POWER DISTRIBUTION SYSTEM RELIABILITY ASSESSMENT AND IMPROVEMENT BY PLACEMENT OF AUTO RECLOSERS AND FUSES BASED ON FUZZY LOGIC (A CASE STUDY OF WELISO TOWN)

TESFAYE NEGESSE GUTEMA

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Power Distribution System Reliability Assessment and Improvement by Placement of Auto Reclosers and Fuses based on Fuzzy Logic (A case Study of Weliso Town)

Tesfaye Negesse Gutema

Advisor: Dr. Prathibha. E

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DECLARATION

I hereby declare that this Master thesis entitled "**Power Distribution System Reliability Assessment and Improvement by Placement of Auto Reclosers and Fuses based on Fuzzy Logic, a case study of Weliso Town**" is my own work and 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 acknowledged through citation.

Tesfaye Negesse	________________________	________________
Name of student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Power Distribution System Reliability Assessment and Improvement by Placement of Auto Reclosers and Fuses based on Fuzzy logic, a case study of Weliso Town**" prepared under my guidance by Tesfaye Negesse, therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Prathibha. E	________________	______________
Major Advisor/Supervisor	Signature	Date

APPROVAL OF BOARD OF REVIEWERS

I, the advisors of the thesis entitled **"Power Distribution System Reliability Assessment and Improvement by placement of Auto Reclosers and Fuses based on Fuzzy Logic a case study of Weliso Town"** and developed by Tesfaye Negesse Gutema; hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Prathibha. E	________________	______________
Major Advisor/Supervisor	Signature	Date

We, the undersigned, members of the Board of reviewers of the proposal open defense by Tesfaye Negesse have read and evaluated the thesis proposal entitled **"Power Distribution System Reliability Assessment and Improvement by placement of Auto Reclosers and Fuses based on Fuzzy Logic a case study of Weliso Town"** and assessed the understanding of the candidate about the proposed research. This is, therefore, to certify that the thesis proposal is accepted and we recommend the implementation of the Thesis.

______________________	____________________	________________
Chairperson	Signature	Date
<u>Dr. C S Reddy</u>		____________
Reviewer 1	Signature	Date
<u>Dr. Firew Tafesse</u>	______________________	_________________
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LIST OF ABBREVATION

ACCI: Average Customer Curtailment Index, 21

AENSI: Average Energy Not Supplied Index, 21

AHP: Analytical Hierarchy Process, 24

ASAI: Average service availability indices, 21

ASUI: Average service unavailability indices, 21

BPSO: Binary particle swarm optimization, 22

CAIDI: Customers average interruption duration indices, 20

CAIFI: Customer Average Interruption Frequency Index, 20

CLS: Connected Load to the line segment, 54, 63

DEF: Distribution Earth Fault, 39

DG: Distribution Generation, 23

DLOL: Distribution Line Overload, 40

DSC: Distribution short circuit, 39

EEA: Ethiopian Electric Agency, 3

EENS: Expected Energy not Supplied, xiii

EEP: Ethiopian Electric Power, 5

EEU: Ethiopia Electric Utility, 3

ENS: Energy Not Supplied Index, 21

ETAP: Electrical Transient Analysis Program, xiii

GUP: Generating Unit Problem, 40

HRC: High Rupturing Capacity, 3

IEEE: Institute of Electrical and Electronics Engineers, 2

KV: Kilo Volt, xii, 80, 81

MAIFI: Momentary Average Interruption Frequency Index, 21

NBC: Number of branches connected to each bus, 54, 63

PTOL: Power transformer Overload, 40

SAIDI: System Average Interruption Duration Index, xiii, 80

SAIFI: System Average Interruption Frequency Index, xii, 80

SOL: System Over Load, 39

TLP: Transmission Line Problem, 3

ABSTRACT

Electric power supply reliability is very crucial factor for economic, political and technology development of the country. Currently, there is a rapid growth of industrial, commercial, residential and other service supplying institutions. All of these institutions need reliable power supply. A power system is reliable if it serves customers at load end without interruption. Increasing distribution system reliability is a necessity in order to reduce interruption events. In this thesis, Weliso Town are taken as a case study. As Weliso Town 15 Kilo Volt(KV) feeder has very important institution (Banks, Telecom, Hospital and University) and residential customers are facing a big challenge in their business and services due to frequent interruption and utility has taken long time to restore it. Major causes of interruptions are due to earth fault, short circuit and planned outage. The existing System Average Interruption Frequency Index (SAIFI) of Weliso is 272 interruptions per customer per year and System Average Interruption Duration Index (SAIDI) is 232 hours per customer per year respectively. These distribution systems are not reliable as Ethiopian Electric Agency standard directives which set SAIDI is below or Equal to 25 and SAIFI is below or equal to 20). The objective of the study is to assess the reliability of the current distribution system and propose solutions of reliability improvement by placement of Auto Reclosers and Fuses to mitigate the identified power reliability problems by making a detail reliability analysis. These analyses is modeled and evaluated using Electrical Transient Analysis Program (ETAP) tool to Simulate SAIFI, SAIDI and Expected Energy not Supplied (EENS). Optimal placement and coordination of Auto Reclosers and Fuses is determined by the Fuzzy Logic optimization technique using Mat lab software. After optimally placement of Recloses and Fuses at the needed location, the SAIFI, SAIDI and EENS are improved by 93.36 %, 87.07% and 87.65% respectively. The proposed solution has been saved 1656303 ETB per year from the unsold energy of one feeder only with 2.67 years' payback period investment.

***KEY WORDS**: Reliability improvement, Reliability Assessment, ETAP software, Crucial Protection devices, Mat lab, Fuzzy logic.*

CHAPTER ONE

INTRODUCTION

1.1. Background

The primary function of an electric distribution power system is to provide electricity to users. Electrical energy must be as cost-effective as possible while maintaining a reasonable degree of continuity and quality, according to modern society demands. By enhancing systems design, increased investment during the planning and operating phases, or doing both, it is possible to increase the reliability of the energy supply. In order to supply different types of loads to different consumers, a power system consists of a number of generating stations of different types that are connected by a system of transmission lines, sub transmission lines, and distribution networks. The substation plays a crucial role in providing the last connections between the utility and the customers (Brown, 2009).

Distribution systems deliver power from bulk power systems to retail customers. To do this, distribution substations receive power from sub transmission lines and step down voltages with power transformers. These transformers supply primary distribution systems made up of many distribution feeders. Feeders consist of a laterals, feeder interconnections, and distribution transformers. The outgoing feeders are connected in radial system. Distribution transformers step down voltages to utilization levels and supply secondary mains or service drops (Brown, 2009).

The key issue of electric power utilities nowadays is that power demand is rising rapidly while supply growth is being limited by a lack of resources, environmental issues, and other societal concerns. Since distribution systems account for up to 90% of all customer reliability problems, improving distribution reliability is the key to improving customer reliability (Brown, 2009).

Most of the time, Electric Power distribution system in Weliso are interrupted and affecting the customer's satisfaction and making EEU company cost. Reliability, availability together with maintainability is analyzed to determine the ability of system to accomplish an intended task. Availability is defined as the percentage of time a voltage source is uninterrupted. Its complement, unavailability, is the percentage of time a voltage source in interrupted. Since availability and unavailability deal strictly with interruptions, they are classified as a subset of reliability. Power reliability can be defined as the degree to which the performance of the elements in a bulk system results in electricity being delivered to customers within accepted standards and in the amount desired. The degree of reliability may be measured by the frequency, duration, and magnitude of adverse effects on the electric supply. There are many indices for measuring reliability. The three most common are referred to as SAIFI, SAIDI, and CAIDI, defined in Institute of Electrical and Electronics Engineers(IEEE) Standard 1366 (Kirby, 2004)

1.2. Overview of Study Area

Weliso is a town in Southwest Shewa Zone of the Oromia Regional state in Ethiopia, 114 km southwest of Addis Ababa, it has a latitude and longitude of 8°32′N 37°58′E / 8.533°N 37.967°E with an elevation of 2063 meters above sea level. It is one among the known big government institutional areas in Ethiopia, and therefore its power supply performance at distribution level need to be studied, evaluated and a better solution must be proposed, since the existing system has poor performance.

Weliso Mobile distribution substation is supplied from 66 KV from Welkite Substation. It has Three 12 Mega Volt Ampere(MVA) power transformers that step down a transmission voltage of 66 KV to 15 and 33 KV. There are four outgoing 33 KV and Five 15KV lines feeders.

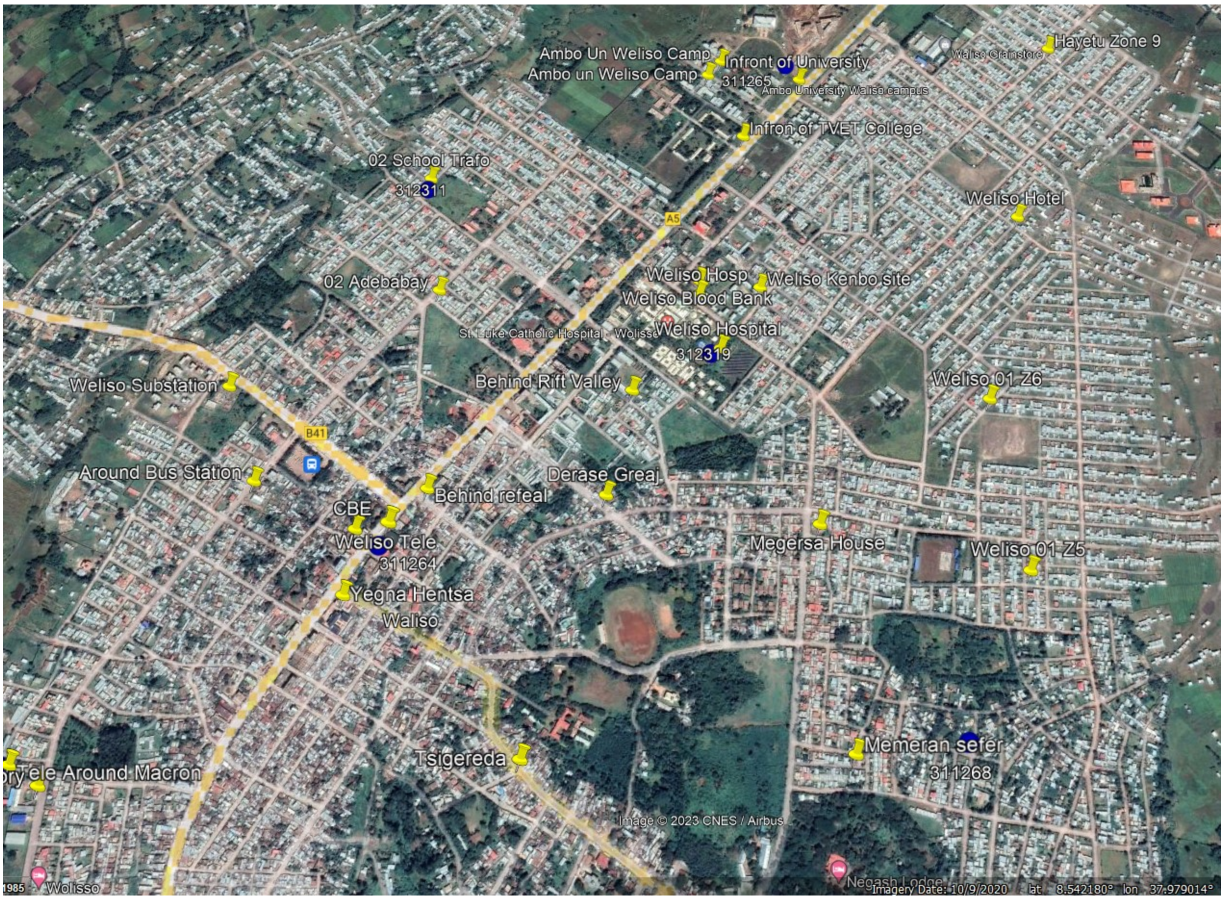


Figure 1.1:Google map of the study area

1.3. Statement of The Problem

Weliso Town have large to medium, and small industries as well as residential customers with in the Town are currently experiencing significant challenges with their regular company operations and goods. Following fault recognition and with the goal of restoring the system to a state where it can carry out its intended function, Weliso Ethiopia Electric Utility(EEU) employees always perform corrective maintenance to address these issues.

To provide services for customers, they always manually tracing fault location one by one and opening and closing the manual Section. They also replace some defective equipment, such as High Rupturing Capacity (HRC) fuses, which will immediately break. Interruption data record of the years 2020 up to 2022 G.C shows that, the reliability indices of the distribution system SAIFI is 272 interruptions per customer per year and SAIDI is 232 hours per customer per year which are very high compared to Ethiopian Electric Agency (EEA) reliability standard. This shows the need for reliability improvement methods to be implemented in the distribution system. The reliability of a radial distribution system can be improved by placing protection devices like Auto Reclosers at suitable feeder sections. The eventual aging of the electrical network, severity of the damages, repetition of repairs, and a lack of strategic maintenance trends are all contributing to the decline of the distribution network.

Additionally, it has been observed that Weliso EEU district staff is unable to offer a long-term solution to reduce the random power outages and provide reliable power to the premises. There is no any Auto Recloser, Auto Sectionalizer and tie switches on all distribution Feeders, most of the distribution Transformers are working without drop out Fuses and there is frequently power outage. Corrective maintenance does not provide a long-term solution for recurrent failures unless other protection devices configuration are implemented.

This thesis focused on assessment and improvement of reliability by placement of Auto Reclosers and Fuses in Weliso Town power distribution network. It tried to evaluate the performance of the existing system and finds reliability improvement solution.

1.4. Objectives of The Thesis

1.4.1. General Objectives

The main objective is to assess and evaluate the power distribution system reliability problem of Weliso for improving the reliability by placement of Auto Reclosers and Fuses based on Fuzzy Logic.

1.4.2. Specific Objectives

- To assess the reliability performance of existing distribution network.
- To Identify the possible causes of Weliso existing distribution system reliability problems
- To model the distribution system using ETAP (Electrical Transient Analysis Program) software
- To configure the system by determining number and location of Auto Reclosers using fuzzy logic optimization, and evaluate its reliability indices, such as SAIFI, SAIDI and EENS.
- To estimate the economic impact of power interruption utility.

1.5. Methodology

Methodology goes starting with problem identification and detail literature review studied from books and magazine. Problem identification is the first step toward solving the problem.

The methodology for data collection and system design procedures are the main activity of this thesis:

- **Literature review**: A number of Journals, Article, Papers and books are studied on Power Distribution system reliability.
- **Data Collection**
  - Two-year Interruption data (like interruption frequency, duration, Types of faults and causes of faults) has been gathered from Weliso Substation and Weliso EEU District office.
  - Collected data is analyzed and reliability of existing Power distribution system are assessed, then it is compared with EEA reliability standard.
  - Causes of Interruption are identified.
- **System Modeling**
  - The Power distribution system is represented by one-line diagram.
  - Reliability indices are calculated by Analytical method for Weliso Town.
  - Short Circuit current was calculated for protection devices Coordination's.
  - Optimal Placement and location of Auto Recloser by Fuzzy Logic tools using Matlab Software. Input Variables are number of branches connected with each section of the feeder, total connected load to the given section of the feeder and Section Line length. The Output variable are optimal location of Auto Reclosers.

- System will be modeled and evaluated by ETAP 19 software and power distribution system with protection devices along the feeder will be evaluated.
- Analysis will be done to estimate the revenue saved after the reliability is improved.

1.6. Significance of the Thesis

The primary goal is to assess and improve reliability while enhancing the performance of the distribution system being studied. Reliability of the network will be improved when a protection devices technique is put into practice. Generally, the importance of this study is:

- To indicate the influence of power interruption on economy of both customers and utility.
- It is regarded as a tool for the planning engineer to assure a fair level of service continuity and to select from a variety of expansion plans that are cost-effective when compared to system investment and loss costs.
- Increase reliability of the system by reducing the interruption.
- Increase the economy of the society and enhance industry sectors.

Thus, a methodology for Auto Reclosers location with the objective of identifying, in normal operating conditions, the optimal configuration for the distribution system that minimizes interruption costs while also enhancing reliability.

1.7. Scope and Limitation of the Thesis

It is focused on:

- Assessing and analyzing reliability of Weliso distribution system.
- Employing fuzzy logic optimization for optimal number and placement of Auto Reclosers on the selected feeder for improving system reliability.
- Comparing and discussing the results of the initial and optimal configuration.
- Make recommendations for utilities how the unwanted power interruptions can be minimized.
- Make a recommendation for utilities to use best maintenance to minimize the probability of occurrence of interruption in the distribution system.
- This analysis will help the power system planners and utilities to identify the sensitive components of the distribution system that need more attention for better improvement.

The main limitation of this thesis proposal is that the data handling of EEU and Ethiopian Electric Power(EEP) offices. They record every interruption data as the form of hardcopy and this was the very challenge during carrying out this thesis. Additionally, lack of adequate, consistent and timely data which are the key to electrical distribution system performance analysis.

1.8. Thesis Organizations

The thesis work has been done in such a way that it gives a clear flow and understanding regarding the thesis work.

Chapter one presents introduction, objectives and problem explanation.

Chapter two discusses the various literatures reviewed on the reliability of distribution systems.

Chapter three discusses methodologies for analyzing, assessing, and the reliability indices.

Chapter four, discusses results and discussion of the study.

Chapter five, discusses about conclusion and recommendation.

CHAPTER TWO

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1. Distribution System Reliability

The basic function of a power system is to supply its customers with electrical energy as economically and as reliably as possible. The application of reliability concepts to distribution systems differs from generation and transmission applications in that it is more customer load point oriented instead of being system oriented, and the local distribution system is considered rather than the whole integrated system involving the generation and transmission facilities.

Generation and transmission reliability also emphasizes capacity and loss of load probability, with some attention paid to components, whereas distribution reliability looks at all facets of engineering: design, planning, and operations. Because the distribution system is less complex than the integrated generation and transmission system, the probability mathematics involved is much simpler than that required for generation and transmission reliability assessments. (Brown, 2009; Turan Gonnen, 2006).

It is important to note that the distribution system is a vital link between the bulk power system and its customers. In many cases, these links are radial in nature that makes them vulnerable to customer interruptions due to a single outage event. A radial distribution circuit generally uses main feeders and lateral distributors to supply customer energy requirements (Brown, 2009). In the past, the distribution segment of a power system received considerably less attention in terms of reliability planning compared to generation and transmission segments. The basic reason behind this is the fact that generation and transmission segments are very capital intensive, and outages in these segments can cause widespread catastrophic economic consequences for society (Brown, 2009).

More than 90% of all customer interruptions occur due to failures in the distribution system. At present, in many electric utilities, acceptable levels of service continuity are determined by comparing the actual interruption frequency and duration indices (Brown, 2009).

Reliability is a measure of the ability of the power system to deliver electricity to all points of utilization within accepted standards and in the amount desired, for the period of time intended, under the operating conditions (Brown, 2009).

There are two main types of the reliability analysis of power system.

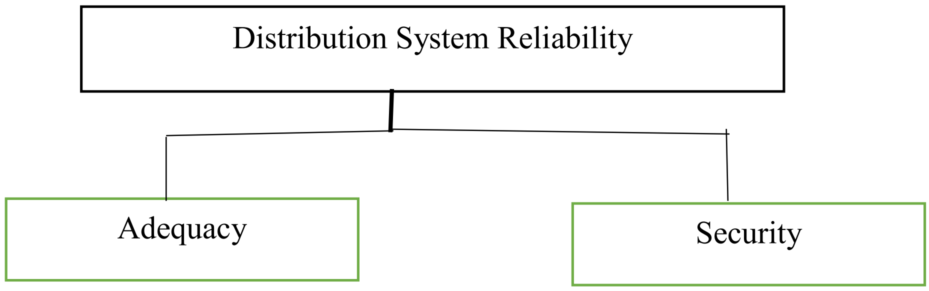


Figure 2. 1: Block diagram of power distribution system reliability

Security: Ability of the electric systems to respond to sudden disturbances arising within that system, such as electric short circuits. It is assessed using dynamic calculation

Adequacy: Relates to the existence of sufficient facilities within the system to satisfy the consumers load demand at all times; taking into account scheduled or unscheduled outages. It is assessed using the power flow solution (Chemdi Meteku, 2020).

Scheduled and unscheduled events disrupt normal operating conditions and can lead interruption to power supply. The unscheduled events may be as a result of oversights during installation or maintenance operations and faults. The scheduled events are usually as a result of the need to carry out maintenance operations on the equipment, consumer request, and usually consumers do get notice of interruption of supply in advance. From this, both scheduled and unscheduled events lead to operational interruptions (Brown, 2009).

2.2. Several Key Definitions Relating to Distribution Reliability

Contingency: - an unexpected event such as a fault or an open circuit. Another term for a contingency is an unscheduled event.

Open circuit: - a point in a circuit that interrupts load current without causing fault current to flow. An example of an open circuit is the false tripping of a circuit breaker.

Fault: - a short circuit. Faults are caused by dielectric breakdown of insulation systems and can be categorized as self-clearing, temporary, and permanent. A self-clearing fault will extinguish itself without any external intervention (e.g., a fault occurring on a secondary network that persists until it burns clear). A temporary fault is a short circuit that will clear if re-energized and then re-energized (e.g., an insulator flashover due to a lightning strike after the circuit is de-energized, the fault path will de-ionize, restoring the insulator to full dielectric strength). A permanent fault is a short circuit that will persist until repaired by human intervention.

Outage: - An outage occurs when a piece of equipment is de-energized. Outages can be either scheduled or unscheduled. Scheduled outages are known in advance (e.g., outages for periodic maintenance). Unscheduled outages result from contingencies.

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

Momentary Interruption Event: - a momentary interruption event consists of one or more momentary interruptions within a several minute time interval (e.g., if a Recloser operates three times and then holds, downstream customers experience three momentary interruptions and one momentary event).

Sustained Interruption: - a sustained interruption occurs when a customer is de-energized for more than a few minutes. Most sustained interruptions result from open circuits and faults (Brown, 2009).

2.3. Causes of Distribution Power System Interruption

The reasons for power interruption can vary, and can affect the length of time it takes to restore service back to customers. Here are some of the most common causes of interruption.

1. Storms: Wind, heat, ice and snow are the most common causes of widespread power outages.

2. Trees: During high winds, or trimming by an untrained professional, limbs can come into contact with power lines and cause interruptions.

3. Vehicles: A vehicle collision with a utility pole can cause a power outage.

4. Earthquakes: Quakes of all sizes can damage electrical facilities and power lines.

5. Animals: Although we place barriers between wildlife and electricity equipment, squirrels, snakes and other small animals may still cause a short circuit.

6. Lightning: When lightning strikes electrical equipment, transmission towers, wires and poles, outages can occur.

7. Excavation digging: Sometimes, underground cables are disturbed by digging.

8. High Power Demand: During heat waves and other times of unusually high power demand, overburdened electric cables, transformers, and other electrical equipment can melt and fails.

2.4. Electrical Power Distribution System Protection

The main objectives of distribution system protection are (1) to minimize the duration of a fault and (2) to minimize the number of consumers affected by the fault.

The secondary objectives of distribution system protection are:

- **i.** To eliminate safety hazards as fast as possible.
- **ii.** To limit service outages to the smallest possible segment of the system.
- **iii.** To protect the consumers' apparatus.
- **iv.** To protect the system from unnecessary service interruptions and disturbances.
- **v.** To disconnect faulted lines, transformers, or other apparatus.

Overhead distribution systems are subject two types of electrical faults, namely, transient (or temporary) faults and permanent faults. Depending on the nature of the system involved, approximately 75-90% of the total number of faults are temporary in nature. Usually transient faults occur when phase conductors electrically contact other phase conductors or ground momentarily due to trees, birds or other animals, high winds, lightning, flashovers, and so on. Transient faults are cleared by a service interruption of sufficient length of time to extinguish the power arc. Here, the fault duration is minimized and unnecessary fuse blowing is prevented by using instantaneous or high-speed tripping and automatic reclosing of a relay-controlled power circuit breaker or the automatic tripping and reclosing of a circuit Recloser. The breaker speed, relay settings, and Recloser characteristics are selected in a manner to interrupt the fault current before a series fuse (i.e. the nearest source-side fuse) is blown, which would cause the transient fault to become permanent.

Permanent faults are those which require repairs by repair crew in terms of:

- **i.** Replacing burned-down conductors, blown fuses, or any other damaged apparatus.
- **ii.** Removing tree limbs from the line.
- **iii.** Manually reclosing a circuit breaker or Recloser to restore service.

Here, the number of customers affected by a fault is minimized by properly selecting and locating the protective apparatus on the feeder main, at the tap point of each branch, and at critical locations on branch circuits. Permanent faults are cleared by fuse cutouts installed at sub main and lateral tap points. This practice limits the number of customers affected by a permanent fault and helps locate the fault point by reducing the area involved. In general, the only part of the distribution circuit not protected by fuses is the main feeder and feeder tie line. The substation is protected from faults on feeder and tie lines by circuit breakers and/or Reclosers located inside the substation.

Most of the faults are permanent on an underground distribution system, there by requiring a different protection approach. Although the number of faults occurring on an underground system is relatively much less than that on the overhead systems, they are usually permanent and can affect a larger number of customers. Faults occurring in the underground residential distribution (URD) systems are cleared by the blowing of the nearest sectionalizing fuse or fuses. Faults occurring on the feeder are cleared by tripping and lockout of the feeder breaker (Gonen, 2015).

A wide variety of equipment is used to protect distribution networks. The particular type of protection used depends on the system element being protected and the system voltage level, and, even though there are no specific standards for the overall protection of distribution networks, some general indication of how these systems work can be made.

