 KV)	Single Tariff	0.9280
	Demand Charge	87.6400
Straight Light	Single Tariff	2.1240

IV. Adama District 2013 E.C Annual MV Interruption Report

YEAR :-2013 E.C

To:- Oromia region

District Name...Adama

MV INTERRUPTION SUMMARY REPORT

Item No.	Substation Name	Feeder Name	No of Feeders	DPEF F	DPEF D [Hr.]	DPSC F	DPSC D [Hr.]	DTEF F	DTEF D [Hr.]	DTSC F	DTSC D [Hr.]	DLOL(LDC) F	DLOL(LDC) D [Hr.]	OP F	OP D [Hr.]	Frequency Of Interruption F	Duration Of Interruption D(Hr)	Remark
1	Adama Substation	LINE1	15KV	24	45.37	30	53.75	23	15.17	3	1.17	22	33.62	28	31.30	130	180.36	
2		LINE2	15KV	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	Not Working
3		LINE3	15KV	9	9.75	5	11.87	10	3.93	2	2.75	21	46.03	9	18.75	56	93.08	
4		LINE4	15KV	5	3.70	34	63.85	9	1.92	19	6.68	28	44.75	20	20.96	115	141.86	
5		LINE5	15KV	17	38.50	5	23.83	20	2.52	1	0.08	17	38.58	20	34.48	80	138.00	
6		LINE6	15KV	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	Not Working
7		LINE7	15KV	3	2.67	6	9.41	2	0.58	7	2.52	19	27.94	23	39.21	60	82.32	
8		MOBILE1	15KV	37	71.73	53	162.54	41	5.04	48	8.63	2	2.06	81	118.33	262	368.33	
9		MOBILE2	15KV	29	70.85	62	159.03	15	5.58	1	0.42	17	36.82	48	52.37	172	325.07	
10		MOBILE3	15KV	46	97.02	26	59.75	15	5.25	8	3.92	21	48.75	28	28.72	144	243.41	
11		MOBILE4	15KV	34	104.40	45	170.85	16	5.17	2	2.09	18	39.17	43	42.33	158	364.00	
12		MOBILE5	15KV	4	8.58	8	31.03	3	1.16	0	0.00	15	44.25	41	46.75	71	131.77	
13		MOBILE6	15KV	0	0.00	0	0.00	0	0.00	0	0.00	13	38.42	20	92.78	33	131.20	
	Sum			**208**	**452.56**	**274**	**745.91**	**154**	**46.33**	**91**	**28.25**	**193**	**400.38**	**361**	**525.98**	**1281**	**2199.41**	

prepaid by Gesite Mengiste

Sign

TEMESGAN NERI
Oromia Region Electric Utility
Adama District Distribution
Operation Manager