The devices most used for distribution system protection are overcurrent relays, Reclosers, Sectionalizer and Fuses.

2.4.1. Recloser

A distribution Recloser is designed to interrupt both load and fault current. Also, per its term, it is designed to "reclose" on the fault repeatedly in a predefined sequence in an attempt to clear the fault. Reclosers have two basic functions on the system, reliability and over current protection. Nowadays, Reclosers are more frequently applied for reliability reasons, mainly due to three of their benefits: Reclosing capability, single phase reclosing, and automated loop capabilities.

A Recloser is a device with the ability to detect phase and phase-to-earth overcurrent conditions, to interrupt the circuit if the overcurrent persists after a predetermined time, and then to automatically reclose to reenergize the line. If the fault that originated the operation still exists, then the Recloser will stay open after a preset number of operations, thus isolating the faulted section from the rest of the system. In an overhead distribution system between 80 to 95 per cent of the faults are of a temporary nature and last, at the most, for a few cycles or seconds. Thus, the Recloser, with its opening/closing characteristic, prevents a distribution circuit being left out of service for temporary faults. Typically, Reclosers are designed to have up to three open close operations and, after these, a final open operation to lock out the sequence. One further closing operation by manual means is usually allowed.

The counting mechanisms register operations of the phase or earth-fault units which can also be initiated by externally controlled devices when appropriate communication means are available (J.Holmes, 2005).)

Coordination with other protection devices is important in order to ensure that, when a fault occurs, the smallest section of the circuit is disconnected to minimize disruption of supplies to customers. Generally, the time characteristic and the sequence of operation of the Recloser are selected to coordinate with mechanisms upstream towards the source. After selecting the size and sequence of operation of the Recloser, the devices downstream are adjusted in order to achieve correct coordination.
A typical sequence of a Recloser operation for a permanent fault is shown in figure 2.2. The first shot is carried out in instantaneous mode to clear temporary faults before they cause damage to the lines. The three later ones operate in a timed manner with predetermined time settings. If the fault is permanent, the time-delay operation allows other protection devices nearer to the fault to open, limiting the amount of the network being disconnected. Earth faults are less severe than phase faults and, therefore, it is important that the Recloser has an appropriate sensitivity to detect them. One method is to use CTs connected residually so that the resultant residual current under normal conditions is approximately zero. The Recloser should operate when the residual current exceeds the setting value, as would occur during earth faults (J.Holmes, 2005)

Reclosers can be classified as single-phase and three-phase, mechanisms with hydraulic or electronic operation and oil, vacuum or SF6.

Single-phase Reclosers are used when the load is predominantly single-phase. In such a case, when a single-phase fault occurs the Recloser should permanently disconnect the faulted phase so that supplies are maintained on the other phases. Three-phase Reclosers are used when it is necessary to disconnect all three phases in order to prevent unbalanced loading on the system. Reclosers with hydraulic operating mechanisms have a disconnecting coil in series with the line. When the current exceeds the setting value, the coil attracts a piston that opens the Recloser main contacts and interrupts the circuit. The time characteristic and operating sequence of the Recloser are dependent on the flow of oil in different chambers. The electronic type of control mechanism is normally located outside the Recloser and receives current signals from a CT-type bushing. When the current exceeds the predetermined setting, a delayed shot is initiated that finally results in a tripping signal being transmitted to the Recloser control mechanism. The control circuit determines the subsequent opening and closing of the mechanism, depending on its setting. Reclosers with electronic operating mechanisms use a coil or motor mechanism to close the contacts. Oil Reclosers use the oil to extinguish the arc and also to act as the basic insulation. The same oil can be used in the control mechanism.

Vacuum and SF6 Reclosers have the advantage of requiring less maintenance.

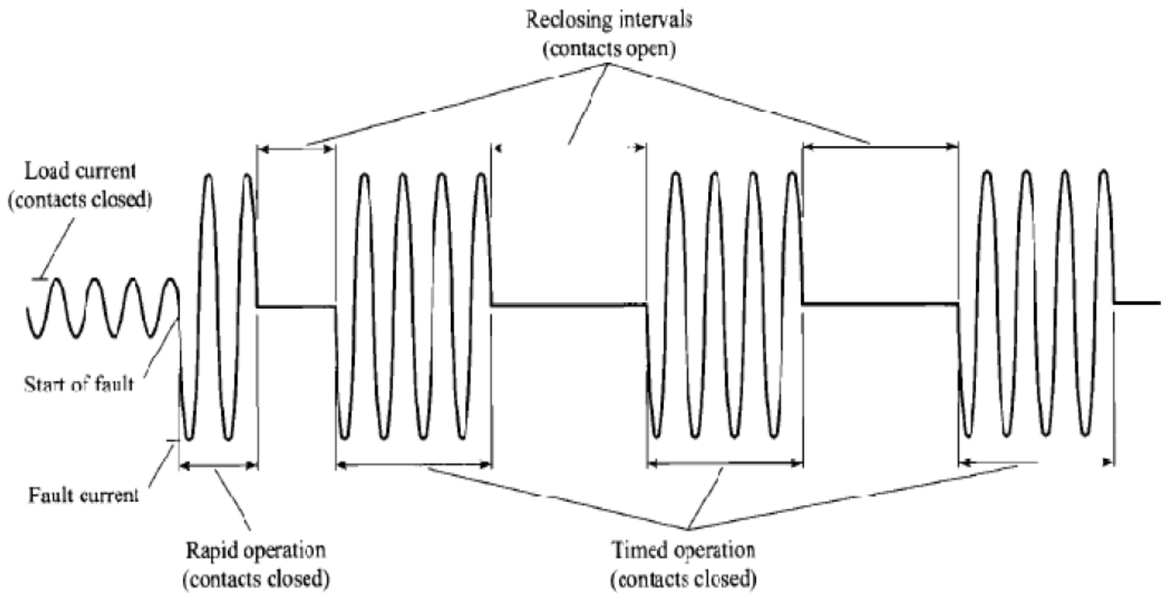


Figure 2. 2:Typical Sequence for Recloser Operation

Reclosers are used at the following points on a distribution network:

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

When installing Reclosers it is necessary to take into account the following factors:

- **i.** System voltage: System voltage will be known. The Recloser must have a voltage rating equal to system voltage.
- **ii.** Maximum fault current available at the Recloser location: Maximum fault current will be known or can be calculated. The Recloser interrupting must be equal to (or greater than) the maximum available fault current at the Recloser location.

iii. Maximum load current: The Recloser continuous current rating must be equal to (or greater than) anticipated circuit load. For series-coil-type Reclosers, the coil size can be selected to match the present load current, the anticipated future load current, or the substation transformer capacity. Generally, a trip-current value of at least twice the expected load current is used.

iv. Minimum-fault current within the zone to be protected: Minimum fault current that might occur at the end of the line section must be checked to confirm that the Recloser will sense and interrupt this current.

v. Coordination with other protective devices on both source & load sides of the Reclosers. Proper selection of time delays & sequences is vital to ensure that any momentary interruption or longer outage due to faults is restricted to the smallest possible section of the system.

vi. Ground Fault Sensing. The ground fault settings (minimum trip & timing) must be coordinated with the phase trip settings of the downline single phase devices like single phase Reclosers & fuses.

The voltage rating and the short-circuit capacity of the Recloser should be equal to, or greater than, the values that exist at the point of installation. The same criteria should be applied to the current capability of the Recloser in respect of the maximum load current to be carried by the circuit. It is also necessary to ensure that the fault current at the end of the line being protected is high enough to cause operation of the Recloser.

The operation of a Recloser depends on its time current curve (TCC). Each Recloser has two TCCs: the fast and delayed curves. The Recloser is on the fast tripping setting if it operates on the fast curve. Similarly, it is considered to be on the delayed setting if it operates on the delayed curve. Figure 2.3 shows a fault current on a typical TCC of a Recloser. The Recloser will interrupt within 0.04 s on the instantaneous setting or within 1.3 s if on the time-delay setting (Hailemariam, July 2016).

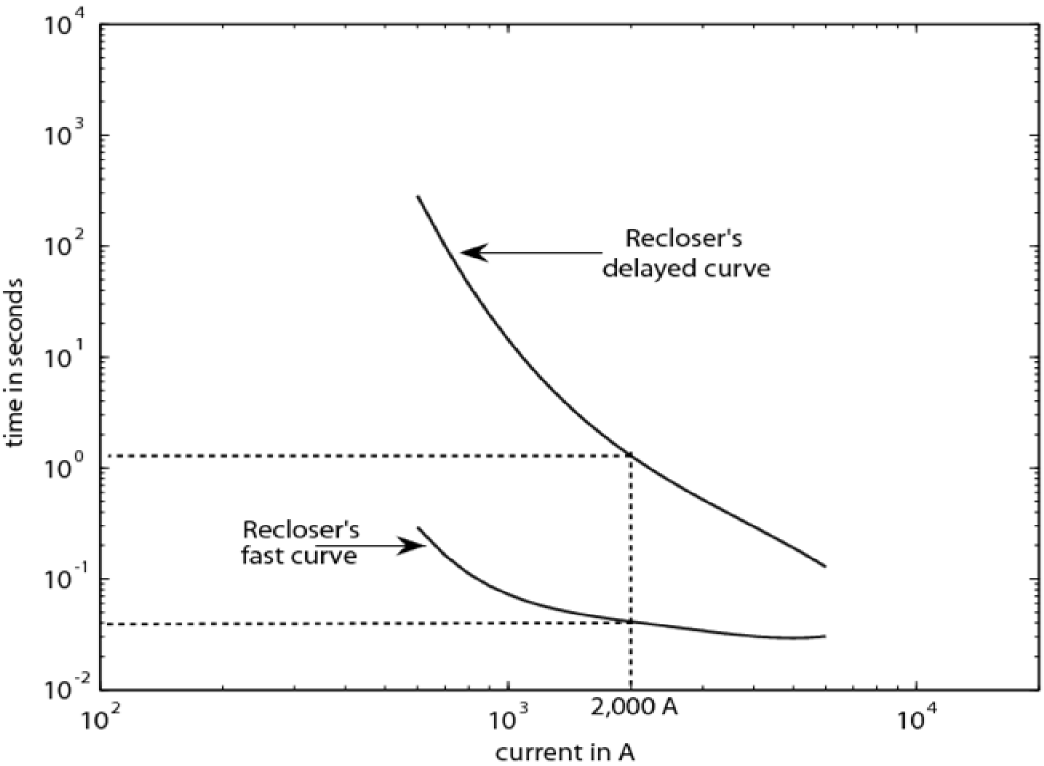


Figure 2. 3:Time-current characteristics of a Recloser: fast and delayed curves

2.4.2. Sectionalizer

A Sectionalizer is a device that automatically isolates faulted sections of a distribution circuit once an upstream breaker or Recloser has interrupted the fault current and is usually installed downstream of a Recloser. Since Sectionalizer have no capacity to break fault current, they must be used with a back-up device that has fault current breaking capacity. Sectionalizer count the number of operations of the Recloser during fault conditions. After a preselected number of Recloser openings, and while the Recloser is open, the Sectionalizer opens and isolates the faulty section of line. This permits the Recloser to close and re-establish supplies to those areas free of faults. If the fault is temporary, the operating mechanism of the Sectionalizer is reset.

Sectionalizers are constructed in single- or three-phase arrangements with hydraulic or electronic operating mechanisms. A sectionalizer does not have a current/time operating characteristic, and can be used between two protective devices whose operating curves are very close and where an additional step in coordination is not practicable.

Sectionalizers with hydraulic operating mechanisms have an operating coil in series with the line. Each time an overcurrent occurs the coil drives a piston that activates a counting mechanism when the circuit is opened and the current is zero by the displacement of oil across the chambers of the sectionalizer. After a prearranged number of circuit openings, the sectionalizer contacts are opened by means of pretensioned springs. This type of sectionalizer can be closed manually. Sectionalizers with electronic operating mechanisms are more flexible in operation and easier to set. The load current is measured by means of CTs and the secondary current is fed to a control circuit which counts the number of operations of the Recloser or the associated interrupter and then sends a tripping signal to the opening mechanism. This type of sectionalizer is constructed with manual or motor closing (J.Holmes, 2005).

The following factors should be considered when selecting a sectionalizer:

- **i.** System voltage.
- **ii.** Maximum load current.
- **iii.** Maximum short-circuit level.
- **iv.** Coordination with protection devices installed upstream and downstream.

The nominal voltage and current of a sectionalizer should be equal to or greater than the maximum values of voltage or load at the point of installation. The short circuit capacity (momentary rating) of a sectionalizer should be equal to or greater than the fault level at the point of installation. The maximum clearance time of the associated interrupter should not be permitted to exceed the short-circuit rating of the sectionalizer. Coordination factors that need to be taken into account include the starting current setting and the number of operations of the associated interrupter before opening.

2.4.3. Fuses

A fuse is an overcurrent protection device; it possesses an element that is directly heated by the passage of current and is destroyed when the current exceeds a predetermined value. A suitably selected fuse should open the circuit by the destruction of the fuse element, eliminate the arc established during the destruction of the element and then maintain circuit conditions open with nominal voltage applied to its terminals, (i.e. no arcing across the fuse element).

The majority of fuses used in distribution systems operate on the expulsion principle, i.e. they have a tube to confine the arc, with the interior covered with de-ionizing fiber, and a fusible element. In the presence of a fault, the interior fiber is heated up when the fusible element melts and produces de-ionizing gases which accumulate in the tube. The arc is compressed and expelled out of the tube; in addition, the escape of gas from the ends of the tube causes the particles that sustain the arc to be expelled. In this way, the arc is extinguished when current zero is reached. The presence of de-ionizing gases, and the turbulence within the tube, ensure that the fault current is not re-established after the current passes through zero point. The zone of operation is limited by two factors; the lower limit based on the minimum time required for the fusing of the element (minimum melting time) with the upper limit determined by the maximum total time that the fuse takes to clear the fault.

There are a number of standards to classify fuses according to the rated voltages, rated currents, time/current characteristics, manufacturing features and other considerations. For example, there are several sections of ANSI/UL 198-1982 standards that cover low voltage fuses of 600 V or less. For medium and high voltage fuses within the range 2.3-138 kV, standards such as ANSI/IEEE C37.40, 41, 42, 46, 47 and 48 apply. Other organizations and countries have their own standards; in addition, fuse manufacturers have their own classifications and designations.

In distribution systems, the use of fuse links designated K and T for fast and slow types, respectively, depending on the speed ratio, is very popular. The speed ratio is the ratio of minimum melt current that causes fuse operation at 0.1 s to the minimum melt current for 300 s operation. For the K link, a speed ratio (SR) of 6-8 is defined and, for a T link, 10-13.

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

- **i.** Voltage and insulation level.
- **ii.** Type of system.
- **iii.** Maximum short-circuit level.
- **iv.** Load current.

Pick-up current

Pickup is defined as that minimum current that starts an action and it is the minimum value of current that will cause the relay to close its contacts.

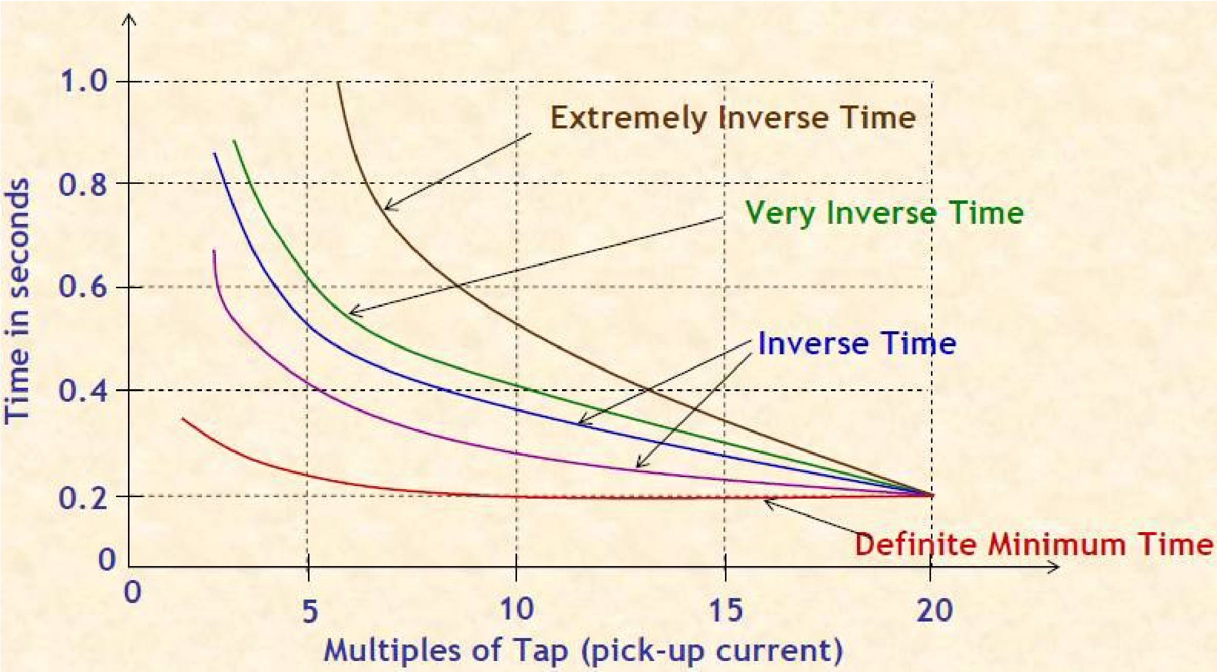


Figure 2. 4:Multiples of Tap (pick up current)

Pickup current should be above maximum load current seen by the feeder. This ensures that relay does not trip on load. Typical norm is to set $I_p > 1.25\ I_{Lmax}$ where I_P is relay pickup current and I_{Lmax} is the maximum load current on the relay. The pickup current should also be below the minimum fault current i.e.; $I_P < I_{fmin}$ where Ifmin is the minimum fault current on the relay. This ensures that protection system operates for low as well as high fault current. During this condition, in the utility least number of generators are in service. Hence, this coordination occurs at light load condition and at the remote end of the feeder of the respective devices. Pick up current should also be below the minimum fault current of the feeder that it has to backup. Otherwise, a relay's backup protection responsibility will not be fulfilled.

In an overcurrent relay, an additional feature of Time Multiplier Setting (TMS) is provided. The basic idea is that by increasing or decreasing the TMS, the relay operating time can be increased or decreased proportionately. TMS is also referred to as TDS (Time Dial Setting). It is means of adjusting the time taken by the relay to trip once the current exceeds the set value.

T.M.S. is defined as, $$T.M.S = \frac{\mathrm{T}}{Tm} \qquad (2.1)$$

T - is the required relay operating time

Tm - is the corresponding operating time at TMS of 1.0.

The ratio (I/Ip) is called the Plug Setting Multiplier (PSM) where Ip is the pickup current which is the reference or threshold for discriminating over current and I is measured device current. Since currents are measured through current transformer, both Ip and I should be referred to either primary or secondary of the CT. The value of PSM indicates the severity of the fault as seen by the relay. Trip the device, if PSM is above the threshold. The threshold should be strictly greater than 1, e.g. 1.5.

For relays which do not have co-ordination responsibility (e.g. relays at the leaf nodes), usually TMS can be set to the minimum. With the knowledge of PSM and TMS, the desired relay operating time is calculated. Strong inverse time-current curve is chosen for the circuit breakers and Reclosers since expulsion fuse types shall be used in the medium voltage network and supposed to be coordinated accordingly. (Hailemariam, July 2016)

2. 5. Distribution System Reliability Indices

Supply reliability, a crucial concept in the calculation of supply continuity, is one of the perspective from which the performance of the distribution network can be analyzed. Reliability indices are a statistical aggregations of reliability data for a well-designed set of system components (B. Tomoiag, 2018).

Reliability indices typically consider such aspects as:

- The number of customers;
- The connected load;
- The duration of the interruption measured in seconds, minutes, hours, or days;
- The amount of power (kVA) interrupted; and
- The frequency of interruptions.

2.5.1. Customer-Oriented Indices

i. System average interruption frequency indices (SAIFI)

This the measure or the indicators of how much customers experienced sustained interruptions over the predefined period of time .in which it express in a year. In other words, it is calculated by dividing the total number of customers interrupted by an outage by the total number of customers in the system. SAIFI describes how often the average customer experiences an interruption.

$$\text{SAIFI} = \frac{\text{Total Number of Interruptions}}{\text{Total Number of Customers Served}} = \frac{\sum_{i=1}^{n} Ni}{\text{NT}} \quad (2.2)$$

Where Ni is the number of customers at load points i; and NT is the total number of customers in the system for which the index is calculated.

Lower SAIFI numbers represent less interruptions and better electric reliability.

SAIFI can be improved by reducing the frequency of outages through better preventative maintenance. Improved equipment maintenance and tree-trimming, for example, can limit the number of service interruptions. Also be improved by "reducing the number of customers interrupted when outages do occur (for example, by adding Recloses and fuses).

ii. System average interruption duration indices (SAIDI)

SAIDI is the measure of the total number of duration interruption over the predefined period of time. In other words, it is calculated by multiplying the average duration of customer interruptions by their total number and then dividing by the total number of customers in the system. SAIDI describes the total duration of the average customer interruption.

$$\text{SAIDI} = \frac{\text{Total Customer Interruption Durations}}{\text{Total Number of Customers Served}} = \frac{\sum_{i=1}^{n} ri\ Ni}{\text{NT}} \qquad (2.3)$$

Where, ri is the restoration time for each incident, Ni is the number of customers affected by each incident; and NT is the total number of customers in the system for which the index is calculated (expressed in hours lost per customers per year).

SAIDI can be improved by reducing the number of interruptions or the duration of the interruptions.

iii. Customers average interruption duration indices (CAIDI)

CAIDI refers to "Customer Average Interruption Duration Index." It is calculated as total minutes of customer interruption divided by the total number of customers interrupted.

CAIDI describes the average time required to restore service. Unlike SAIDI/SAIFI, CAIDI includes only customers who actually experienced an interruption. This fact makes it useful for measuring response to interruptions, but not the prevention of interruptions.

$$\text{CAIDI} = \frac{\text{Total Customer Inte rruption Durations}}{\text{Total Number of Customers Interruptions}} = \frac{\sum_{i=1}^{n} ri\ Ni}{\sum_{i=1}^{n} Ni} = \frac{\text{SAIDI}}{\text{SAIFI}} \qquad (2.4)$$

CAIDI improvement strategies include automated call-out of troubleshooters and crews for faster outage resolution and increased troubleshooter staffing.

iv. Customer Average Interruption Frequency Index (CAIFI)

This index gives the average frequency of sustained interruptions for those customers experiencing sustained interruptions. It is calculated by dividing the number of interruptions by the number of customers experiencing interruptions.

$$\text{CAIFI} = \frac{\text{Total Customer Interruptions}}{\text{Number of Distinict Customers Interrupted}} = \frac{\sum_{i=1}^{n} NT}{\sum_{i=1}^{n} Ni} \qquad (2.5)$$

CAIFI describes how many interruptions each impacted customer experiences. Therefore, it helps detect whether problems are being resolved effectively or left vulnerable to recurrence.

Like, CAIDI, this metric only includes customers who actually experienced interruptions (not customers across the whole system).

v. Average service availability indices (ASAI)

The fraction of time that customer has supplying power during the specific reporting period of time I called ASAI.

$$\mathrm{ASAI} = \frac{\text{Customer Hours Service Available}}{\text{Customer Hours Service Demanded}} = \frac{8760\frac{hr}{year} - CAIDI}{\frac{\text{8760Hr}}{\text{year}}} \quad (2.6)$$

vi. Average service unavailability indices (ASUI)

ASUI can be express mathematical as $ASUI$=1−Average Services Availability indices($ASAI$) $ASUI$= $duration\ of outage\ in\ hours\ total\ hours\ demand.$

$$\mathrm{ASUI} = 1 - \mathrm{ASAI} = \frac{\text{SAIDI}}{\text{8760 Hr/year}} \quad (2.7)$$

The total hour demand is for one year which is 8760 hours.

2.5.2. Load or Energy-Oriented Indices

1) **Energy Not Supplied Index (ENS):** This index represents the total energy not supplied by the system. And it is given by

$$\mathrm{ENS} = \sum_i^n La(i)Ui \quad (2.8)$$

Where, La (i) is the average load given by:

$$\mathrm{La(i)} = \mathrm{LP\ (i)}*\mathrm{LF(i)} = \frac{-\mathrm{Ed(i)}}{\mathrm{t}} \quad (2.9)$$

LP is peak load demand, LF is the load factor, and Ed is the total energy demanded in the period of interest t.

Load Factor: is the ratio of actual Energy used in a year to the possible Energy that could have been used in a year.

2) **Average Energy Not Supplied Index (AENSI)**

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

$$AENS = \frac{\text{Total energy not supplied}}{\text{Total number of customers served}} = \frac{\sum_i^n La(i)Ui}{\sum_i^n Ni} \quad (2.10)$$

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

$$ACCI = \frac{\text{Total energy not supplied}}{\text{Total number of customers Affected}} = \frac{\sum_i^n La(i)Ui}{\sum_i^n No} \quad (2.11)$$

Where: La (i) is the average load, No is the number of customers affected

4) **Momentary Average Interruption Frequency Index(MAIFI)**.

MAIFI is the total number of customer momentary interruptions divided by the total number of customers served. Momentary interruptions are defined in IEEE Std. 1366 as those that result from each single operation of an interrupting device. The momentary interruptions are the interruptions that occur in a specified time not to exceed five minutes.

$$\text{MAIFI} = \frac{\text{Total number of customer momentry interruption}}{\text{Total number of customer served}} = \frac{\sum_{i=1}^{n} \text{IDi}* \text{Ni}}{NT} \quad (2.12)$$

Where: IDi is the number of interrupting device operations, Ni is the number of customers experiencing momentary interruptions, and NT is the total number of customers served.

In this thesis, SAIDI, SAIFI and ENS are taken for comparison of reliability indices after Optimal Placement of Protection devices (Auto Reclosers and Fuses).

2.5.3. Economic Cost Outage

Power interruption costs in both the utility and the customer sides. The size of the economic losses due to interruptions depends largely on the composition of the customers that experience interruptions.

$$\text{Interruption cost} = \frac{\sum_{i=1}^{n} Li* \text{IDi}* \text{Tariif birr}}{NT} \quad (2.13)$$

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

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

IDi = Interruption Duration (hr.) for event i.

2.6. Literature Review

The research publications which are related to power distribution system reliability enhancements are discussed in this section. Power interruption becomes a serious problem in the country, Ethiopia and the number of outages is very high and it takes long time for service restoration, the distribution systems need to be automated to improve their reliability, efficiency, and service quality.

Desta Tegegne (Asradew, 2022) have studied the reliability assessment on 15kV Ankober electric power system to assess the performance of the existing system and also predictive reliability improvement for the future system considering distribution system reconfiguration (optimal coordination of switches. For predictive reliability and power quality improvement binary particle swarm optimization has been applied which delivers optimal number and optimal placement of switches on the selected. The placement of switches in strategic places reduces the outage time in case of interruption, and improves the reliability of the network. To solve the problem of number of sectionalizes switches allocation a binary particle swarm optimization (BPSO) method has been selected. As the result the optimal number and placement of sectionalizes switches changed and the existing energy not supplied (EENS) can be improved. The Authors mentioned only about sectionalize switches, not how to restore power immediately.

J. N. Nweke (Nweke, 2020)have developed a system planning approach as part of the key mitigation strategies for improved reliability and protection of the distribution network. The developed algorithm is tested using 33kV feeder supplying electricity to Kaura-Namoda, Zamfara State, Nigeria. A customer-based reliability index was used as a tool to evaluate the reliability assessment of the feeder test system. The result showed that alternative 3 gives better results in terms of improvement of the system average interruption duration index (SAIDI), which in turn gives the minimum interrupted energy. The author mentioned that is very important to place the sectionalizing switches at a strategic location. If it is located at such points that will facilitate to sectionalize the faulty sections faster and to make the supply available to the unfaulty part of the network. The author does not reveal the method used to locate the Sectionalize switches at strategic location.

Chemdi Mitiku (Chemdi Meteku, 2020)Evaluates the best solution for improving the reliability of distribution system. Therefore, the best solutions to distribution system reliability problems, integrating Distribution Generation (DG) to the existing network as backup. For best placement of DG on the distribution system at different load point, reliability improvement with DG has been investigated. With DG option at the end of the line, the simulation result shows that the SAIFI and SAIDI of the feeder improved. The authors mentioned as Inserting of a Distributed Generation to the existing distribution system has its own challenges, like might cause power quality problems (such as Over-voltage, fluctuation, etc.) if coordination with the utility supply is not properly achieved. This need high investment cost.

Eyasu Berhanu (Eyasu Berhanu, 2017) have studied power system reliability assessment and improvement with a case study in Jimma town of 15kV feeder to assess the performance of the present system and also predictive reliability analysis for the future. The author has evaluated different mitigation alternatives to improve the system reliability at reasonable cost. Many alternatives have been assessed using heuristic method and the alternative with low SAIDI, SAIFI and EENS at a reasonable cost has been selected. The thesis work reveals that the reliability of the system has been improved significantly by implementing reliability improvement solutions that are justified economically. Even if the uncertainty of the input data is taken into account, SAIFI, SAIDI and EENS have been decreased.

Getaye Yeshaneh Sinishaw (Sinishaw, 2021)have studied smart grid technology applications using optimal placement of switching/automating de- vices, network reconfiguration and rapid power restoration is performed to improve the reliability problem of Bahir Dar power distribution system. Optimal placement of switching/automating devices and network reconfiguration is determined by the Genetic Algorithm optimization technique using mat lab software. The rapid power restoration is carried out by Prim 's Algorithm used for constructing the Minimum Spanning Tree in mat lab software. The existing network is assessed and the reliability indices such as SAIFI, SAIDI, ASAI, CAIDI and EENS are evaluated using ETAP software. The study need communication infrastructure to Automate and SMART, it need also Power for Electronics devices.

Masoud AMOHADI (M. Amohadi, 2019)suggests a new method to determine the optimal number and locations of Auto Recloser and sectionalizer switches in distribution networks. The costs of AR/S investment, switch maintenance, and undistributed energy as well as reliability coefficients are considered in the objective function. Reliability parameters such as SAIFI, SADI, MAIFI and ENS are evaluated in the case study system. As a new method, the weights of the reliability parameters are obtained by decision-makers using the Analytical Hierarchy Process (AHP). The optimal size, type, and location of automatic switches are determined by minimizing the objective function using the Particle Swarm Optimization (PSO) algorithm. The paper did not describe about power restoration. Therefore, by including power restoration mechanisms reliability can be improved more and more.

In general, the aforementioned reliability analysis, evaluation, and improvement include the distribution system's reliability but some of the Authors did not include about Power restoration and reliability of Distribution system doesn't improved in excellent way. Some are need communication infrastructure, method to place and coordinate the protection devices doesn't consider, they do not used or proposed Auto Recloser and they were used high investment cost like DG integration to improve Reliability.

In this Thesis, the problem of Auto Reclosers placement in Power distribution system can be modeled by using Fuzzy Logic to reduce SAIFI & SAIDI in order to achieve a good of reliability improvement.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Introduction

The methodologies used for data collection and the design procedures to improve the reliability of Weliso Town power distribution system is discussed in in detail in this chapter. A mathematical model (often simplified for actual systems) and direct mathematical solutions are used in the analytical technique for the evaluation of reliability indices.

3.2. Site Description

The geographical coordinates of Weliso substation latitude and longitude of 8.586947657, 38.01456129, 114 km away from Addis Ababa, capital of Ethiopia.

Weliso substation supplies electric power to Weliso town and the nearby areas and it receives power from Welkite Substation via 66kv power lines The 66KV is stepped down and distributed by 15 and 33kv feeders.

The substation consists of 9 outgoing feeders out of this, two feeders are reserved, the nominal voltage of the five feeders is 15 kV and the other four feeders is 33KV. There are two Power Transformers which have 12MVA capacity and step down to 15KV. The Two Transformers are working in parallel. The other Transformer has a capacity of 12MVA and step down to 33KV. The breakers are vacuum and SF6. The 15KV medium voltage feeders were renamed by the local names of the area. These are Weliso, Tulubollo, Amaya and Goro. The 33KV Medium Voltage feeders local name are Kota, Acheber and Busa. The 33KV lines are used for far rural areas which has to be extended further in order to cover all the rural electrification activities. The main feeder and sub feeders before the transformer are three phase three wire circuits and the laterals are three phase four wire or single phase two wire circuits.

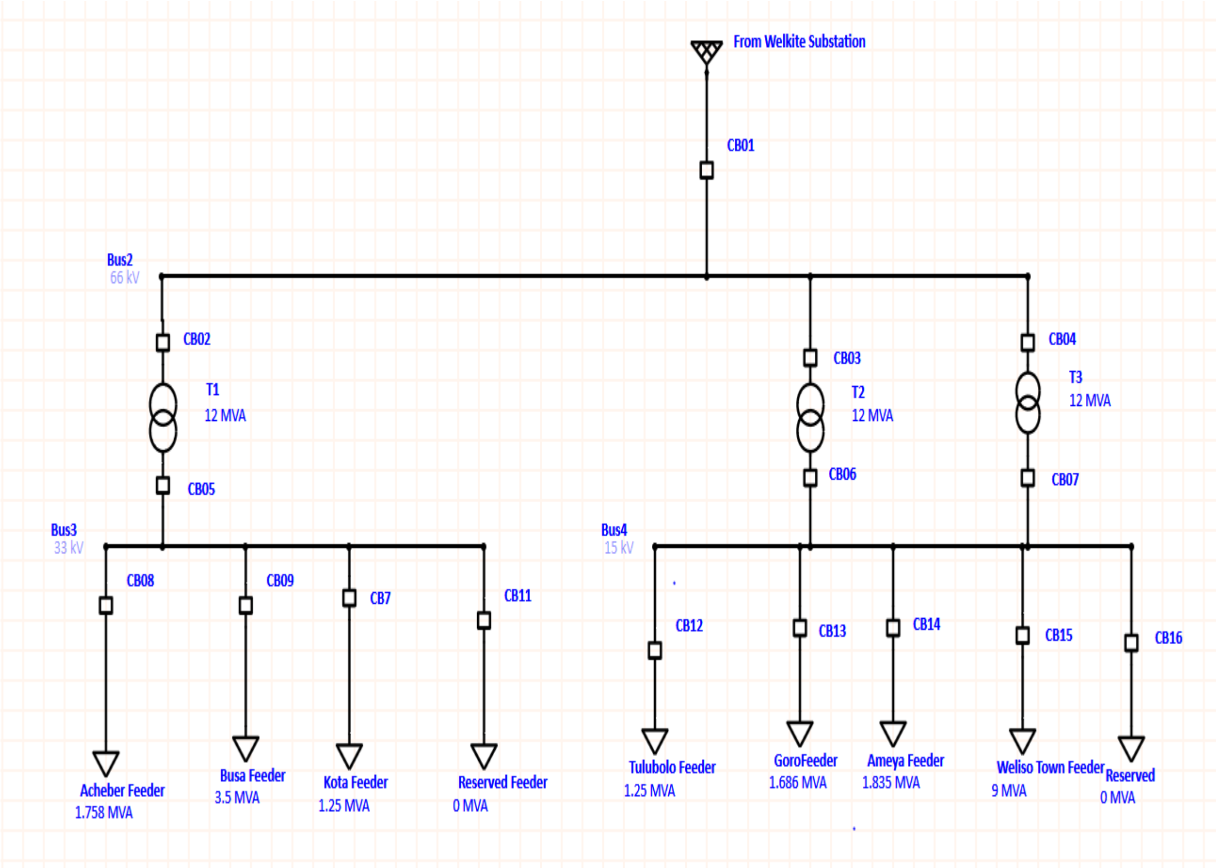


Figure 3. 1: Single line diagram of Weliso distribution substation

Figure 3. 2:Weliso distribution substation

3.3. Methodology

The overall thesis is as figure below.

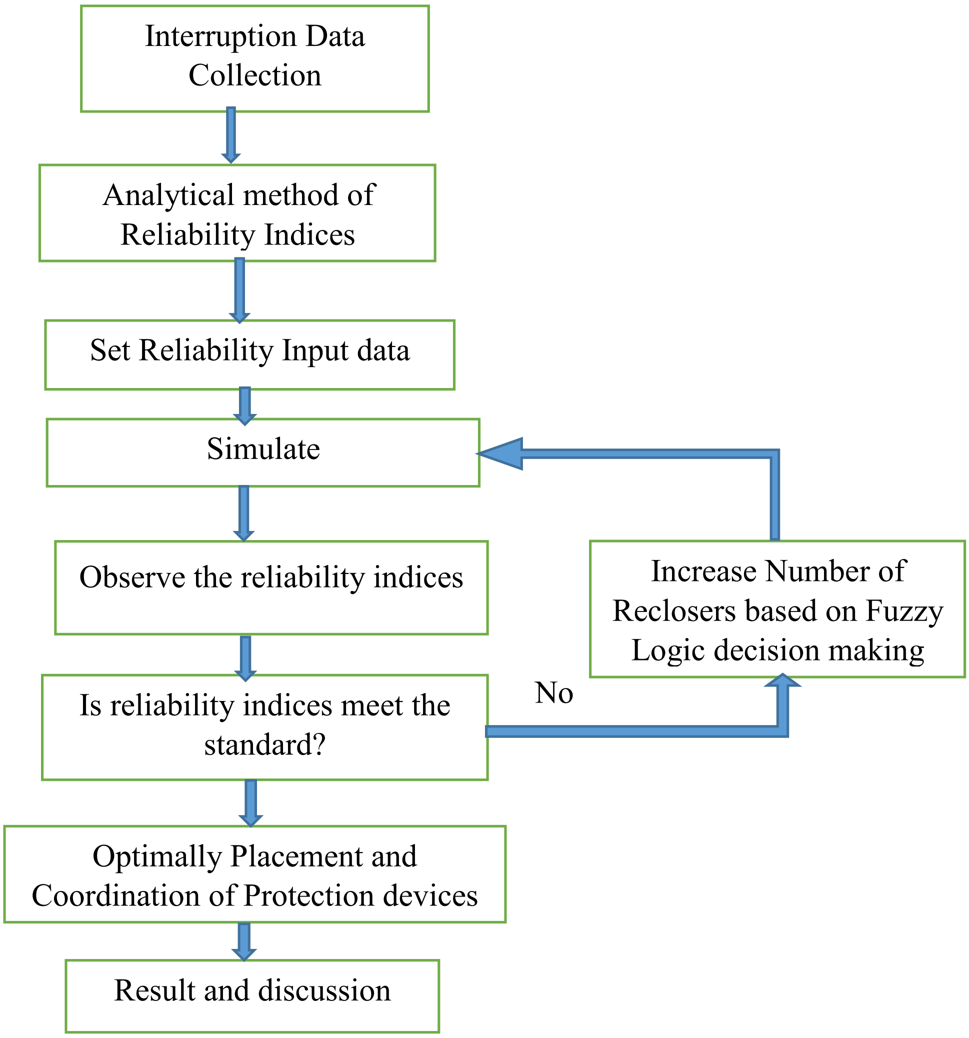


Figure 3. 3: Reliability assessment method flow chart.

Historical and predictive reliability assessment methods are the two reliability evaluation methods utilized in the distribution system. Historical reliability assessment, is the first phase in the reliability study of the distribution system of past performance of the existing system. Predictive reliability is taken as after a change in system configuration or the implementation of any improvement method. (Billinton, 2008).

3.3.1. Data Collection

To carry out Weliso Town reliability analysis, detail assessment and investigation, relevant data for the work was collected using the following:

- Site visit (field work)
- Two years (2020/21 & 2021/2022 G.C) interruption data from the event log for the existing

system is collected from Weliso distribution substation and Ambo EEU district.

- The feeder length, number and ratings of transformers was collected from Weliso and Ambo EEU district and existing distribution substation.

The data collected from the EEU and EEP office are analyzed and the distribution system reliability problems are investigated. These analyses will be executed, simulated, evaluated and modeled using ETAP software.

In Weliso distribution network site survey, the primary and secondary data necessary for Thesis have been collected from Weliso District EEU team and Weliso Substation as follow.

Table 3. 1: Frequency and duration of interruption of two years(from 2020 to 2022 G.C)

No.	Feeder Name	Voltage Level(KV)	Frequency and Duration of Interruption							
			DEF		DSC		TLP		SOL	
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]
1	Tulubolo	15	57.5	49.19	129.5	108.14	1	0.025	0	0
2	Goro	15	37.5	27.52	70.5	30.62	1	0.025	0	0
3	Weliso	15	62	66.295	109.5	79.52	4	1.405	0	0
4	Acheber	33	63	53.51	98.5	75.075	1	0.025	0	0
5	Busa	33	64	67.745	111	115.57	1	0.025	0	0
6	Kota	33	100	89.075	114.5	67.71	1	0.025	0	0
7	Ameya	15	96.22	40.04	109	76.095	1	0.025	0	0

Table 3.1 shows that Weliso Substation feeders faces high distribution short circuit(DSC) and distribution earth fault(DEF).

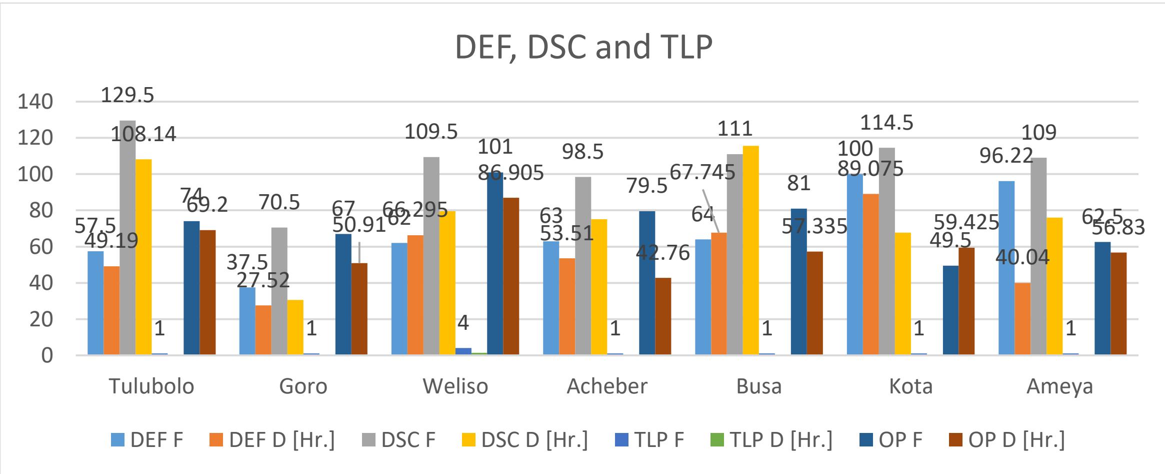


Figure 3. 4: DEF, DSC and TLP interruption data of Weliso Substation Feeders

System over load (SOL) is occurred when generated power is below the total demand.

Table 3. 2: Frequency and duration of interruption of two years(from 2020 to 2022 G.C)

Frequency and Duration of Interruption								Frequency of Interruption (No.)	Duration of Interruption (Hr.)
GUP		DLOL		PTOL		OP			
F	D[Hr.]	F	D[Hr.]	F	D[Hr.]	F	D [Hr.]		
0	0	0	0	0	0	74	69.2	261	226.55
0	0	0	0	0	0	67	50.91	175	109.05
0	0	0	0	0	0	101	86.905	276	234.125
0	0	0	0	0	0	79.5	42.76	241	208.085
0	1	0	0.43	0	0	81	57.335	256	240.65
0	0	0	0	0	0	49.5	59.425	264	216.21
0	0	0	0	0	0	62.5	56.83	267	172.965

From Table 3.2, the total frequency and duration of Weliso Town is high. All distribution feeder has zero frequency and duration interruption of generating unit problem(GUP) due to generation unit failure, distribution line overload(DLOL) this can occur when medium voltage feeders are loaded beyond their capacity or CT ratio, power transformer overload (PTOL) can occur when the load is beyond the capacity of substation transformer and operational problem(OP) this occurred when medium voltage feeders are interrupted voluntarily for maintenance, Load transfer, new transformer erection, etc. .

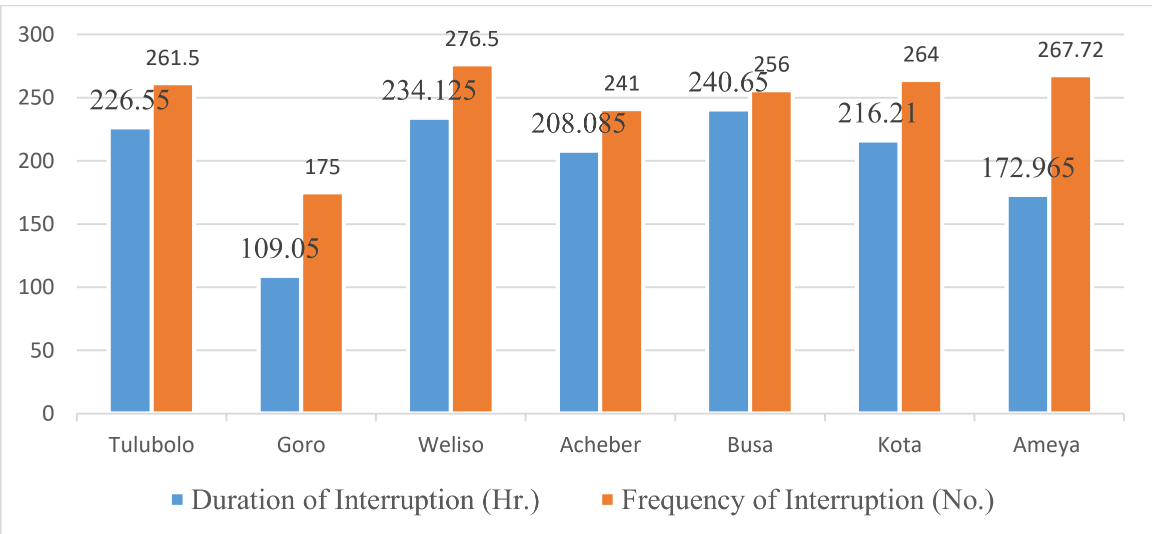


Figure 3. 5: Summary of duration of interruption and frequency

Table 3. 3: Substation load data

Substation Name	Feeder Name	15/33 KV	Number of Outgoing Feeder	Load (MVA)	Peak load in MW	Average Load	Reserved Feeder	Not working CB	Working Feeder
Weliso	Tulubolo	15			0.973	0.7733	1		
	Goro	15			1.1317	0.93833			
	Ameya	15	5	12	1.233	1.023			
	Weliso	15			9.56	7.96666			
	Acheber	33			1.13	0.89333	1		
	Busa	33		12	2.295	1.8575			
	Kota	33	4		0.8	0.62666		0	7

Table 3. 4: Feeder and Transformers data

No	Feeder Name	Transformer Rating (KVA) and Number								Total No of Distribution Transformers	Total Capacity of Transformers(MVA)
		25	50	100	200	250	315	500	630		
1	Acheber(33KV)		4	4	1		1	2	1	13	2.745
2	Weliso(15KV)	12	13	18	19	1	8	1	4	76	12.34
3	Busa(33KV)	1	2	3	3				4	13	3.545
4	Kota(33KV)	1	5	5	1		1	1		13	1.765
5	Tulu Bolo(15KV)	2	2	3	1		1			9	0.965
6	Goro(15Kv)	14	20	14	8		4		3	63	7.5
7	Ameya(15Kv)	5	6	3	3		2		1	20	2.585
Total Transformers		38	82	57	35	1	17	4	14	249	
Total Capacity(MVA)		0.95	4	5.7	7	0.25	5.36	2	8.82		35.375

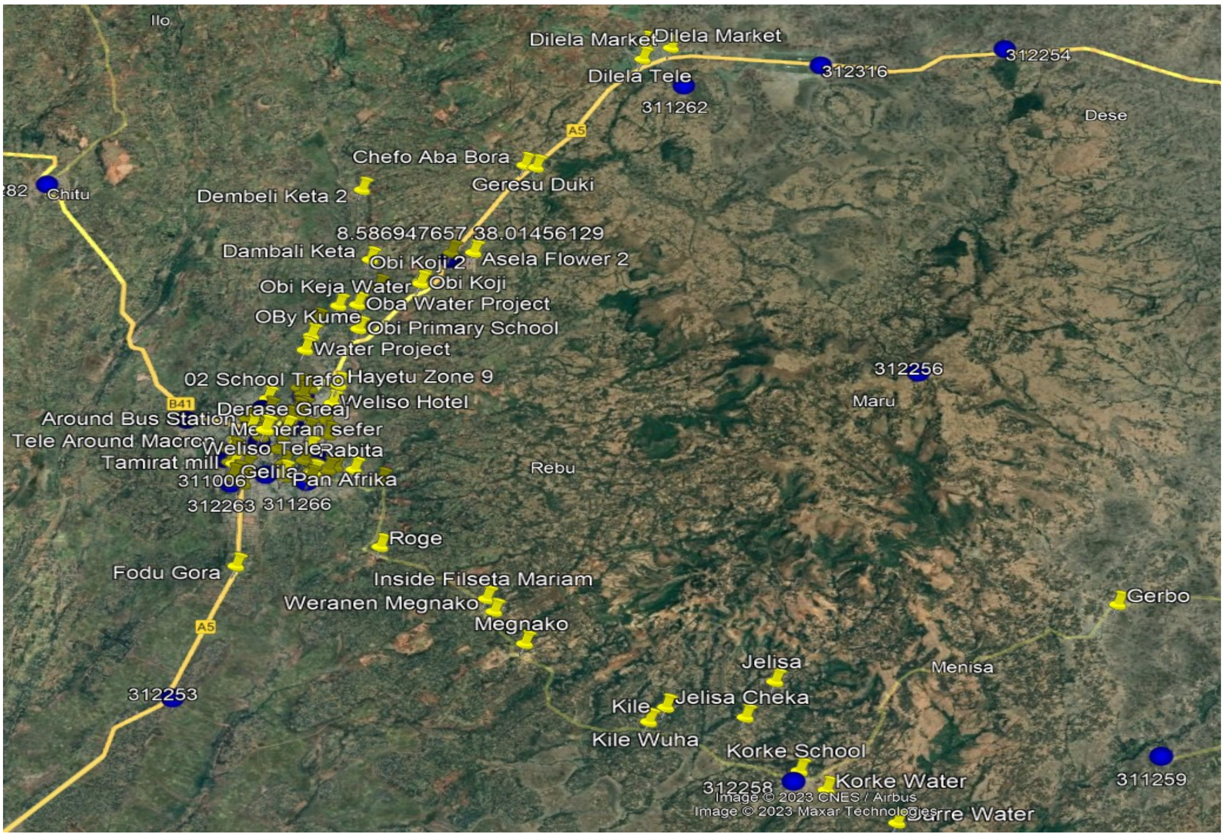


Figure 3. 6: Transformer location by google earth.