V. Adama District 2014 E.C Annual MV Interruption Report

Year:- 2014 E.C
To:- Oromia region
District Name:-Adama

MV INTERRUPTION SUMMARY REPORT

No.	Substation Name	Feeder Name	Voltage Level	Distribution												Frequency Of Intrruption (No.)	Duration Of Intrruption (Hr.)	Remark
				DPEF		DPSC		DTEF		DTSC		DLOL(LDC)		OP				
				F	D(Hr)	F	D(Hr)	F	D(Hr)	F	D(Hr)	F	D(Hr)	F	D(Hr)			
1	ADAMA SUBSTATION	LINE1	15KV	1	0.08	4	3.72	0	0.00	0	0.00	10	15.54	17	26.24	32	45.58	
2		LINE2	15KV	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	Not Working
3		LINE3	15KV	0	0.00	2	0.26	1	0.05	0	0.00	4	9.12	9	24.46	16	33.89	
4		LINE4	15KV	14	3.99	17	10.83	3	0.25	1	0.03	11	10.20	20	34.04	66	59.34	
5		LINE5	15KV	21	10.41	5	17.54	25	6.67	0	0.00	3	11.57	22	40.49	76	86.68	
6		LINE6	15KV	4	1.37	2	0.41	1	1.67	0	0.00	4	9.86	7	14.21	18	27.51	
7		LINE7	15KV	2	2.43	4	3.04	0	0.00	0	0.00	5	8.91	8	15.21	19	29.59	
8		MOBILE1	15KV	49	67.86	55	134.01	21	0.85	15	0.75	0	0.00	63	60.94	203	264.42	
9		MOBILE2	15KV	44	90.32	43	102.96	7	3.01	0	0.00	9	23.81	61	44.06	164	264.17	
10		MOBILE3	15KV	18	6.21	3	2.95	3	1.10	2	1.15	8	14.79	10	7.98	44	34.17	
11		MOBILE4	15KV	40	69.08	46	71.11	4	0.52	0	0.00	7	10.72	33	28.54	130	179.97	
12		MOBILE5	15KV	6	16.72	6	22.85	0	0.00	0	0.00	5	7.42	59	46.64	76	93.62	
13		MOBILE6	15KV	2	6.66	3	13.07	5	4.82	1	0.45	4	5.28	12	43.96	27	74.24	
	TOTAL			201	275.13	190	382.75	70	18.93	19	2.38	70	127.22	321	386.77	871	1193.18	

Pre Paired by : Getu Rorisa

TEMESGAN NERI
Oromia Region Electric Utility
Adama District Distribution
Operation Manager

VI. Adama District 2015 E.C Annual MV Interruption Report

Month :-Annual 2015 E.C
To:- Oromia region
District Name:-Adama

MV INTERRUPTION SUMMARY REPORT

No.	Substation Name	Feeder Name	Voltage Level	Distribution												Frequency Of Intrruption (No.)	Duration Of Intrruption (Hr.)	Remark
				DPEF		DPSC		DTEF		DTSC		DLOL(LOC)		OP				
				F	D(Hr)	F	D(Hr)	F	D(Hr)	F	D(Hr)	F	D(Hr)	F	D(Hr)			
1	ADAMA SUBSTATION	LINE1	15KV	3	0.25	3	7.18	0	0.00	4	1.20	19	17.83	6	7.69	35	34.15	
2		LINE2	15KV	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	Not Working
3		LINE3	15KV	3	5.90	5	1.93	2	0.67	2	0.56	4	2.05	8	22.27	24	33.37	
4		LINE4	15KV	8	9.32	14	4.70	5	0.58	19	6.25	9	5.78	7	8.54	62	35.17	
5		LINE5	15KV	5	3.48	14	33.37	47	7.49	6	2.35	2	0.93	32	35.69	106	83.31	
6		LINE6	15KV	4	12.38	1	1.03	0	0.00	1	0.40	3	1.28	4	8.19	13	23.29	
7		LINE7	15KV	2	0.20	4	2.24	0	0.00	3	1.16	7	6.31	4	12.14	20	22.06	
8		MOBILE1	15KV	44	81.31	65	129.90	16	4.97	3	3.90	14	12.62	52	52.91	194	285.61	
9		MOBILE2	15KV	1	6.68	2	0.63	0	0.00	1	0.11	7	3.32	8	8.08	19	18.83	
10		MOBILE3	15KV	6	2.16	1	10.10	4	1.43	0	0.00	7	3.45	1	0.87	19	18.01	
11		MOBILE4	15KV	35	72.40	34	72.66	7	4.07	1	0.53	10	15.46	31	23.27	118	188.41	
12		MOBILE5	15KV	3	9.32	1	1.08	0	0.00	0	0.00	6	4.35	31	20.36	41	35.11	
13		MOBILE6	15KV	4	2.76	0	0.00	2	0.75	0	0.00	7	4.42	4	4.22	17	12.15	
	TOTAL			118	206.158	144	264.83	83	19.967	40	16.464	95	77.828	188	204.226	668	789.473	

TEMESGAN NERI
Oromia Region Electric Utility
Adama District Distribution
Operation Manager

Prepared By: Addis Ashebir