Table 3.5: Line length data for the selected Weliso Town feeder.

	Section Length(KM)	Buses	Number of Branches	Total Connected Load(MVA)
Section 1	3	B1 - B2	3	0.18
Section 2	3	B2 - B3	5	0.532
Section 3	2.43	B3 - B4	4	0.24
Section 4	1.05	B3 - B5	3	0.02
Section 5	12.12	B5 - B6	6	0.6
Section 6	18.3	B6 -B7	5	0.732
Section 7	21.25	B7 -B8	3	0.504
Section 8	0.15	B8 - B9	4	0.979
Section 9	0.15	B8 - B10	5	0.48
Section 10	13.65	B10 - B11	5	0.32
Section 11	12	B11 - B12	6	0.14
Section 12	5.25	B12 - B13	1	0.04
Section 13	27	B12 - B14	1	0.8
Section 14	4.5	B5- B15	8	1.316
Section 15	5.65	B15 - B16	7	1.428
Section 16	5.65	B15 - B17	7	0.96
Section 17	12.35	B17 - B18	8	0.58
Section 18	21.45	B18 - B19	7	1.067
Section19	12.6	B19 - B20	5	0.24
Total	**181.55**		**93**	**10.458**

From above Table 3.5 the the total capacity of Transformer on Weliso Town feeder is 12.34MVA.

The basic parameters needed to design of the existing system using ETAP is length of the line. This feeder length has been segmented based on the location of sections, tap points and transformers. The total length of the feeder was 181.55 KM.

3.4. Causes of Weliso Town Power Distribution System.

In Weliso town power distribution systems the mainly fault occurring frequently are earth fault, short circuit, transmission line problem and there is planned outage for operations and maintenance.

Faults occurring can either be of momentary and sustained type. Momentary (Temporary) interruptions with duration of less than 5 minutes' interruptions whereas Permanent (Sustained) interruptions are long-duration interruptions which last longer than 5 minutes. Many of the distribution problems are momentary and mainly caused by animal contact, Tree and whether condition. It can be solved with little or no intervention from the system. Then by simply reclosing, the system will be re-energized. But, sustained faults can't be restored by simple re-energizing. Sustained faults can be caused by Equipment malfunction, cable failure, down line or persistent tree contact (Chimdi Mitiku).

A planned interruption occurs at a selected time less inconvenient for the customers and the customers have been notified before the interruption. On the other hand, if the occurrence time of the interruption has not been selected, then the interruption is unplanned.

Unplanned interruption occurs, for example, due to fault clearing, unwanted operation of the protection system or due to in advertent initiation of opening operation of a switching device by a human.

Sustained interruption: are the results of the following faults.

i. Distribution Earth(ground) fault

This fault occurs when there is a conducting connection between any electric conductor and any conducting material that is grounded or that may become grounded. Electricity always wants to find a path to the ground. In a ground fault, electricity has found a path to ground, but it is a path the electricity was never intended to be on, such as through a person's body. The earth fault, caused by an insulation loss between a live conductor and an exposed conductive part, represents a plant engineering problem, which may cause damage ((Teshome, 2016)

ii. Distribution Short Circuit

Short circuit is the most commonly used term to describe the cause of a power failure. It occurs when an electric current travels along a path that is different from the intended one in an electrical circuit. When this happens, there is an excessive electric current which can lead to circuit damage, fire, and explosion. In fact, short circuits are one of the primary causes of electrical fires throughout the world (Teshome, 2016). It also occurs when the insulation of the wiring used breaks down. It can also occur due to the presence of an external conducting material (such as water) that is introduced accidently into the circuit. Electrical batteries can explode if they are subjected to a large current. Short circuits can even occur when electric motors are forced to operate when the moving parts are jammed. This can result in abnormal buildup of current, ultimately leading to a short circuit.

Water can lead to short circuits and power failure. Because water is conductive, so the current easily flows through it. Current will always take the easiest path. Since there is little resistance in water, the current will flow from positive to negative (or vice-versa) through the water causing the short circuit. The damage caused due to water in electrical circuits can be very expensive so it makes sense to ensure that you are well protected from it. Electrical switchboards, wires, and circuits should be protected from exposure to water.

iii. Distribution Line Overload

Increasing demands for electric power have caused existing power grids to become overloaded. Overloading is a common cause of line voltage fluctuations. Inadequate power generation and inadequate distribution systems are also causes of line voltage problems. Improper or poorly designed power regulating devices may create voltage fluctuations. Loose or corroded connections at the electric service user end can create voltage irregularities. The same conditions on the distribution power lines may also affect voltage. Many voltage fluctuation problems can be traced back to inadequate infrastructure (Teshome, 2016).

iv. Blackout

Blackout is a total loss of the electric service in one area. It can be caused by catastrophic equipment failure or severe weather. It can also be caused by the utility itself for peak shaving purpose.

v. System overload

System overload is a total loss of electric service in all area. It can be happening when the generating capacity less than the load demand.

3.5. Distribution System Reliability Analysis

Reliability evaluation involves observing outages in the distribution system, noting their causes and effects, compressing this historical data into relevant summary information, and using this information to propose performance improvement methods of the existing system and predict the performance of proposed system.

Reliability analysis of electrical distribution system is considered as a tool for the planning engineer to ensure a reasonable quality of service and to choose between different system expansion plans, comparably cost wise, considering system investment and cost of losses.

Failure rate (FR), Mean time between failures (MTBF), Mean time to repair (MTTR), Availability factor (AVF), and Maintainability (M) are Equipment or component-oriented reliability indices. Failure rate (λ) refers to the number of failure that the component or the system has occurred during the studied period (Abraham O. Amole, 2020). In this study, the failure rate is measured by

$$\lambda = \frac{\text{Number of failures (interruption)}}{\text{Studied periods}*\text{circuit length(for transmission line or cables)}} \quad (\frac{\text{interruption}}{\text{km}}.\text{year}) \qquad (3.1)$$

Failure rate is the sum of the active failure rate and passive failure rate.

$$\lambda = \lambda A + \lambda p \qquad (3.2)$$

Active failure rate causes the operation of the protection device around the failed component (a circuit fault) or is the failure of the component itself that restore services after replacement. The passive failure rated does not cause the operation of protection around the failed component (an open circuit fault).

Mean Time to Repair (MTTR) refers to the average time taken to identify the location of failure of a component or the system and to repair that failure. MTTR is also known as repair time (r). MTTR is usually measured by hour.

$$\text{MTTR} = \frac{\text{Total duration of Outage}}{\text{Frequency of Outage}} \qquad (3.3)$$

Mean time to repair (MTTR) describes is the average time interval before the first failure in the system is observed.

By using the above two equations, the basic reliability parameters used in ETAP for reliability analysis are also calculated as follows:

The expected repair rate (μ) is the reciprocal of the mean time to repair (MTTR)

$$\mu = \frac{1}{\text{MTTR}} \qquad (3.4)$$

Mean time between failures (MTBF) is described as the time average intervals between successive failures in a system. It is expressed as;

$$\text{MTBF} = \frac{\text{Total system operation hours}}{\text{Number of failure}} = \frac{(8760 - SAIDI)}{\text{SAIFI}} \qquad (3.5)$$

MTBF= MTTR+MTTF, MTTF= Mean time to failure.

$$\text{MTTF} = \frac{\text{Total hours of operation}}{\text{Total Number of failures}} = \text{MTBF} - \text{MTTR} \qquad (3.6)$$

The forced outage duration (FOR) or unavailability (U) of the component or the system refers to the average duration the component or the system is not operating over the studied period . The dimension of this unavailability is hours per year or minutes per year. The unit unavailability can be calculated as follows.

$$U = \frac{\text{Failure rate}}{\text{failure rate} + \text{repair rate}} = \frac{\lambda}{\lambda + \mu} \qquad (3.7)$$

Availability (A) of the component or the system refers to the average duration that the component or the system is operating over the studied period (Zaw Win Htun). The dimension of this availability is hours per year or minutes per year. The unit availability can be calculated as follows. (Htun, 2017)

$$A = \frac{\text{repair rate}}{\text{failure rate+repair rate}} = \frac{\mu}{\lambda + \mu} \qquad (3.8)$$

Availability factor (AVF) describes the ratio of the mean time between failures to the sum of the mean time between failures and mean time to repair.

$$AVF = \frac{MTBF}{MTBF + MTTR} \qquad (3.9)$$

Maintainability (M) gives an indication of the probability of time for an already failed system to effectively return to the operation. It is expressed as;

$$M = \frac{MTTR}{MTBF+MTTR} \qquad (3.10)$$

3.5. Reliability Indices Calculation

The reliability indices for Weliso distribution substation can be calculated by using equation 2.2 to 2. 9 in chapter two. Based on the input of the data the result is given in below table which include two years (2020 and 2021) reliability.

Table 3. 6: Reliability indices calculation result of Weliso substation.

No	Feeder Name	Number of Customers Connected	Year	SAIFI	SAIDI	CAIDI	CAIFI
1	Tulubolo	4500	2020	253	213.4	0.8433992	1.185678
		5521	2021	270	239.7	0.8878519	1.126314
2	Goro	256	2020	138	72.96	0.5286957	1.891447
		352	2021	212	145.1	0.6846226	1.460659
3	Weliso	17246	2020	269	228.2	0.8483271	1.178791
		20000	2021	284	240.1	0.8452465	1.183087
4	Acheber	245	2020	252	248.6	0.9865079	1.013677
		400	2021	230	167.6	0.7285652	1.372561
5	Busa	1024	2020	248	245.4	0.9893548	1.01076
		1500	2021	264	235.9	0.8937121	1.118929
6	Kota	300	2020	254	217.4	0.8559449	1.1683
		500	2021	274	215	0.784708	1.274359
7	Ameya	1470	2020	281	166.5	0.5925267	1.687688
		2000	2021	254	179.4	0.7064173	1.415594

Table 3. 7: Reliability indices calculation result of Weliso substation.

No	Feeder Name	Number of Customers Connected	Year	ASAI	ASUI	EENS(MWh/Yr)	AENS(MWHr/Yr)
1	Tulubolo	4500	2020	0.975642	0.024358	153.6336	0.0341408
		5521	2021	0.972635	0.027365	143.832	0.026051802
2	Goro	256	2020	0.991671	0.008329	56.1792	0.21945
		352	2021	0.983432	0.016568	137.1573	0.38965142
3	Weliso	17246	2020	0.97395	0.02605	1414.84	0.082038734
		20000	2021	0.972597	0.027403	2088.435	0.10442175
4	Acheber	245	2020	0.971621	0.028379	171.534	0.700138776
		400	2021	0.980871	0.019129	140.7588	0.351897
5	Busa	1024	2020	0.971991	0.028009	364.973	0.356418945
		1500	2021	0.973066	0.026934	462.4424	0.308294933
6	Kota	300	2020	0.975182	0.024818	104.3568	0.347856
		500	2021	0.975455	0.024545	129.006	0.258012
7	Ameya	1470	2020	0.980993	0.019007	139.86	0.095142857
		2000	2021	0.979517	0.020483	184.6335	0.092316735

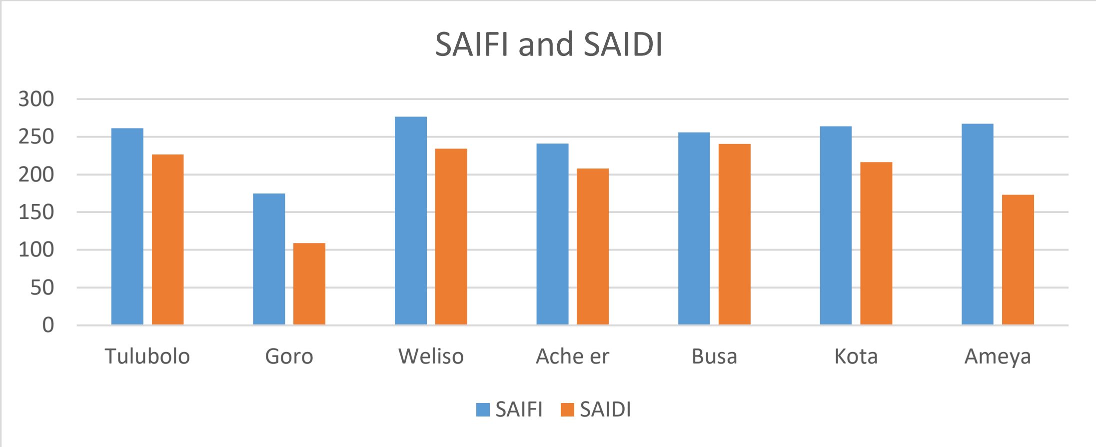


Figure 3. 7: SAIFI and SAIDI of Weliso Substation Feeders

3.6. Different Country Reliability Indices Benchmarks

Reliability benchmarks are the standard against which measured reliability is judged. The purpose of reliability benchmarks is to define minimum average reliability performance, by feeder type, for a distribution network, for a substation based on summing the performance of the feeders and provide a basis against which a distribution network service provider's reliability performance can be assessed.

A benchmark of SAIFI and SAIDI, for nine countries is shown in Table 3.10. And comparing the average SAIFI and SAIDI, value of Weliso substation with the benchmarks shows that has worse performance.

Table 3. 8: Different country reliability bench marks

Country	SAIFI(Int/cust.year)	SAIDI(Hr/Cust.yr)
France	0.5	1.033
Italy	2.2	0.1967
Austria	0.9	1.2
United States	1.5	4
Germany	1	0.383
Spain	2.2	1.733
NetherLand	0.3	0.55
Denmark	0.5	0.4
Uk	0.8	1.5
Ethiopia	20	25
Weliso	**272**	**232**

According to the Ethiopian Electric Agency (EEA) directive, the average System frequency interruption must be below 20 per customer per year, and the System Average duration must be below 25 hours per customer per year (Chemdi Meteku, 2020). Due to there are many factors to achieve this EEA standard a more effort is expected to improve the reliability of distribution system of Weliso Town. since their SAIFI and SAIDI is not as standards.

Table 3. 9: Weliso Town feeder MTTR, MTBF, MTTF and active rate

Event	Average of Two Years
MTTR(Hr)	0.832
MTBF(Hr)	1.387
MTTF(Hr)	0.556
λ	1.55

3.7. Power system reliability assessment Tool

Commercial software's such as CREAM (Developed by EPRI, USA), MECORE (Developed at the University of Saskatchewan and then at BC Hydro, Canada) NARP (Developed by ERCOT, USA) SICRET (Developed by ENEL, Italy) and NH2 (developed by CEPEL, Brazil) for evaluating composite power system reliability. Those software has been most of them focus on HL-II. ((XAVIER, 2011))

ETAP is a fully integrated AC and DC electrical power system analysis tool. It has several modules, among assessment model. The reliability analysis using ETAP assist reliability level for radial and looped systems with a very efficient analytical algorithm.

The algorithm used is based on the reliability evaluation and component modeling presented inabilities al listed below: Model reliability characteristics of each component defined parameters & settings to calculate bus and load point reliability indices, system reliability indices, reliability energy (cost) indices and element contributions to energy (cost) indices.

3.8. System Modeling

ETAP stand for **E**lectrical **T**ransient and **A**nalysis **P**rogram. It is the most comprehensive analysis platform for the design, simulation, operation, and automation of generation, distribution, and industrial power systems. It is developed under an established quality assurance program and is used worldwide as a high impact software. (ETAP.com, 2023)

ETAP software is used to obtain the result of reliability analysis by performing and design below things.

- One-line diagram of the existing system.
- Useful parameters calculation for load flow, short circuit and reliability
- Type and operation characteristics of switching and protection devices can be checked
- Protection coordination and switching sequence interlocking can be checked.
- Run Load flow, short circuit and the reliability assessment.

3.9. Reliability Cost and Worth

It is universally accepted that the reliability of a system can be increased by increased investment. At the same time, the outage costs of the system will decrease and this leads to the concept of an optimum reliability. (Billinton, 2008)

The outage costs have two parts that seen by the utility' and that seen by society or the customer. The utility outage costs include: (a) loss of revenue from customers not served; (b) loss of customer goodwill; (c) loss of future potential sales due to adverse reaction; (d) increased expenditure due to maintenance and repair. These costs, however, usually form only a very small part of the total outage costs.

The customer interruption cost when an electric supply failure occurs depend on many factors. The thesis work evaluate cost lost by utility from outgoing feeder based on Ethiopia electric utility tariff.

Cost of energy not supplied due to interruption for Weliso substation is calculated using the formula,

Cost of Energy = Power * time * tariff of electric. (3.11)

From Table 3.10 The average electric price of EEU is 1.66445 Birr/KWH

Table 3. 10: Electric tariff of Ethiopia Electric Utility ((Ethiopia Electric Utility, 2023)

Tariff amendment		**As of Dec. 21 onward**
Tariff Category	**KWH/month**	**Birr/KWH**
1.Residential tariff block		
1.1 1st block	Up to 50KWH	0.27
1.2 2nd block	Up to100KWH	0.7670
1.3 3rd block	Up to 200KWH	1.6250
1.4 4th block	Up to 300KWH	2.0000
1.5 5th block	Up to 4 00 KWH	2.2000
1.6 6th block	Up to 500KWH	2.4050
1.7 7th block	Above 500KWH	2.4810
2. General Tariff		
2.1 Flat Rate		2.1240
3. Low Voltage Industry Tariff		
3.1 Flat Rate		1.531
3.2 Demand Charge rate		200
4. Medium Voltage Industry Tariff. 15kv & 33KV		
4.1 Flat Rate		1.193
4.2 Demand Charge rate		147.54
5. High Voltage Industry Tariff. Above 66KV		
5.1 Flat Rate		0.928
5.2 Demand Charge rate		87.64
6. Street Light Tariff		
6.1 Flat Rate		2.124
7. Bulk Supply Tariff		
7.1 Demand Charge rate per KW		157.16
7.2 Generation Tariff. Monthly per KWH		0.887

The average energy not supplied and the average cost of energy not supplied due to power interruption for two years of Weliso outgoing feeders are calculated and tabulated in Table 3.11.

Table 3. 11: Average energy not supplied and cost of energy not supplied for Weliso outgoing Feeders.

Feeder Name	**15/33 KV**	**Number of Outgoing Feeder**	**Load (MVA)**	**Peak load In MW**	**Average Load(MW)**	**SAIDI**	**ENS(MWH/Yr)**	**Cost of energy supplied(ETB/year)**
Tulubolo	15	5	12	0.9733	0.7733	226.55	175.1979	291608.2
Goro	15			1.1316	0.9383	109.05	102.3249	170314.7
Ameya	15			1.233	1.023	172.965	1865.194	3104523
Weliso	15			9.56	7.9666	234.125	185.8886	309402.2
Acheber	33	4	12	1.13	0.8933	208.085	447.0074	744021.4
Busa	33			2.295	1.8575	240.65	135.4902	225516.6
Kota	33			0.8	0.6266	172.965	176.9432	294513.1
Total				**17.123**	**9.243**	**201.09**	3088.046	**5139899**

As shown in Table 3.11, the average energy not supplied due to power interruption of Weliso Town is 1657.744 MWH/Year and average cost of energy not supplied due to this power interruption for Two years' at Weliso feeder is 2759231.72 birr/year.

3.10. Placement of Protection devices by Fuzzy logic using Mat lab

Fuzzy means uncertain, indefinite, vague, or unclear. Fuzzy logic is a computing technique that is based on the degree of truth. A fuzzy logic system uses the input's degree of truth and linguistic variables to produce a certain output. The state of this input determines the nature of the output. This technique is different from Boolean logic which uses only two categories (true or false). In Boolean Logic, two categories (0 and 1) are used to describe objects.

Why fuzzy logic is used

- It solves the problem of uncertainty in the engineering field.
- When accurate reasoning is not available, it provides an accurate level of reasoning.
- Fuzzy logic has a simple structure that is easy to understand.
- It is an effective way of controlling machines.
- It provides solutions to various industrial problems (especially decision making).
- It requires little data to be executed.

Fuzzy logic architecture

The following diagram shows a fuzzy logic architecture.

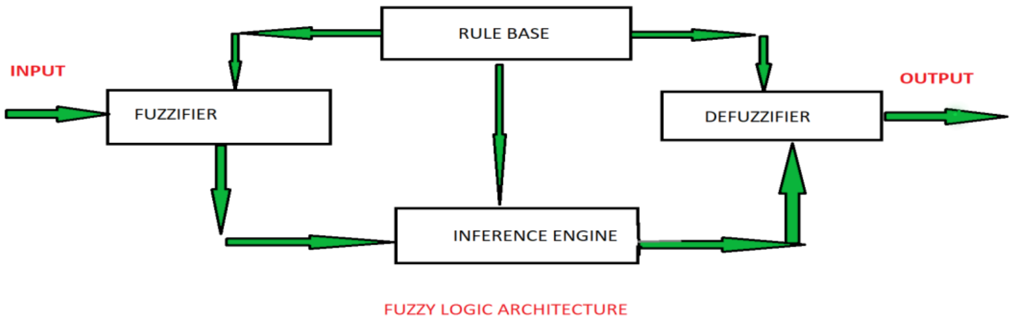


Figure 3. 8: Fuzzy logic architecture

Its Architecture contains four parts:

- **Rule Base**: It contains the set of rules and the IF-THEN conditions provided by the experts to govern the decision-making system, on the basis of linguistic information. Recent developments in fuzzy theory offer several effective methods for the design and tuning of fuzzy controllers. Most of these developments reduce the number of fuzzy rules.
- **Fuzzification:** It is used to convert inputs i.e. crisp numbers into fuzzy sets. Crisp inputs are basically the exact inputs and passed into the control system for processing.
- **Inference Engine**: It determines the matching degree of the current fuzzy input with respect to each rule and decides which rules are to be fired according to the input field. Next, the fired rules are combined to form the control actions.
- **Defuzzification:** It is used to convert the fuzzy sets obtained by the inference engine into a crisp value. There are several defuzzification methods available and the best-suited one is used with a specific expert system to reduce the error.

3.9. 1. Fuzzy logic membership function

A membership function is a graphical representation of a fuzzy set. It shows how values ranging between 0 and 1 are mapped to inputs. the fundamental concept of Fuzzy Logic is the membership function, which defines the degree of membership of an input value to a certain set or category. The membership function is a mapping from an input value to a membership degree between 0 and 1, where 0 represents non-membership and 1 represents full membership.

Fuzzy Logic is implemented using Fuzzy Rules, which are if-then statements that express the relationship between input variables and output variables in a fuzzy way. The output of a Fuzzy Logic system is a fuzzy set, which is a set of membership degrees for each possible output value. In summary, Fuzzy Logic is a mathematical method for representing vagueness and uncertainty in decision-making, it allows for partial truths, and it is used in a wide range of applications. It is based on the concept of membership function and the implementation is done using Fuzzy rules.

3.9.2. Implementation of fuzzy logic (algorithm)

The fuzzy logic technique can be implemented in various systems (hardware and software). A simple, practical example of a fuzzy logic system can help us understand how fuzzy logic is implemented.

The following are the main algorithmic steps for fuzzy logic.

Step 1: Define the linguistic terms (or variables).

Step 2: After defining the linguistic terms, we should create membership functions. This step involves providing a graphical representation of our fuzzy set.

Step 3: In the third step, we will construct rules for control of location of protection devices. Here, we can apply the IF-THEN logic to set effective rules.

Step 4: After setting the system's rules, the fuzzifier uses them to transform the raw input into fuzzy sets. This is done through fuzzy operations. These fuzzy sets are used to generate a membership function output.

Step 5: Defuzzification: This is the last algorithm step. In this step, the defuzzifier uses the membership function to establish the output.

The proposed Fuzzy Logic Controller Optimization for benefit of protection devices allocation in Weliso (15kV) feeder consists of /lthree Linguistic Inputs.

1. Number of branches connected to each bus (NBC)
2. Connected Load to the line segment/bus (CLB)
3. Line Length between Buses (LLB)

3.10. Protection Coordination and Switching Sequence

Protection coordination is **the selection, arrangement, installation, and maintenance of protective devices to limit the effects of an overcurrent (short-circuit) situation to the smallest area.** Protection Coordination determines the appropriate settings of protective relays, circuit breakers, fuses and other devices to safely break and make a circuit within an integrated power system in the advent of an overload, short circuit and other electrical unsafe conditions.

The following basic criteria should be employed when coordinating time/current devices in distribution systems:

1. The main protection should clear a permanent or temporary fault before the backup protection operates, or continue to operate until the circuit is disconnected. However, if the main protection is a fuse and the back-up protection is a Recloser, it is normally acceptable to coordinate the fast operating curve or curves of the Recloser to operate first, followed by the fuse, if the fault is not cleared.
2. Loss of supply caused by permanent faults should be restricted to the smallest part of the system for the shortest time possible.

The required characteristics necessary for protective equipment to perform its function properly are sensitivity, selectivity, speed and reliability (Eyasu Berhanu, 2017).

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

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

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

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

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

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

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

In the following sections criteria and recommendations are given for the coordination of different devices used on distribution systems (J.Holmes, 2005)

1. **Recloser - Fuse Coordination**

The criteria for determining Recloser-fuse coordination depend on the relative locations of these devices, i.e. whether the fuse is at the source side and then backs up the operation of the Recloser that is at the load side, or vice versa. These possibilities are treated in the following paragraphs.

Fuse at the Source Side

When the fuse is at the source side, all the Recloser operations should be faster than the minimum melting time of the fuse. This can be achieved through the use of multiplying factors on the Recloser time/current curve to compensate for the fatigue of the fuse link produced by the cumulative heating effect generated by successive Recloser operations. The Recloser opening curve modified by the appropriate factor then becomes slower but, even so, should be faster than the fuse curve.

The multiplying factors referred to above depend on the reclosing time in cycles and on the number of the reclosing attempts. It is convenient to mention that if the fuse is at the high voltage side of a power transformer and the Recloser at the low voltage side, either the fuse or the Recloser curve should be shifted horizontally on the current axis to allow for the transformer turns ratio. Normally it is easier to shift the fuse curve, based on the transformer tap that produces the highest current on the high voltage side.

Fuses at the Load Side

The procedure to coordinate a Recloser and a fuse, when the latter is at the load side, is carried out with the following rules:

1) The minimum melting time of the fuse must be greater than the fast curve of the Recloser times the multiplying factor.

2) The maximum clearing time of the fuse must be smaller than the delayed curve of the Recloser without any multiplying factor; the Recloser should have at least two or more delayed operations to prevent loss of service in case the Recloser trips when the fuse operates.

Better coordination between a Recloser and fuses is obtained by setting the Recloser to give two instantaneous operations followed by two timed operations. In general, the first opening of a Recloser will clear 80 per cent of the temporary faults, while the second will clear a further 10 per cent. The load fuses are set to operate before the third opening, clearing permanent faults. A less effective coordination is obtained using one instantaneous operation followed by three timed operations.

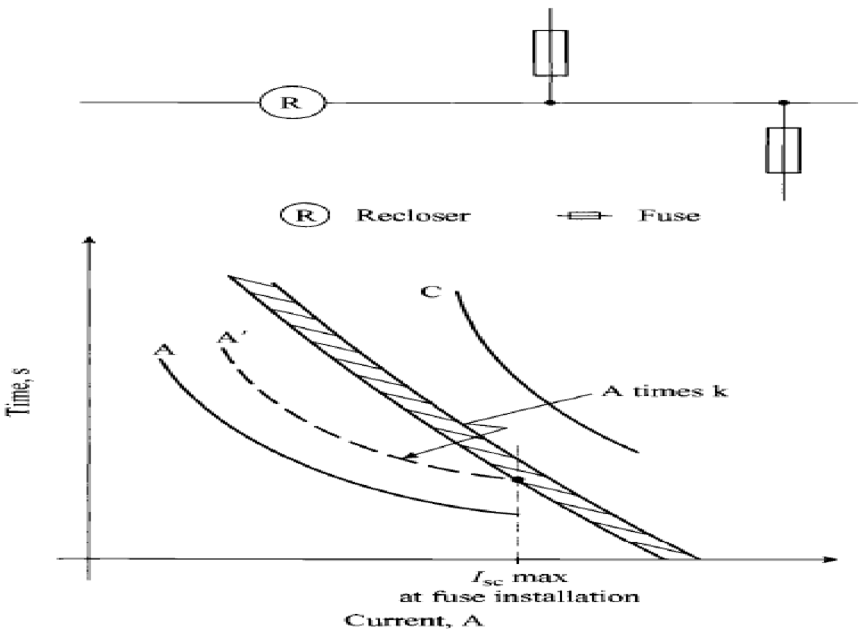


Figure 3. 9: Criteria for Recloser and load-side Fuses coordination

2. **Recloser- Recloser Coordination**

The coordination between Reclosers is obtained by appropriately selecting the amperes setting of the trip coil in the hydraulic Reclosers, or of the pick-ups in electronic Reclosers.

Hydraulic Reclosers

The coordination margins with hydraulic Reclosers depend upon the type of equipment used. In small Reclosers, where the current coil and its piston produce the opening of the contacts, the following criteria must be taken into account:

i. Separation of the curves by less than two cycles always result in simultaneous operation;

ii. Separation of the curves by between two and 12 cycles could result in simultaneous operation;

III. Separation greater than 12 cycles ensures non-simultaneous operation.

With large capacity Reclosers, the piston associated with the current coil only actuates the opening mechanism. In such cases the coordination margins are as follows:

i. Separation of the curves by less than two cycles always result in simultaneous operation;

ii. A separation of more than eight cycles guarantees non-simultaneous operation.

3. Recloser- Sectionalizer Coordination

Since the Sectionalizers have no time/current operating characteristic, their coordination does not require an analysis of these curves.

The coordination criteria in this case are based upon the number of operations of the back-up Recloser. These operations can be any combination of rapid or timed shots as mentioned previously, for example two fast and two delayed. The sectionalizer should be set for one shot less than those of the Recloser, for example three disconnections in this case. If a permanent fault occurs beyond the sectionalizer, the sectionalizer will open and isolate the fault after the third opening of the Recloser. The Recloser will then re-energies the section to restore the circuit. If additional Sectionalizers are installed in series, the furthest Recloser should be adjusted for a smaller number of counts. A fault beyond the last sectionalizer results in the operation of the Recloser and the start of the counters in all the sectionalizes.

4. Recloser- Relay Coordination

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

5. Recloser- Sectionalizer- Fuse Coordination

Each one of the devices should be adjusted in order to co-ordinate with the Recloser. In turn, the sequence of operation of the Recloser should be adjusted in order to obtain the appropriate coordination for faults beyond the fuse by following the criteria already mentioned.

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

To accommodate for the varying tolerances and to ensure that multiple protection devices do not unnecessarily trip for the same fault current, the protection devices should be coordinated to each other based on their settled pickup currents and tripping times. In this paper, Star is a fully integrated system protective device coordination and selectivity module within ETAP.

CHAPTER 4

RESULT AND DISCUSSION

4.1. Existing System Reliability Evaluation Using Analytical Method

For better reliability improvement in distribution system network, feeder that has more frequency interruption, duration of interruption and more number of customers should be selected (Chemdi Meteku, 2020).

Weliso own existing distribution system reliability assessment is performed by analytical method from the recorded interruption data of EEU office for the years 2020 and 2021. These feeders feed urban and rural areas around the city. The interruption data is recorded for each feeder when the outgoing circuit breaker in the substation is tripped and all customers connected to the feeder are interrupted. Weliso Town feeder has high values of SAIDI and SAIFI comparing with other feeders and has much duration of interruptions, frequency interruptions and more number of customers as shown in Chapter Three.

Weliso Town Feeder is characterized by poorest reliability, having the highest energy not supplied and interruption cost compared to other feeders in the distribution system due to it is availability is also poor and number of the affected customers feed from this feeder are many. Because of these reasons, improvement methods are proposed in this thesis so as to reduce these system reliability indices of the feeder.

In this thesis study, most faults are temporary in nature Auto Reclosers are selected to improve reliability of Weliso Town power distribution system.

4.2. Reliability Evaluation of Weliso Town Feeder using ETAP Software.

Due to fault occurring on distribution feeder depends on the feeder line length, the reliability of the system is evaluated by taking feeder length into consideration, because fault happen on the feeder was affecting the whole customer who were connected to it. The total feeder length 181.5 KM. But, for simulation and optimal Reclosers placement, the feeder line was segmented by considering existing section and total connected number of transformers on the route. The important parameters used for distribution system reliability analysis are entered in the ETAP software as figure 4.1 and figure 4.2 below.

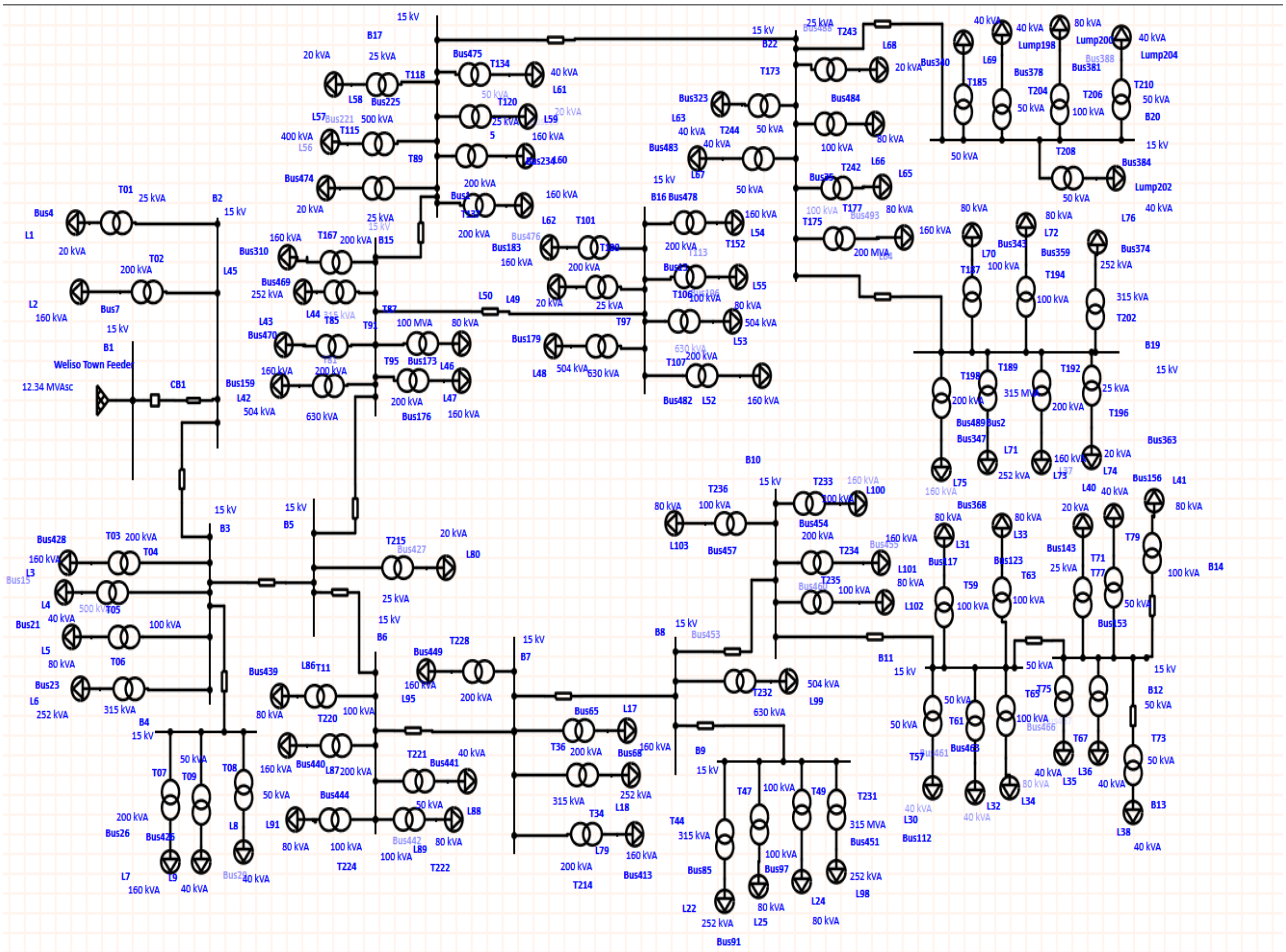


Figure 4. 1: One line diagram of Weliso Town Feeder

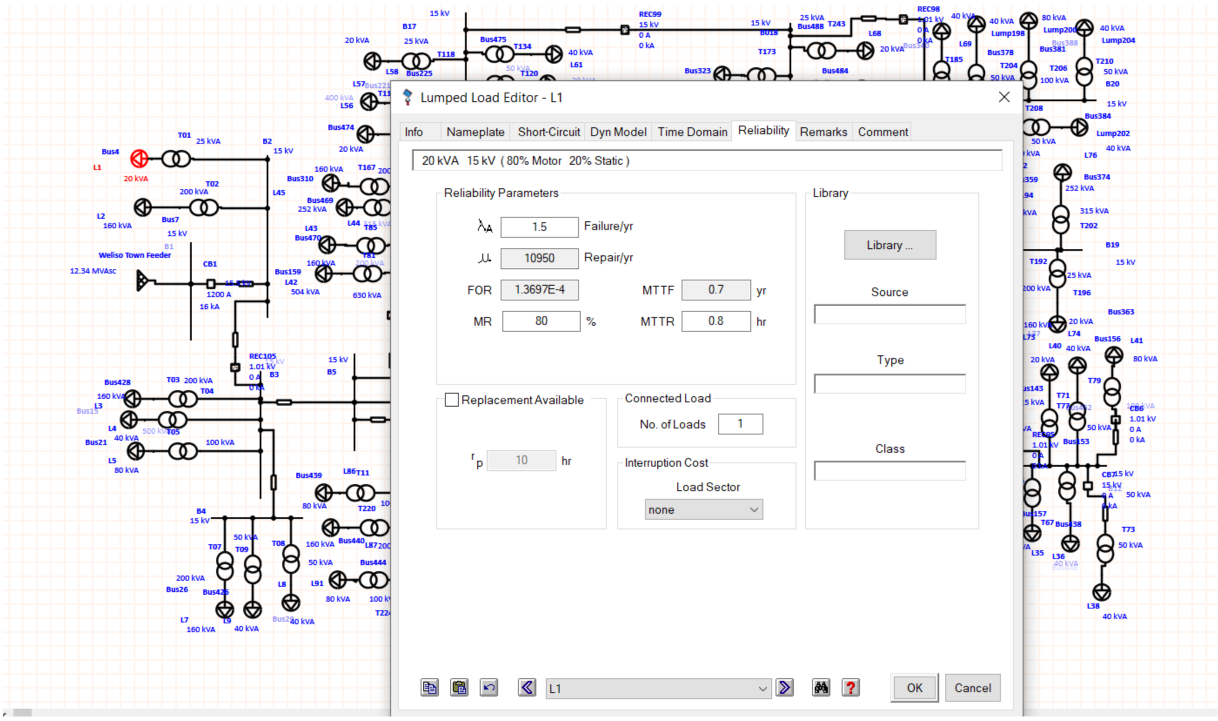


Figure 4. 2: ETAP Reliability parameters.

As show in above Figure by using equation 3.1 and equation 3.3 from chapter three, failure rate is 1.5 failure/year/km and mean time to repair(MTTR) is 0.8 Hr.

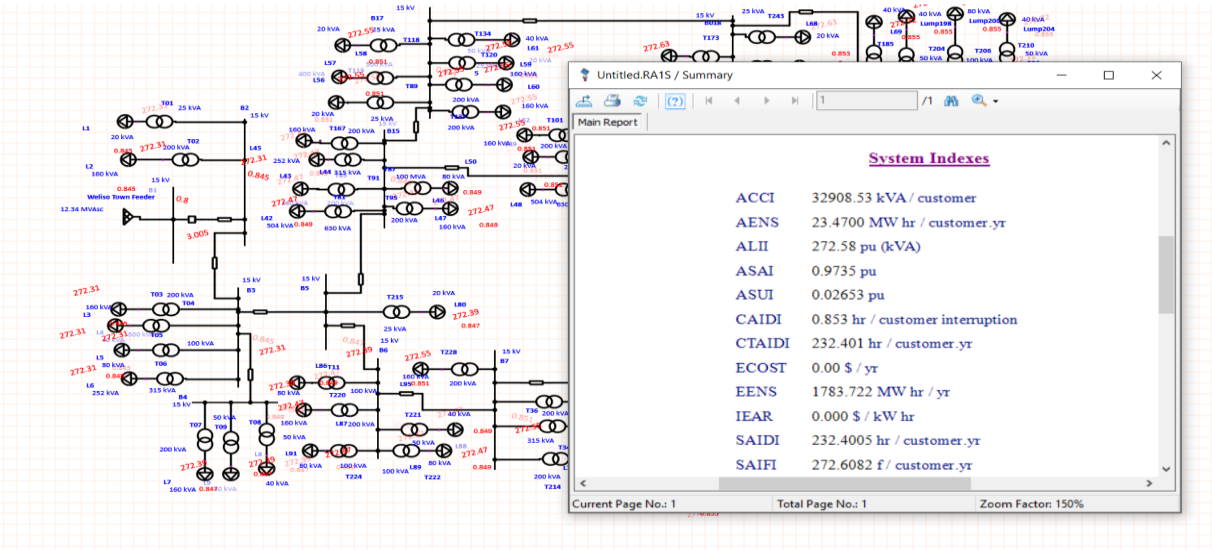


Figure 4. 3: Existing reliability indices

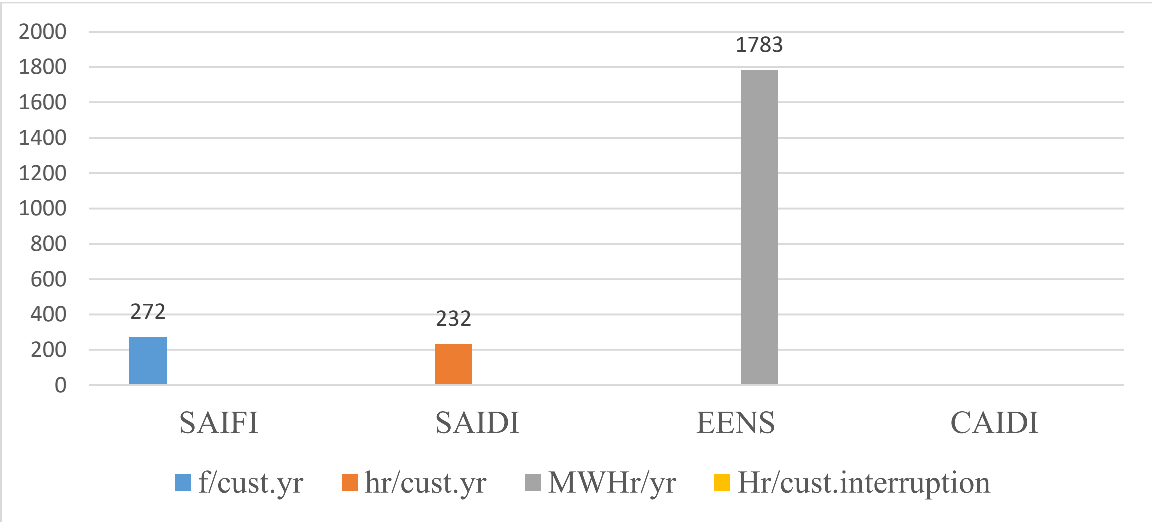


Figure 4. 4: Existing system common reliability indices in graph

4.3. Power Distribution System Reliability Improvement by Optimal Placement of Auto Reclosers based on Fuzzy logic controller

A fuzzy logic system uses the input's degree of truth and linguistic variables to produce a certain output. The state of this input determines the nature of the output. This technique is different from Boolean logic which uses only two categories (true or false). In Boolean Logic, two categories (0 and 1) are used to describe objects.

An optimization technique called fuzzy logic controller is utilized to determine the right number and location of Reclosers in order to improve the reliability of Weliso Town of distribution system. Based on the fuzzy output, it is possible to determine the number and locations of recloses on the distribution system. Three linguistic variables are chosen as input variables

1. Number of branches connected to each bus (NBC).
2. Connected Load to the line segment(Bus(CLB).
3. Line Length between buses (LLB).

and the output is optimal location of Protection devices (Reclosers).

Number of branches connected to each bus (NBC): it is a normalized representation of the branching at the start of the section.

Total connected load to the given section of the feeder (CLB):it is the amount of load that is applied to the section under consideration.

Section line length (SLL): it is a representation of the length between the main buses, buses to which the load points are connected.

The fuzzy rule base is a set of IF-THEN statements that store the practical knowledge of human operators about the process. It is used in the design of the proposed fuzzy logic controller inference engine. Every linguistic input and output has a set of membership functions (MF), and the associated MF used for all inputs and outputs are triangular MF. Five fuzzy sets – Very low, Low, medium, High and very high - are employed in the representation of the input, as illustrated in figure 4.4

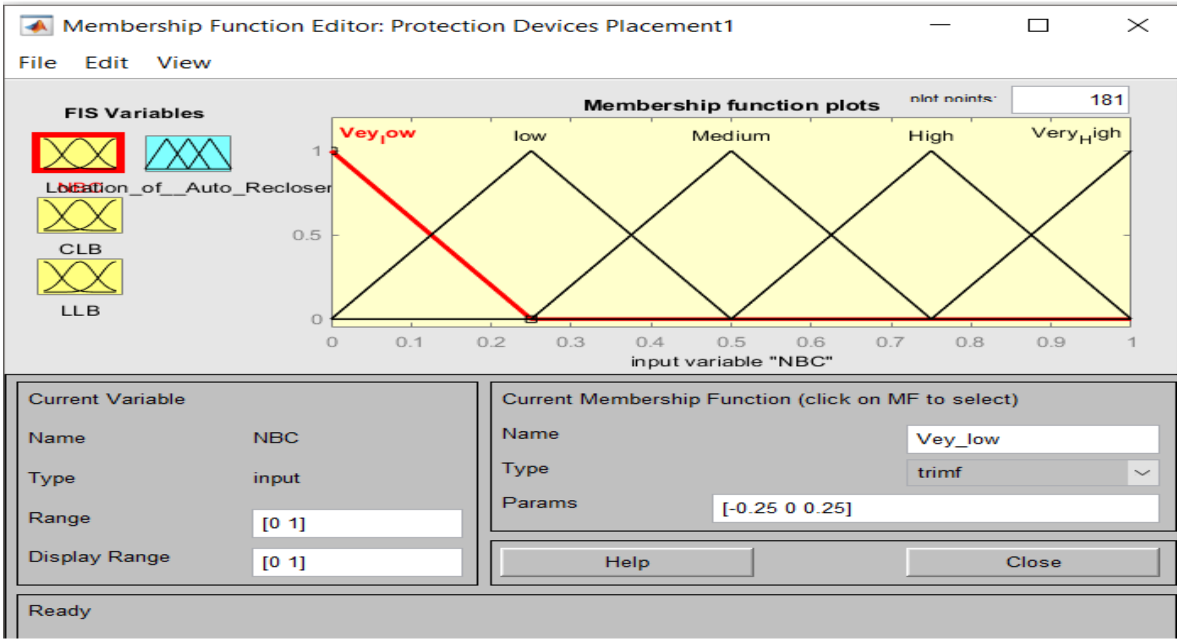


Figure 4. 5: Fuzzy logic member ship function.

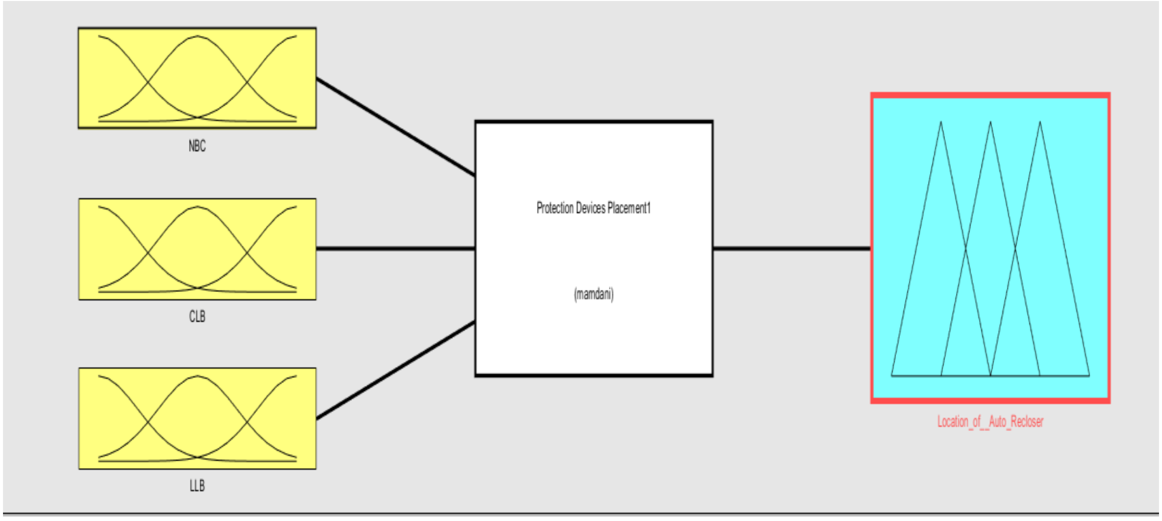


Figure 4. 6: Fuzzy input and output design

Number of branches, total connected load, and section line length are described in various shapes in Figure 4.5.

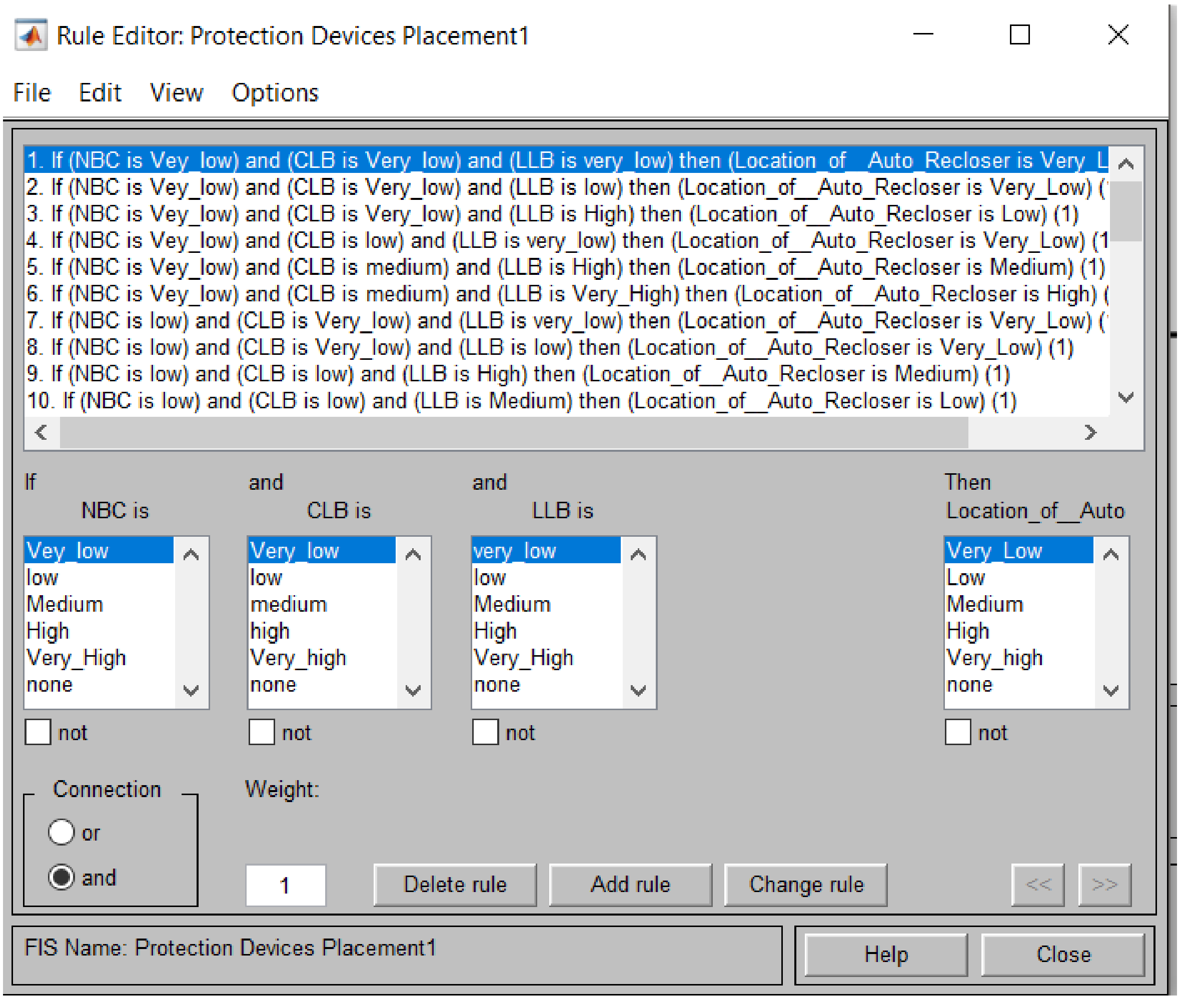


Figure 4. 7: Fuzzy rule created for Auto Reclosers placement.

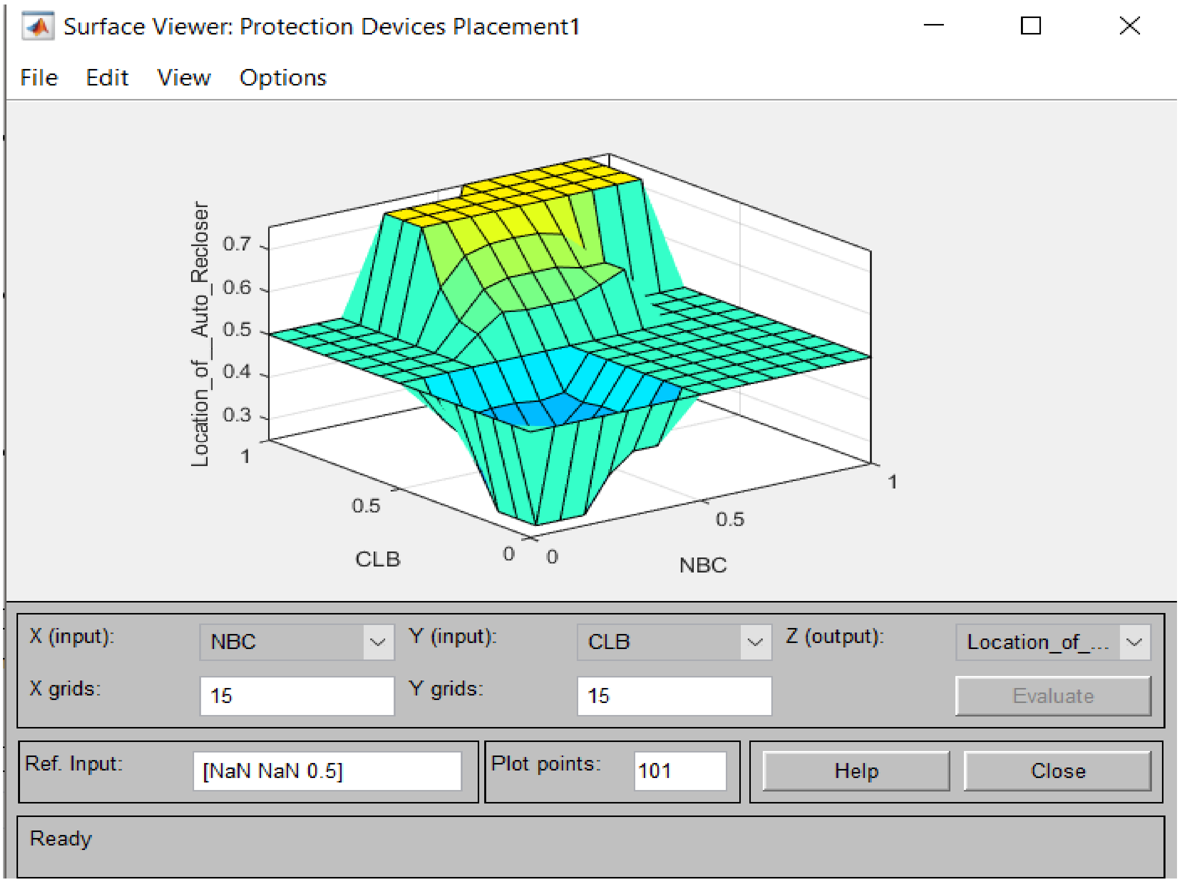


Figure 4. 8: Surface viewer of CLB and NBC

The fuzzy rule viewer shown in figure below is used to view the inference process of fuzzy inference system. It can be used to adjust the input values and view the corresponding output of each fuzzy rule, the aggregated output fuzzy set, and the defuzzified output value. To view the inference process, we must specify the input and output variables of fuzzy inference system, their corresponding membership functions, and the fuzzy rules (Mathworks, 2023)

Figure 4. 9: Rule viewer of Fuzzy logic optimal placement of Auto Recloser

Since the Fuzzy uses 0 and 1 objects, we should have to normalize the input parameters which was described in chapter 3 as Table 4.1 below.

Normalization is the process of taking a count and dividing it by something else in order to make a number more comparable or to put it in context.

Table 4. 1: Normalization of input parameter for making decision.

Section Number	Normalized Number of Branches	Normalized Total Connected Load(MVA)	Normalized Section Length(KM)	Buses	Value of Fuzzy logic Output for decision making
Section 1	0.375	0.12605042	0.11111111	B1 - B2	0.375
Section 2	0.625	0.37254902	0.11111111	B2 - B3	0.5
Section 3	0.5	0.168067227	0.09	B3 - B4	0.5
Section 4	0.375	0.014005602	0.03888889	B3 - B5	0.0375
Section 5	0.75	0.420168067	0.44888889	B5 - B6	0.75
Section 6	0.625	0.512605042	0.67777778	B6 -B7	0.5
Section 7	0.375	0.352941176	0.78703704	B7 -B8	0.0944
Section 8	0.5	0.68557423	0.00555556	B8 - B9	0.687
Section 9	0.625	0.336134454	0.00555556	B8 - B10	0.625
Section 10	0.625	0.224089636	0.50555556	B10 - B11	0.583
Section 11	0.75	0.098039216	0.44444444	B11 - B12	0.5
Section 12	0.125	0.028011204	0.19444444	B12 - B13	0.0235
Section 13	0.125	0.070028011	1	B13 - B14	0.342
Section 14	1	0.921568627	0.16666667	B5- B15	0.811
Section 15	0.875	1	0.20925926	B15 - B16	0.902
Section 16	0.875	0.672268908	0.20925926	B15 - B17	0.4
Section 17	1	0.406162465	0.45740741	B17 - B18	0.888
Section 18	0.875	0.74719888	0.79444444	B18 - B19	0.567
Section19	0.625	0.168067227	0.46666667	B19 - B20	0.525

The result showed in table 4.1 is the basic result that determines the location of selected section for protection devices (Reclosers) that depends on the main factors parameters of the distribution system in in large. Based on this the index greater than 0.525 is taken and the simulation result is performed.

4.3.1. Placement of Auto Reclosers and Fuses

Predictive reliability is a programmatic approach to maintenance where maintenance activities are tailored based on the condition of equipment to prevent unnecessary failures and improve operational performance. One of the best approach of predictive reliability improvement is placement of Protection devices like Recloses and fuses. Because of the existing Weliso Town feeder distribution network has no any auto Reclosers and sectionalizes switches, Nine Auto Reclosers and Fuse links per Transformers are added using fuzzy logic controller optimal technique. As shown in table 4.1 the decision is taken to place the auto Reclose when value of fuzzy logic output is greater than 0.525. Fuse links are placed before Transformers per each.

Case 1: Placement of one Recloser

Based on above fuzzy logic decision making, when one reclose is added between bus 15 and bus 16 on section. The Recloser 1 is responsible to manage the fault, the SAIFI and SAIDI is reduced from 273 interruptions per customer per year and 232 hours per customer per year to 252 and 216 respectively as below figure.

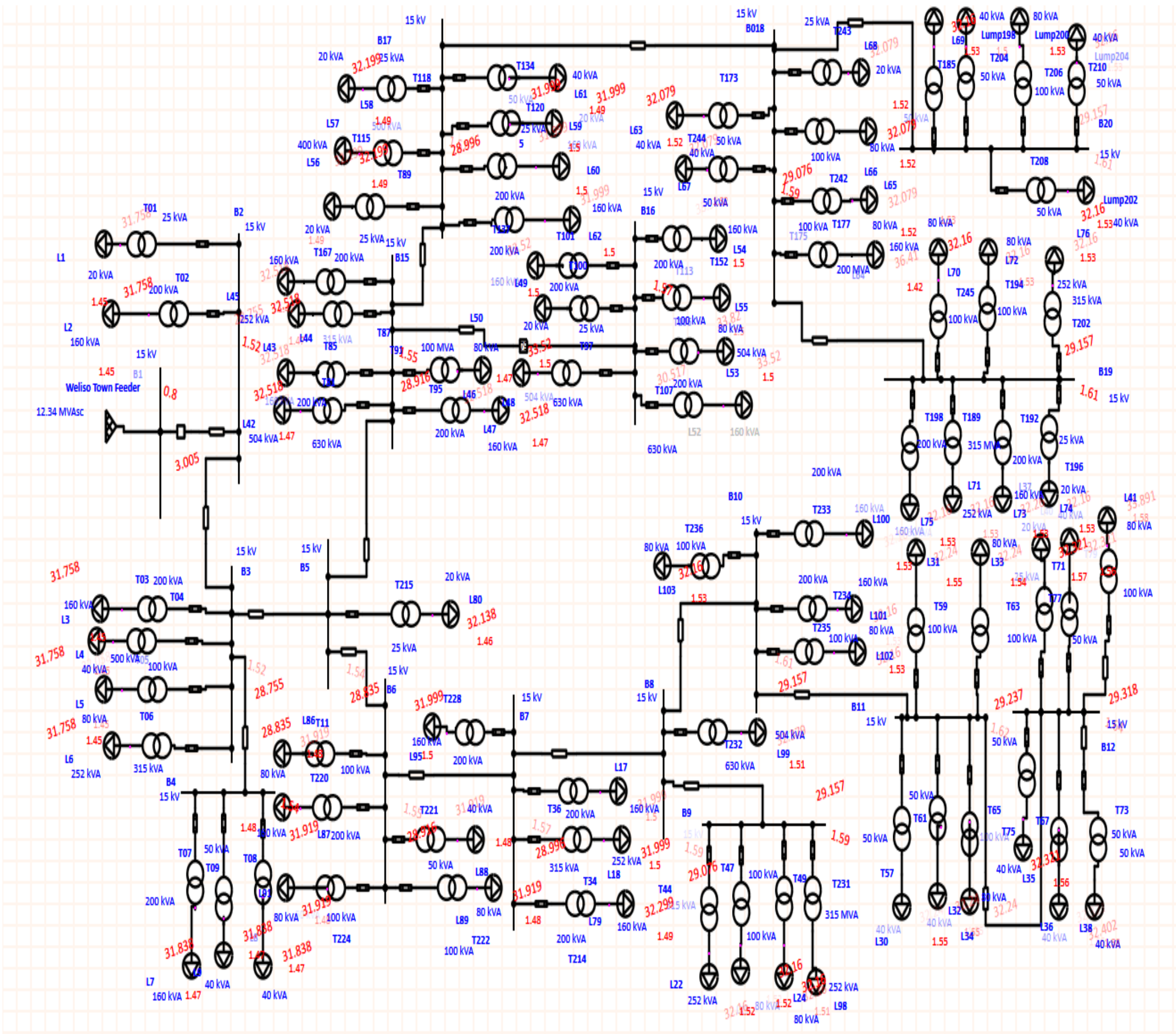
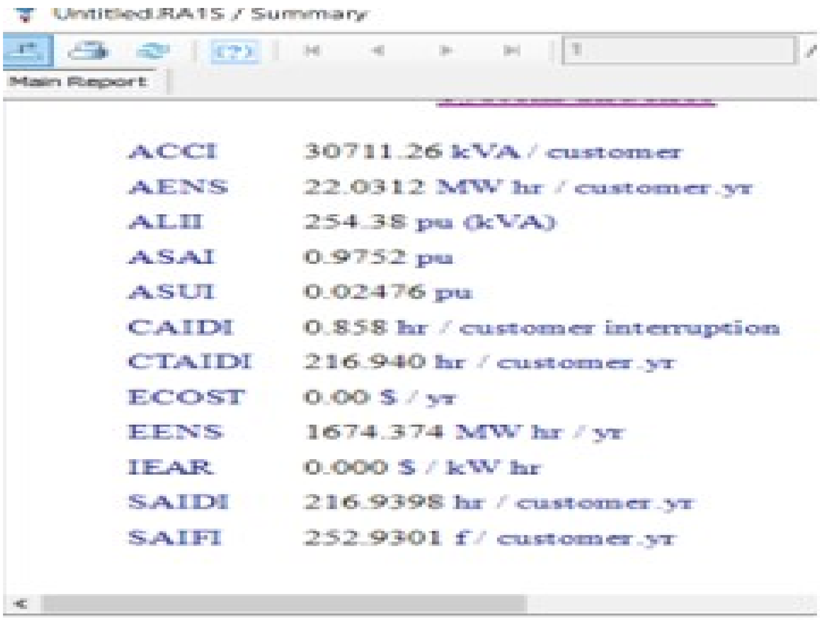


Figure 4. 10: Simulation result when one Auto Recloser Placement



Untitled.RA15 / Summary

Main Report

ACCI	30711.26 kVA / customer
AENS	22.0312 MW hr / customer.yr
ALII	254.38 pu (kVA)
ASAI	0.9752 pu
ASUI	0.02476 pu
CAIDI	0.858 hr / customer interruption
CTAIDI	216.940 hr / customer.yr
ECOST	0.00 $ / yr
EENS	1674.374 MW hr / yr
IEAR	0.000 $ / kW hr
SAIDI	216.9398 hr / customer.yr
SAIFI	252.9301 f / customer.yr

Figure 4. 11: Summary of simulation result by One Auto Recloser placement

Table 4. 2: Summary of simulation result when one Auto Recloser placement

Reliability indices	Result
SAIFI	252.93 F/customer.y
SAIDI	216.9398 hr/customer.yr
EENS	1674.374 MWhr/Yr
CAIDI	0.858 Hr/customer.yr
ASUI	2.48%
ASAI	97.52%

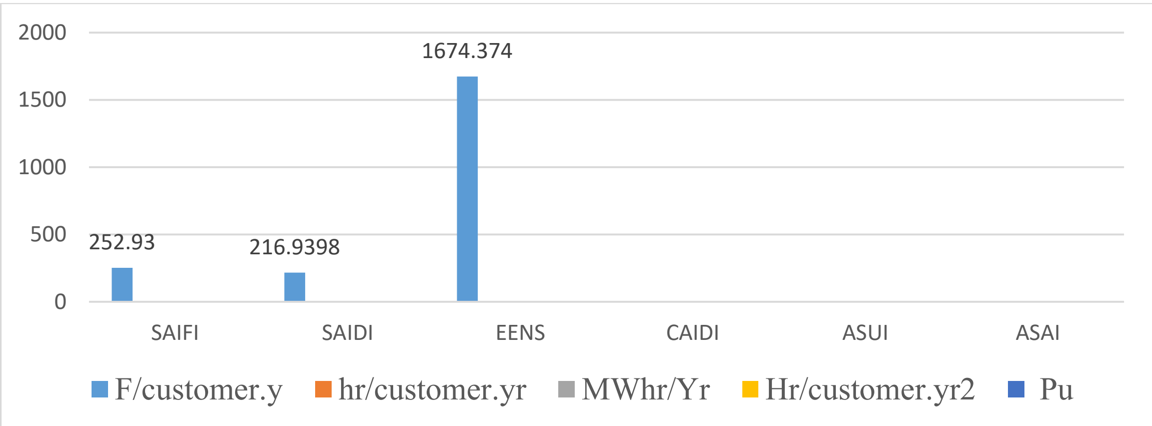


Figure 4. 12: Summary of simulation result when one Auto Recloser placement

Case 2: Placement of additional Auto Reclosers (Two Auto Reclosers)

Based on fuzzy logic output, after adding additional recloses between bus 17 and bus18, the reliability indices are improved as below. This shows that adding required protection devices at needed location on distribution feeder section has benefits of reliability improvements.

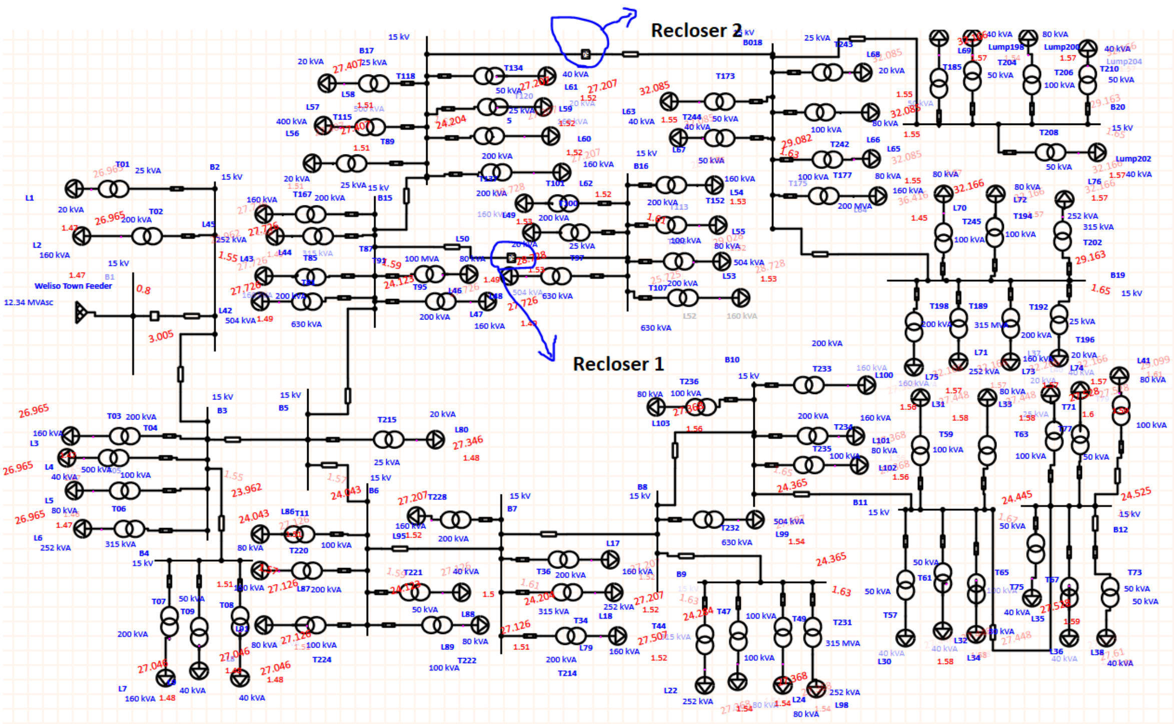


Figure 4. 13: summary of simulation result after adding additional Auto Reclosers

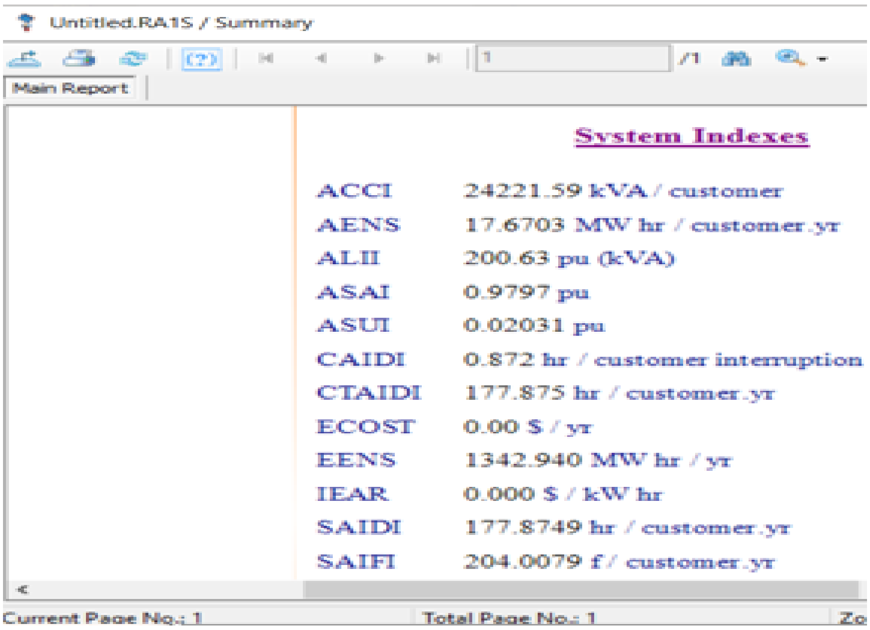


Figure 4. 14: Summary of simulation result by two Auto Reclosers placement.

Table 4. 3: Summary of simulation result when two Auto Reclosers placements

Reliability indices	Result
SAIFI	204.0079 F/customer.y
SAIDI	177.8749 hr/customer.yr
EENS	1342.940 MWhr/Yr
CAIDI	0.872 Hr/customer.yr
ASUI	2.031%
ASAI	97.97%

Case 3: Placement of additional Auto Reclosers (Three Auto Recloser)

The effect of three Auto Reclosers have been presented as below figure 4.9. The result shows Increasing the number of Reclosers on the section of the feeder helps to improve the reliability of the power distribution system.

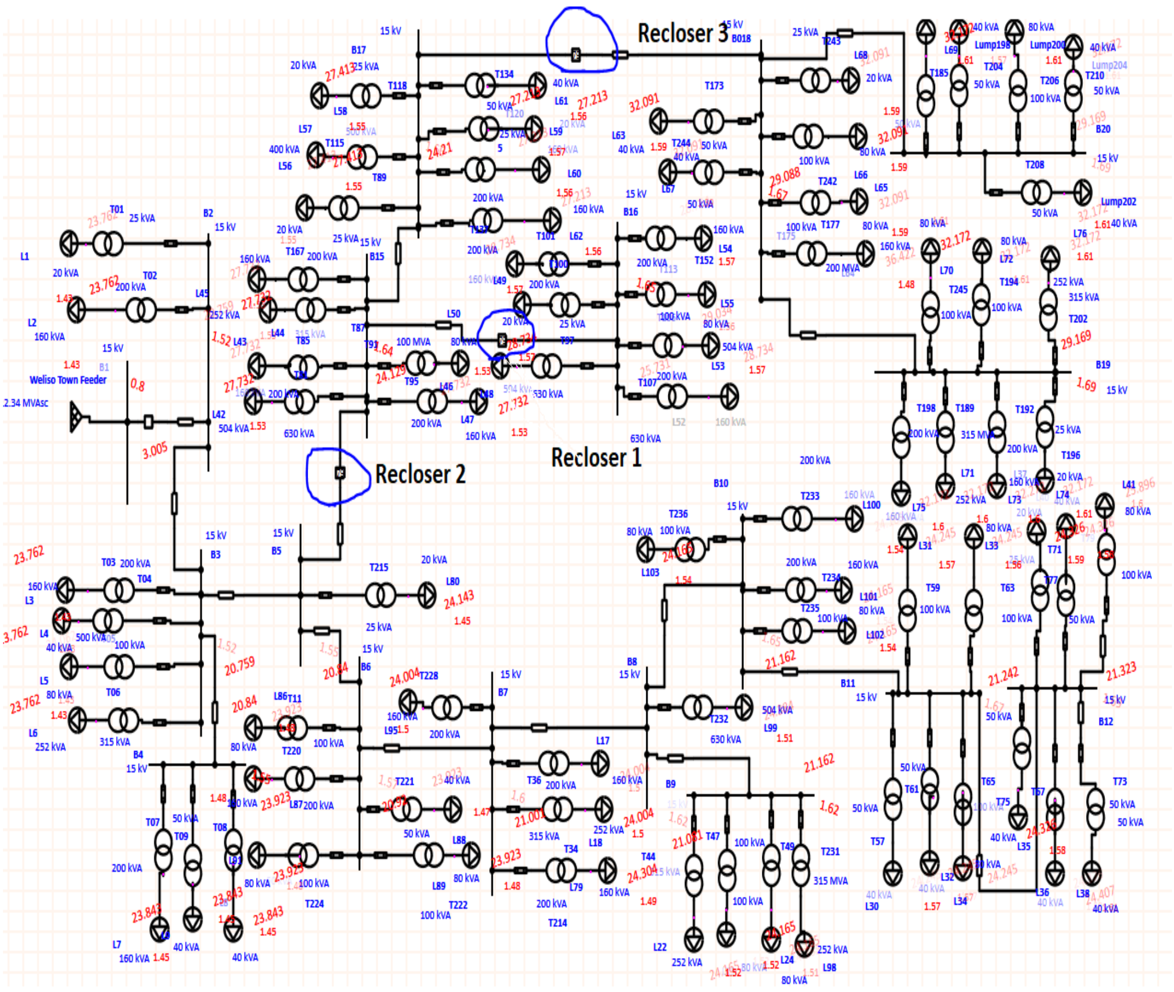


Figure 4. 15: Summary of simulation result by three Auto Reclosers placement

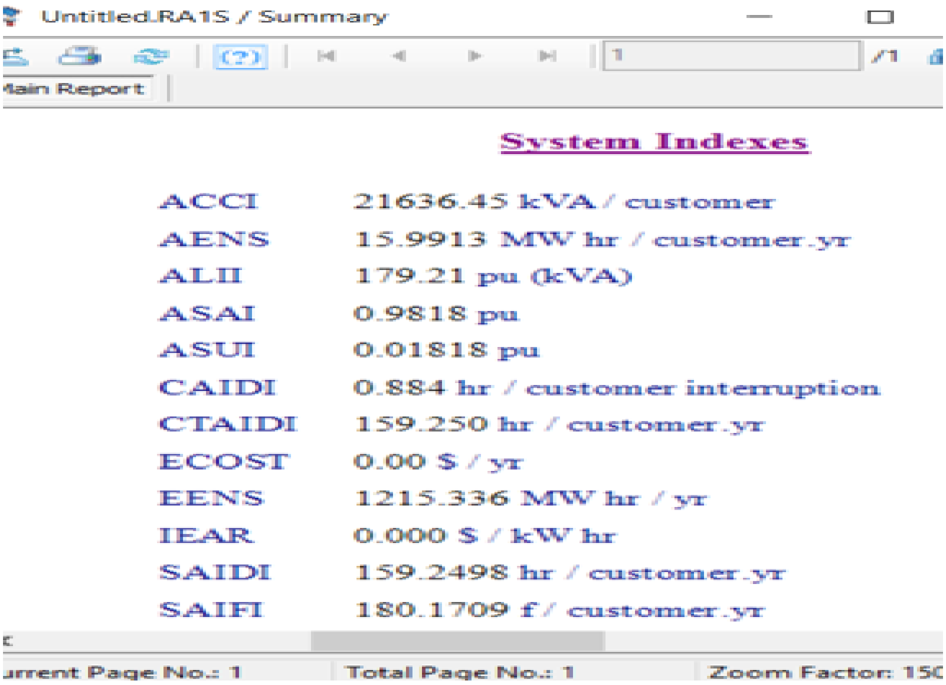


Figure 4. 16: Placement of additional Auto Reclosers (Three Auto Reclosers)

Table 4. 4: Summary of simulation result after adding additional Three Reclosers.

Reliability indices	**Result**
SAIFI	180.1709 f/customer. y
SAIDI	159.2498 Hr/customer.yr
EENS	1215.336 MWhr/Yr
CAIDI	0.884 Hr/customer.yr
ASUI	1.818%
ASAI	98.18%

Case 4: Placement of additional Reclosers and Fuses

ETAP reliability evaluation result on above figure 4.10 of Weliso Town feeder shows great reduction of reliability indices which helps as a method to reduce power interruption to customers.

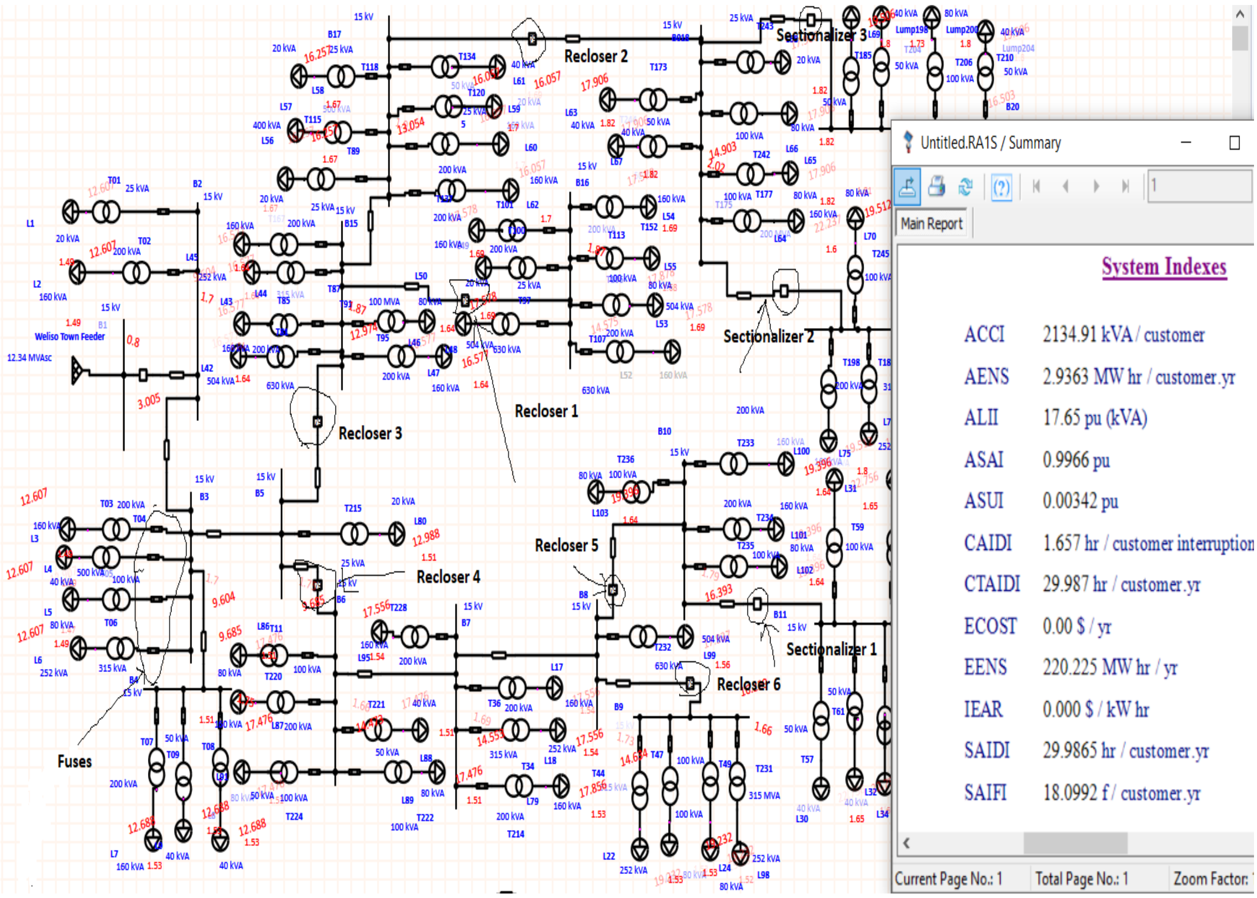


Figure 4. 17: Summary of simulation result by Nine Auto Reclosers placement.

Table 4. 5 : Summary of simulation result by Nine Auto Reclosers placement.

Reliability indices	Result
SAIFI	18.1709 f/customer.y
SAIDI	29.9865 hr/customer.yr
EENS	220.225 MWhr/Yr
CAIDI	1.657 Hr/customer.yr
ASUI	0.342%
ASAI	99.66%

As a result of additional Protection devices installed based on fuzzy logic protection devices optimal placement output SAIFI and SAIDI is reduced from 273 interruptions per customer per year and 232 hours per customer per year to 18.0992 f/customer/year and 29.9865 Hour/customer/year respectively. The power availability is also improved by 2.31% and power un availability was reduced by 2.30%. These reliability indices are very nearest to

SAIFI and SAIDI standard of Ethiopia Electric Agency. The reliability indices SAIFI and SAIDI are improved 93.37% and 87.075 %, which is very good improvements and meet the EEA Standards.

Table 4. 6: Weliso Town reliability indices values and improvements for all cases.

No	Reliability Indices	Existing Configuration	Using one Recloser	Using two Recloser	Using three Recloser	Using9 Recloser,	Improvement b/n Existing Configuration and Protection devices placement
1	SAIFI, f/customer.yr	272.608	252.930	204.008	180.171	18.099	93.36%
2	SAIDI, hr/customer.yr	232.401	216.94	177.8	159.245	29.9865	87.07%
3	EENS(MWHR/YR)	1783.22	1674.22	1342.94	1215.33	220.225	1562.995
4	ASAI(%)	97.35	97.52	97.97	98.18	99.66	2.31%
5	ASUI(%)	2.635	2.476	2.031	1.818	0.34	2.30%

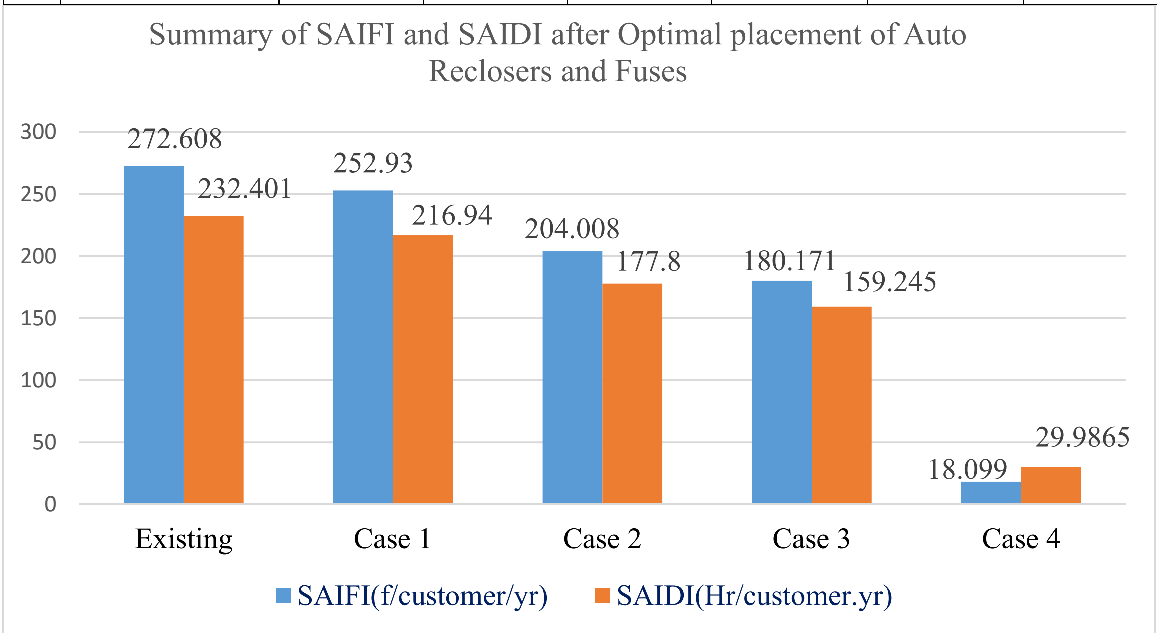


Figure 4. 18 : Summary of reliability result after optimal placement of Auto Reclosers and Fuses

Table 4. 7 : Weliso Town reliability indices improvements for all cases.

No	Reliability Indices	Existing Configuration	Improvement using one Recloser	Improvement using two Reclosers	Improvement using three Reclosers	Improvement using 9 Reclosers,
1	SAIFI, f/customer.yr	272.608	7.22%	25.16%	33.91%	93.36%
2	SAIDI, hr/customer.yr	232.401	6.65%	23.49%	31.48%	87.07%
3	EENS(MWHR/YR)	1783.22	6.11%	24.69%	31.85%	87.65%
4	ASAI(%)	97.35	0.17	0.62	0.83	2.31
5	ASUI(%)	2.635	0.16	0.60	0.82	2.30

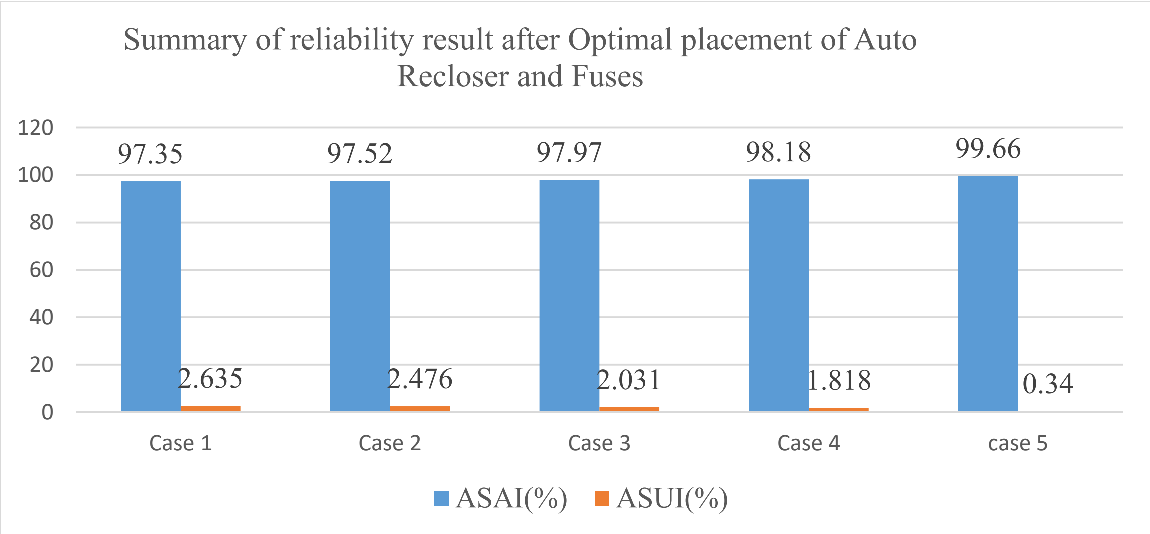


Figure 4. 19 : Summary of reliability result after optimal placement of Auto Reclosers and Fuses

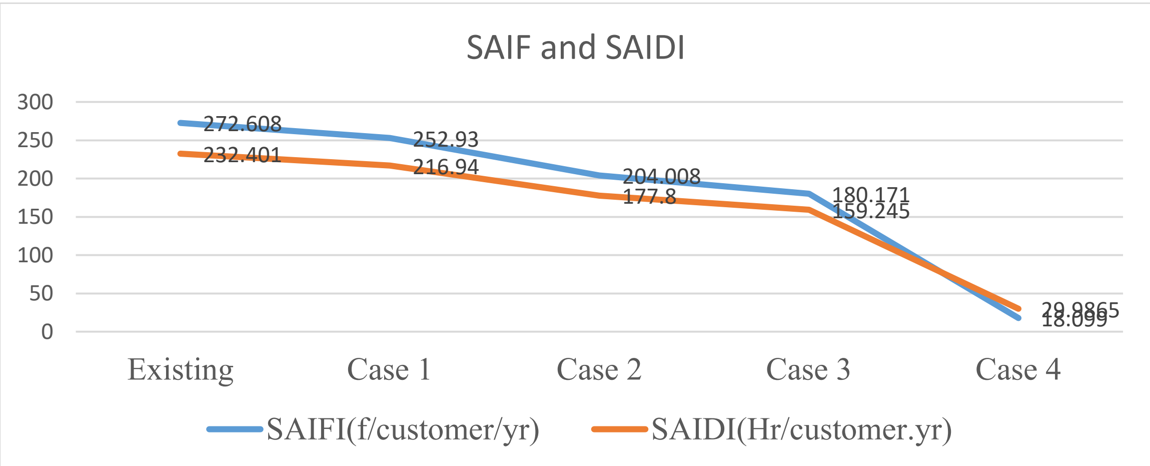


Figure 4. 20: SAIDI and SAIFI improvement

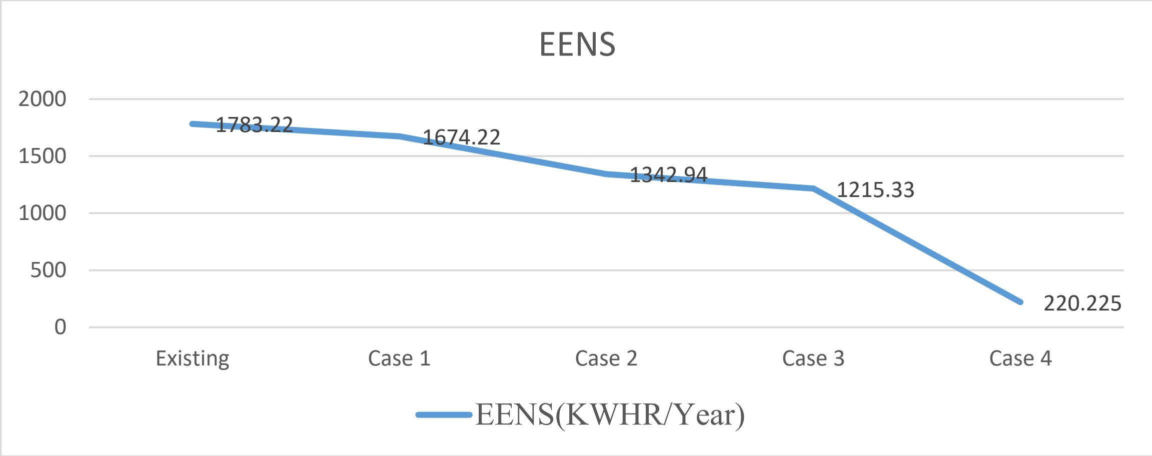


Figure 4. 21: EENS improvement after Auto Reclosers placement

4.4. Protection Devices Coordination.

Coordination means proper trip sequencing of protective devices to isolate the fault and minimizing outage. This means proper coordination between time and current curves during power system abnormal conditions.

The line separation into section is used to minimize the number of customers affected and minimize the time required to visit the line and locate the fault. To reduce the reliability indices, optimal Protection devices placement and coordination is an important concept.

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

The protection coordination has been done by using ETAP Star software. ETAP Star overcurrent device protection and coordination evaluation software provides an intuitive and logical approach to time-current characteristic curve selectivity analysis. provides a plot options tool with all the necessary options to customize the display of the time current characteristic curve. Using plot options, it is possible to customize the display of the current and time axes, legend, grid, curve plotting colors and properties, and more. By setting default Plot options a custom layout can be created without having to repeat the process for each TCC Curve (ETAP.com, 2023).

The total existing capacity of distribution transformers on the 15 kV Weliso Town feeder is 12.34 MVA. By assuming a peak load of each customer is 80% of installed transformer, the total maximum demand on Weliso feeder is 9.872MVA. The expected Peak load (Ip)

$$\text{Ip} = \frac{9872\text{KVA}}{1.732*15\text{Kv}} = 380A.$$

Experience in distribution system shows that the coincident factor in the medium voltage network is 0.28 – 0.5 (Hailemariam, July 2016). Hence, taking an average coincident factor of 0.4, the peak load on the existing 15 kV outgoing feeder will be: 0.4*380 = 152A. Coincidence factor is the ratio of peak load of the entire system to the sum of peak loads of all the components in a system.

The above calculated result is the same to available Circuit breaker on outgoing of the feeder which is 75- 150/1. Reclosers where designed to sense the minimum fault current from the operational rush current in the system. Short circuit analysis has been evaluated by creating a fault at different buses locations in which protection devices was optimally placed on the feeder; and short circuit current values used for coordination has been identified as below table. The Table shows that the short circuit current values are different for different fault types. Buse 2 and Bus 5 are located on the upstream (to source side) from the Recloser. Bus 9, 11,19 and 20 are located on downstream from Reclosers. The CT ratio of the relays is chosen considering the expected loads including load growth. Ip/In (Relay current multiplier setting) shown in the Table is done for pickup values Ip be safely above maximum load current on each protection device. In is CT rated primary current. Iprim is the primary setting current corresponding to Ip/In.

Table 4. 8: Table short-circuit summary report

Bus		**3-Phase Fault (kA)**		**L-G Fault (kA)**	
ID	kV	Symm.	Asymm.	Symm.	Asymm.
B2	15	1.144634	1.145515	0.73463	0.735086
B3	15	1.148839	1.149767	0.733072	0.733516
B5	15	1.176399	1.17754	0.7139	0.714192
B6	15	1.13166	1.132382	0.691987	0.692182
B9	15	0.422579	0.423101	0.274483	0.274483
B10	15	0.423036	0.423573	0.274679	0.274679
B11	15	0.393272	0.393546	0.258659	0.25866
B15	15	0.986358	0.987267	0.575659	0.575697
B16	15	0.603454	0.603497	0.402202	0.402203
B018	15	0.371334	0.371345	0.257486	0.257486
B19	15	0.200905	0.200914	0.151052	0.151052
B20	15	0.216852	0.216852	0.1682	0.1682

Table 4. 9 : Auto Reclosers and circuit breaker maximum load and pick current

Protection Devices	Connected Load(MVA)	Maximum Load(A)	Isc max(KA)	CT Ratio	Ip	Ip/In	Iprim(A)	I/Ip=Iscmax /Iprim
Recloser 1	1.428	54.965358	603	75- 150/1/	69	0.458	68.7067	8.776437
Recloser 2	1.887	72.632794	371	75- 150/1/	91	0.605	90.791	4.086308
Recloser 3	5.591	215.204	986	75- 150/1/	269	1.793	269.005	3.665359
Recloser 4	4.595	174.53963	1132	75- 150/1/	218	1.454	218.175	5.188507
Recloser 5	1.78	68.514242	423	75- 150/1/	86	0.571	85.6428	4.939119
Recloser 6	0.979	37.682833	423	75- 150/1/	47	0.314	47.1035	8.980217
Recloser 7	1.3	50.038491	393	75- 150/1/	63	0.417	62.5481	6.283163
Recloser 8	1.067	41.070054	201	75- 150/1/	51	0.342	51.3376	3.915261
Recloser 9	0.24	9.2378753	217	75- 150/1/	12	0.077	11.5473	18.7922
CB1	12.34	152	1144	75- 150/1/	190	1.267	190	6.021053

From table 4.9 the current multiplier of Recloser 6 at Bus 9 is 8.98. The IEC 60255 defines standard equation governing very inverse characteristic curve,

$$t = T.M.S * \frac{13.5}{\left(\frac{I}{Is}\right) - 1} \tag{4.1}$$

Where T.M.S is time multiplier setting, I is device current and Is is setting current.

by taking T.M. S= 0.5, the operating time of Recloser 6(TR6) = 0.5*(13.5/7.98) =0.84 second.

At Bus 6, the current multiplier is 5.188, by taking coordinate time interval 0.3 sec with Recloser 6, Therefore, the Recloser operating time is: TR4= TR6+CTI= 0.3+0.84=1.15 sec.

The $T.M.S = \frac{1.15*(5.188-1)}{13.5}$ =0.35

At bus 11, the current multiplier is 6.28, the operating time of Recloser 7 = 0.5*(13.5/5.28) = 1.28 sec. At bus 10, the current multiplier is 4.94, by taking coordinate time interval 0.3 sec with Recloser 7, TR5= 0.3 +1.28 =1.58 second.

The $T.M.S = \frac{1.58*(4.94-1)}{13.5}$ =0.33.

At bus 19, the current multiplier is 3.9, the operating time of Recloser 8(TR8) = 0.5*(13.5/2.9) = 2.32 sec. At bus 18, the current multiplier is 4.86, by taking coordinate time interval 0.3 sec with Recloser 8, TR2= 0.3 +2.32 =2.62 second , The $T.M.S = \frac{2.62*(4.86-1)}{13.5}$ =0.75

At Bus 15, the current multiplier of Recloser 3 is 3.66, the Recloser relay operating time, TR3= 0.75*(13.5)/ (3.66-1) =3.8 second. At bus 16, the current multiplier of Recloser R1 is 8.77, So the Operating Recloser time TR1 = 0.5*(13.5/ (7.77) = 0.87 second.

At Bus 2, the Circuit Breaker current multiplier is 6.02, baking time interval 0.3, TCB1= 0.3+3.8 =4.1 seconds.

At bus 20, The current multiplier of Recloser R9 is 18.8, So the Operating Recloser time TR9 = 0.5*(13.5/ (18.8-1) = 0.84 second.

Table 4. 10 : Time sequence of protection devices operation

No	Protection Devices	Time(Second)
1	Recloser 1	0.87
2	Recloser 2	2.62
3	Recloser 3	3.8
4	Recloser 4	1.15
5	Recloser 5	1.56
6	Recloser 6	0.3
7	Recloser 7	1.27
8	Recloser 8	2.32
9	Recloser 9	0.84
10	Fuses	0.2
11	CB1	4.1

The lateral tap fuse is selected based on a criterion that $I = 2 \times I_{load}$. So, the next higher fuse rating available is calculated and mentioned on below table. The TCC curve separation rule for a digital relay with a fuse requires minimum time margin of 0.2 sec. (Hailemariam, July 2016).

Medium Voltage Fuses are current limiting power fuses having voltage ratings from 0.6kV to 34.38kV. Medium Voltage Fuse ratings include continuous current ratings ranging from 0.5 to 1,200 amps. The main Medium Voltage Fuse types include the E Rated Fuse, the R Rated Fuse and the Potential Transformer or PT rated fuse. E-rated medium voltage fuses are general purpose fuses that are primarily used to protect transformers and provide both current overload and short circuit protection. R-Rated fuses are back-up fuses primarily used to protect motors and motor controllers. R-Rated fuses only provide short circuit protection. PT medium voltage fuses are designed to protect potential transformers. Medium Voltage fuses are designed in accordance with the American National Standards Institute (ANSI). Back-up fuses designed in accordance with IEC Standards are also available.

E-rated Fuse standards are 10, 15,20,25,30,40,50,65, 80,100, 125, 150, 175, 200, 250, 300.

Table 4.11: Recommended Fuse rating standard.

NO	Transformer Capacity(KVA)	Line Voltage(KV)	Load in(A)	Recommended Fuse Rating(2*I)	Fuse Rating Available
1	25	15	0.96227868	1.924557352	10
2	50	15	1.92455735	3.849114704	10
3	100	15	3.8491147	7.698229407	10
4	200	15	7.69822941	15.39645881	20
5	315	15	12.1247113	24.24942263	25
6	500	15	19.2455735	38.49114704	40
7	630	15	24.2494226	48.49884527	50

Therefore, the simulation result of Recloser to Recloser coordination and Recloser to Fuses and Recloser to circuit Breaker is as follow.

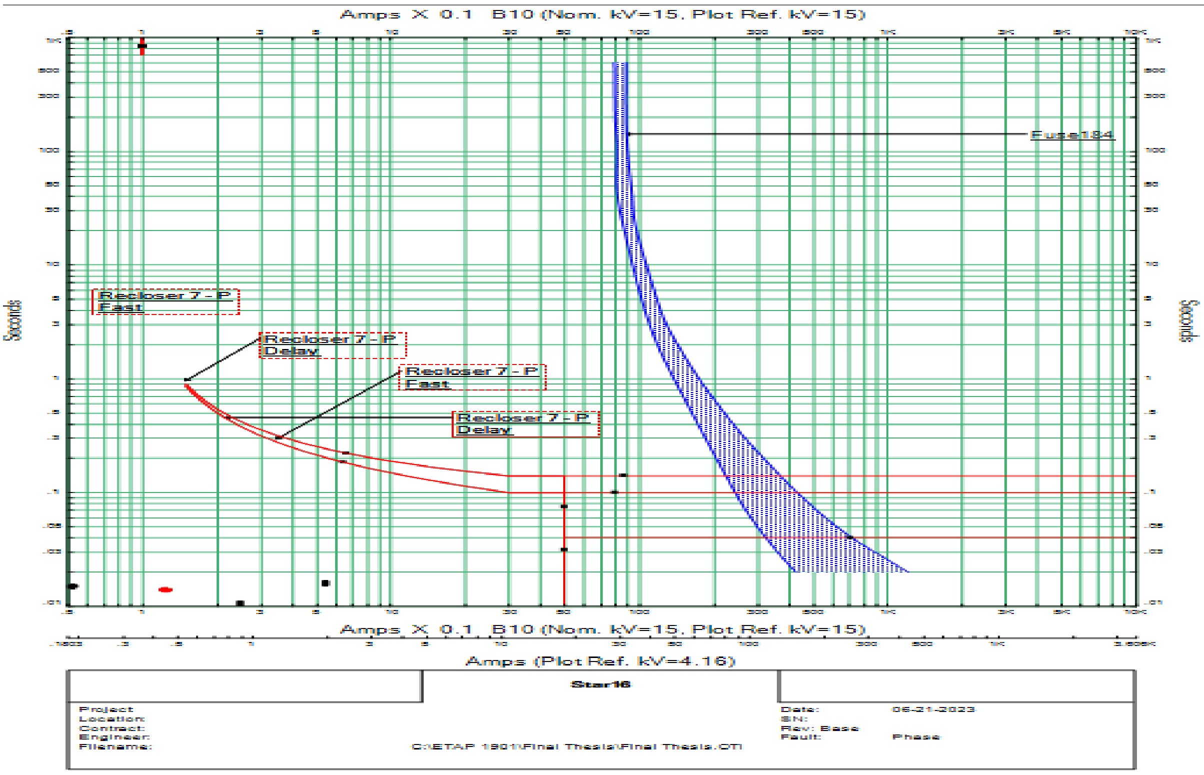


Figure 4. 22 : Simulation result of switching sequence and coordination of downstream Recloser with Fuses.

The above result shows that as there is fault on the branch of Bus 11, The Recloser 7 has fast response to check the fault is cleared or not, If the fault is not cleared the Recloser 7 will lock out after some delay of time to avoid Fuses from explosion and the whole system interruption.

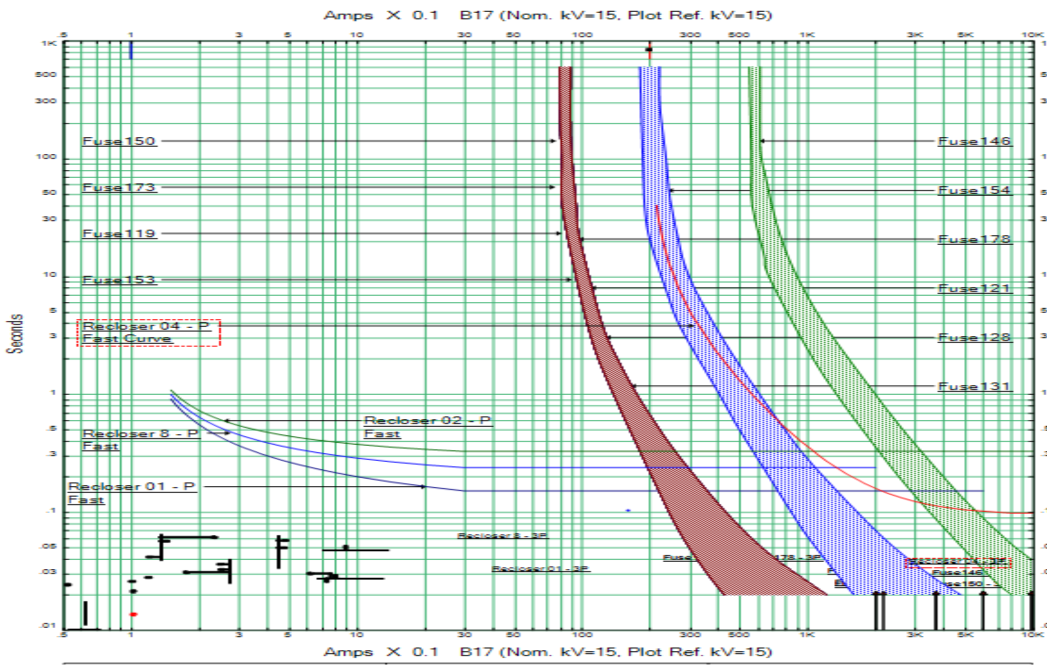


Figure 4. 23 : Simulation result of switching sequence coordination and of downstream Auto Reclosers with Fuses

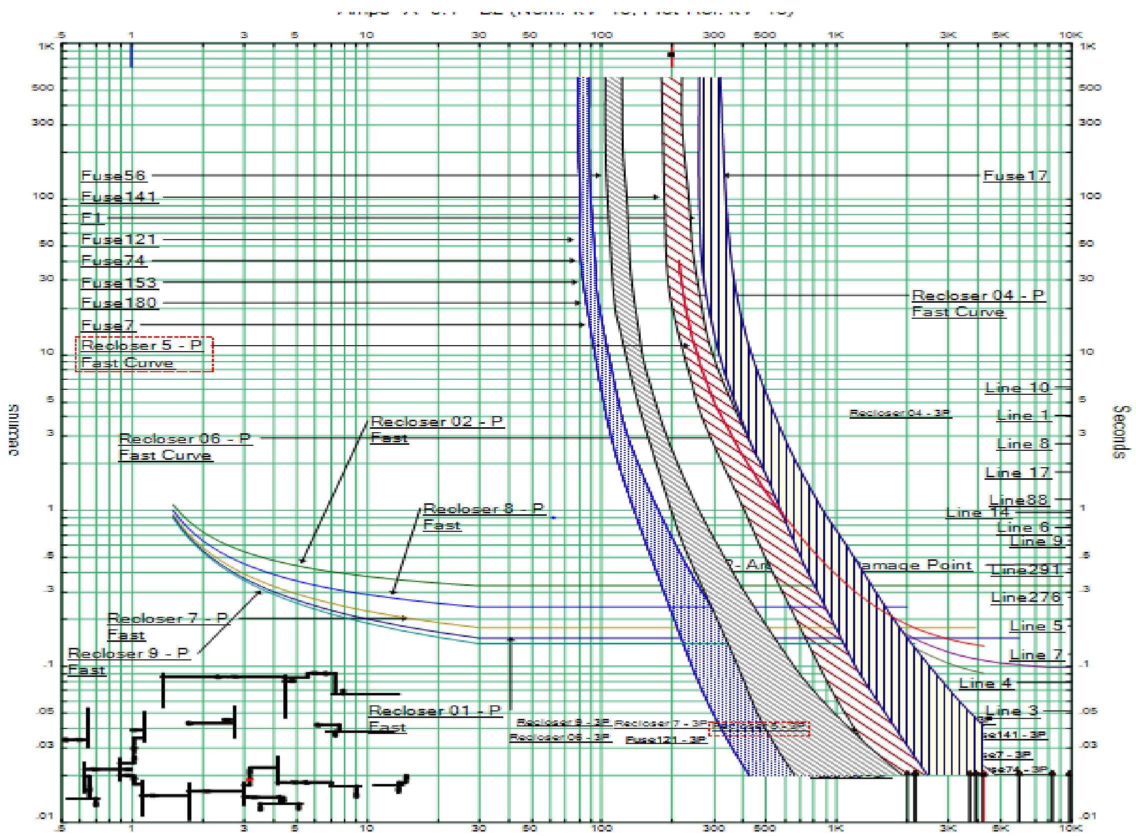


Figure 4. 24 : Simulation result of switching sequence and coordination of all Reclosers and some Fuses.

The above result shows that the Fault clearance sequence starts from downstream Recloser like R7, this is evaluated by inserting fault current ant some points on the feeders.

4.5. Cost Analysis.

Power interruption affects both the utility and the customer sides. It may cause property damages and revenue loses for industries, commercial customers and for private individuals. The size of the economic losses due to interruptions depends largely on the composition of the customers that experience interruptions. There are three customer categories in Weliso Town: residential, commercial, and small industrial customers.

It is difficult to estimate the exact value of interruption costs and economical loses, since the properties of each customer are different and difficult to found important data. In this paper interruption cost only related to the utility side has been analyzed by using Expected Energy Not Supplied (EENS) of each cases. For case -1, after the reliability of the existing power distribution system is improved by using one auto reclose the annual average unsold energy is reduced from 1783.22 to 1674.22 MWHR per year as shown in Table 4.4 above. Therefore, the revenue saved due to reliability improvement can be estimated as follows.

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

$$\text{Revenue Saved } = \frac{\text{ENS before protection device} - \text{ENS after placement of protection device}}{\text{year}} * \frac{\text{Average EEU Tariff}}{\text{KWh}} \quad (4.1)$$

From table 3.12, the average electric price of EEU is 1.66445 Birr/kWh. Therefore revenue saved for Case 1= $\frac{1783220\frac{\text{KWhr}}{\text{yr}} - 1674220\text{ KWhr/yr}}{\text{year}} * \frac{1.66445\frac{\text{Birr}}{\text{kWh}}}{\text{KWh}} = 181425.05\text{ ETB}$

The investment cost can be calculated by using the cost of one out door pole mounted medium voltage auto reclose(15KV/630A-1250A) used to design the system in Case-1. The cost of one Auto Recloser is 1,000 USD ((www.alibaba.com, 2023), therefore based on exchange rate of the Commercial Bank of Ethiopia on May 20, 2023 exchange rate of one US Dollar (USD) is 55.3155 Ethiopian Birr (ETB) (Commercial Bank of Ethiopia, 2023). The cost of one 15KV, 630A pole mounted out door Recloser is: 1,000*55.3155 = 55315.5 ETB.

Average cost of 15KV/10-1200A E-Rated drop out fuse cut out is 18 Euro which 60.0166*18= 1080 ETB. Since there are 76 Transformers, each need 3 drop out fuses, the total cost of drop out fuse is 82080 ETB. The installation cost of both Fuses and Recloser mainly consist of Labor and Transportation cost. Transportation and Labor cost for 6 days are assumed 9000 ETB.

Payback period is defined as **the number of years required to recover the original cash investment**. In other words, it is the period of time at the end of which a machine, facility, or other investment has produced sufficient net revenue to recover its investment costs. It is the ratio of the cost of investment to the annual saving by using that investment.

The payback period of a given investment or project is an important determinant of whether to undertake the position or project, as longer payback periods are typically not desirable for investment positions. Thus, for case-1 the payback period is:

$$\text{Payback period} = \frac{\text{Investment cost}}{\text{Saving Cost}} \tag{4.2}$$

For case 1, the Total investment cost is 55315.5+ 82080 + 9000 ETB = 146395.5ETB.

The payback Period is 146395.5 /181425.05 = 0.8 year, hence, the payback period indicates that it takes 0.8 year to get back the investment cost of for one Recloser and 76 Transformers fuses.

Table 4. 12: Payback Period and cost of investment

Cases	EENS(MWH)	Interruption Cost(ETB)	Investment Cost(ETB)	Annual Revenue saved(ETB)	Payback Period(Year)
Existing	1783.22	2968.081	0		
1	1674.22	2786.655	146395	181425	0.806917014
2	1342.94	2235.256	221710.5	551399	0.402087236
3	1215.33	2022.856	277026	212401	1.304262466
4	220.225	366.5535	620919	1656303	2.667502524

Table 4.12 Shows that the payback period of case-2 very small as compared with the other alternatives, but as mentioned on table 4.4 the percentage reduction for SAIFI and SAIDI compared with the selected base years is minimum. The payback period varies from 0.4 to 2.66 year in these models. This shows that as reliability of the power distribution system improved, the investment cost will increase. Since the project is for 25 years, all payback period is tolerable. When comparing each cases there is improvement of reliability and reduction of Reliability indices, Therefore, case-4 has been improved the reliability of the system very well and the payback period is only 2.67 years.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Weliso Town 15 Kilo Volt(KV) feeders have very important institution (Banks, Telecom, Hospital and University) and residential customers are facing a big challenge due to frequent interruption and utility has taken long time to restore it.

The system modeling and simulation study was done on one of the 15kV distribution feeder of Weliso substation and assessed the performance of the existing system and also predicted reliability analysis for the future. The interruption data of years 2020-2022 has been used as a base year. The existing System Average Interruption Frequency Index (SAIFI) of Weliso town feeder is 272 interruptions per customer per year respectively, System Average Interruption Duration Index (SAIDI) is 232 hours per customer per year respectively. These distribution systems are not reliable as Ethiopian Electric Agency standard directives which set SAIDI is below or Equal to 25 and SAIFI is below or equal to 20).

The selected feeder experienced highest number of outages and The outages are mainly due to distribution earth fault and short circuits, these where happened due to tree, windy rain, distribution equipment failures, scheduled outages and others.

The single line diagram of the existing system feeder was modeled by ETAP software. ETAP 19.0.1 was used for reliability analysis.

Fuzzy logic controller was used for optimal location of Auto Reclosers. The decision is taken to place the auto reclose when value of fuzzy logic output is greater than 0.525. Fuse links are placed before Transformers per each.

Four different alternatives or cases was discussed for improving the reliability of the study area. Each alternative includes a summary of the reliability indices reduction benefits and a cost-effectiveness analysis. SAIFI and SAIDI are used as the main driver for evaluating of each alternative. EENS was also evaluated.

After analysis of the four cases, it was concluded that all cases are good for improving the reliability of the study area. SAIFI has been improved by 93.36 % as compared with the average reliability indices value of the system in the base years. SAIDI and EENS have been improved by 87.07% and 87.65% respectively.

In this different cases Auto Reclosers are used for fault detection, isolation and restoration. Fuses are used for all transformers primary side to minimize equipment damage affected by permanent faults. Protection devices coordination is considered so that faults are localized to the nearest devices instead of affecting the whole network and this is also covered in the thesis

The distribution system models have different Reliability improvement contributions with 0.4 to 2.67-year payback investment cost. All scenarios are tolerable in terms of investment cost. but, to improve reliability indices more and for proper protection coordination, case four is highly recommended. The proposed solution has been saved 1656303 ETB per year from the unsold energy of one feeder only with 2.67 years' payback period investment.

The reliability of the system can be improved and sustained by scheduled preventive maintenance, which can reduce risk or vulnerability in the system.

5.2. Recommendation

The thesis result shows that Weliso Town 15 Kilo Volt(KV) feeders have very important institution and residential customers are facing a big challenge due to frequent interruption, so practical implementation of the recommended alternative solution is very important to improve the reliability of the power distribution system. I highly recommended for Engineers to put their hands on solving such real time problems. Ethiopian Electric Utility (EEU) should have to work to improve the reliability of the power distribution system by using auto restoration protection device along the feeder line.

The EEU should correctly document all distribution data, which is required for reliability analysis such as total number of customer and load in each line.

This thesis is conducted only one feeder, doing reliability assessment and evaluation analysis for whole part of the city is recommended.

5.3. Future Work.

This thesis work uses Auto Reclosers for now, but for future, it can include SMART protection devices which will be monitored by telecom infrastructure.

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APPENDIX

Appendix A: List of Transformers on Weliso Town Feeder

Point Name	Node GPS latitude	Node GPS long	Feeder Name	KV	Transformer Capacity
Inside Tele	8.540094	37.97248	Weliso Town	15	25
Behind Refera No.1	8.540852	37.97322	Weliso Town	15	630
Derasa Geraj	8.5407	37.97697	Weliso Town	15	200
Infront of Tvet College	8.549554	37.97992	Weliso Town	15	200
Tele Around Mocoron Factory	8.535263	37.96559	Weliso Town	15	50
Inside Miciron Factory	8.534874	37.96624	Weliso Town	15	315
Infront of Tamirat Mill	8.531655	37.96646	Weliso Town	15	200
Yegna Hentsa	8.538583	37.9717	Weliso Town	15	50
Gersu school	8.528987	37.96717	Weliso Town	15	25
Inside Dej. Gersu	8.528221	37.96627	Weliso Town	15	50
Bolokete mamirch	8.526476	37.9684	Weliso Town	15	100
Fodu Gora	8.50545	37.96806	Weliso Town	15	100
Infront of university	8.551166	37.98128	Weliso Town	15	25
Weliso	8.547348	37.98615	Weliso Town	15	200
Hayetu zone 9	8.552027	37.98732	Weliso Town	15	200
Weliso blood bank	8.545726	37.9789	Weliso Town	15	100
Weliso Hospital	8.545409	37.9789	Weliso Town	15	200
Infornt of Rf	8.545563	37.98025	Weliso Town	15	630
Weliso Kenbo site					
01 Around Megarsa House Trafo	8.540044	37.98139	Weliso Town	15	630
Memerahan Sefar	8.535459	37.98193	Weliso Town	15	200
Pana Africa Trafo	8.529216	37.97679	Weliso Town	15	315
Trafo Around 02 Adebabay	8.545523	37.9731	Weliso Town	15	200
02 School Trafo	8.548462	37.97266	Weliso Town	15	25
Water project Below Weliso University	8.561245	37.97996	Weliso Town	15	200
Oby Kume Koricha	8.564941	37.98111	Weliso Town	15	100
Inside Negash Lodge	8.532456	37.98095	Weliso Town	15	315
Behinds of Negash Lodge Tele Towers Trafo	8.535593	37.9842	Weliso Town	15	25
Gelila	8.52929	37.98292	Weliso Town	15	25
Negash Lodge Hall	8.529724	37.98251	Weliso Town	15	315
Gelila	8.527814	37.98231	Weliso Town	15	100
Inside Of Woliso Soap Factory	8.530005	37.98592	Weliso Town	15	630
Materia	8.530782	37.98736	Weliso Town	15	200
Rebu Trafo	8.527226	37.99697	Weliso Town	15	100
Obi Primary School	8.56674	37.99101	Weliso Town	15	200
Obi Koji	8.578784	38.00352	Weliso Town	15	25

Obi Koji	8.579282	38.00362	Weliso Town	15	50
Inside Asela Flowers	8.586929	38.00984	Weliso Town	15	315
inside Asela Flowers	8.586948	38.01456	Weliso Town	15	100
Chefo Aba Bora	8.610384	38.0248	Weliso Town	15	100
Inside Geresu Duki	8.609753	38.02724	Weliso Town	15	200
Roge	8.510383	37.99736	Weliso Town	15	100
Inside Filseta Mariam	8.497265	38.01955	Weliso Town	15	50
Megnako	8.486098	38.02765	Weliso Town	15	25
Kile Wuha Trafo	8.466925	38.05303	Weliso Town	15	100
Korke Water Project Trafo	8.450512	38.08856	Weliso Town	15	50
Danbali Keta	8.58525	37.99273	Weliso Town	15	50
Danbali Keta	8.604096	37.99032	Weliso Town	15	50
Kile	8.47049	38.05641	Weliso Town	15	100
Korke school	8.455062	38.08321	Weliso Town	15	25
Jelisa Cheka	8.468039	38.07236	Weliso Town	15	50
Jelisa Cheka	8.476814	38.07825	Weliso Town	15	50
Oby water project	8.573192	37.99048	Weliso Town	15	50
Obi Koji water project	8.568869	37.98218	Weliso Town	15	100
Dellal Tele	8.639131	38.04942	Weliso Town	15	25
Dilela Market Trafo	8.643389	38.04994	Weliso Town	15	315
Dellal	8.642252	38.05544	Weliso Town	15	200
Weliso 01 zone 5	8.539085	37.98563	Weliso Town	15	100
Weliso Around zone 6	8.542848	37.98512	Weliso Town	15	315
Weliso Hospital	8.544068	37.97937	Weliso Town	15	25
Inside Ambo University Weliso Campus	8.551316	37.9791	Weliso Town	15	250
Ambo University Weliso Campus	8.551716	37.97941	Weliso Town	15	500
Gorobo water project Trafo	8.496015	38.1472	Weliso Town	15	50
Woliso com Bank	8.539965	37.97181	Weliso Town	15	100
Weliso araund rabita	8.530064	37.99131	Weliso Town	15	200
Woliso Campus	8.551165	37.9813	Weliso Town	15	25
04 kebele walde mazoria	8.531627	37.97673	Weliso Town	15	200
Stigereda	8.535355	37.97548	Weliso Town	15	200
Ejersa	8.530635	37.96897	Weliso Town	15	200
Weranen megnako chefe	8.494053	38.02117	Weliso Town	15	100
Woliso Union	8.532031	37.96561	Weliso Town	15	100
Around bastation	8.541034	37.96955	Weliso Town	15	200
Danbali kata water	8.577835	37.99474	Weliso Town	15	100
Darree water	8.442592	38.10254	Weliso Town	15	100
Behind riftvally	8.543091	37.97746	Weliso Town	15	315
pan Afrika 2	8.528152°	37.976795°	Weliso Town	15	200
Kata 2	8.58352	37.99459	Weliso Town	15	50

Appendix B: Substation Feeder Load data of 2021 G.C

Substation Name	Feeder Name	15/33 KV	Number of Outgoing Feeder	Load (MVA)	Peak load in MW	Average Load	Reserved Feeder	Out of Work (Breaker burn)	Working Feeder
Weliso	Tulubolo	15	5	12	1	0.6	1	0	7
	Goro	15			1.1	0.77			
	Ameya	15			1.2	0.84			
	Weliso	15			9	6.2			
	Acheber	33	4	12	1.15	0.69	1		
	Busa	33			2.125	1.4875			
	Kota	33			0.8	0.48			

Appendix C: Substation feeder load data of 2021 G.C

Substation Name	Feeder Name	15/33 KV	Number of Outgoing Feeder	Load (MVA)	Peak load In MW	Average Load	Reserved Feeder	Out of Work (Breaker burn)	Working Feeder
Weliso	Tulubolo	15	5	12	1.2	0.72	1	0	7
	Goro	15			1.35	0.945			
	Ameya	15			1.47	1.029			
	Weliso	15			10.98	8.7			
	Acheber	33	4	12	1.4	0.84	1		
	Busa	33			2.8	1.96			
	Kota	33			1	0.6			

Appendix D: Frequency and duration of interruption of 2020/2022 G.C

No.		Feeder Name	Voltage Level(KV)	Frequency and Duration of Interruption							
				DEF		DSC		TLP		SOL	
				F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]
1		Tulubolo	15	66	75.11	116	82.82	1	0.05	0	0
2		Goro	15	31	20.37	68	36.79	1	0.05	0	0
3		Weliso	15	65	62.76	102	90.01	1	0.05	0	0
4		Acheber	33	77	60.82	81	93.78	1	0.05	0	0
5		Busa	33	70	78.92	93	77.79	1	0.05	0	0
6		Kota	33	102	65.64	118	107.26	1	0.05	0	0
7		Ameya	15	135.44	38.78	118	85.01	1	0.05	0	0

Appendix E: Frequency and duration of interruption of 2020/2022 G.C

Frequency and Duration of Interruption								Frequency of Interruption (No.)	Duration of Interruption (Hr.)
GUP		DLOL		PTOL		OP			
F	D[Hr.]	F	D[Hr.]	F	D[Hr.]	F	D [Hr.]		
0	0	0	0	0	0	70	55.4	253	213.38
0	0	0	0	0	0	39	15.8	138	72.96
0	0	0	0	0	0	101	75.38	269	228.2
0	0	0	0	0	0	94	46.19	252	248.6
0	0	2	0.85	0	0	85	88.65	248	245.36
0	0	0	0	0	0	34	44.51	254	217.41
0	0	0	0	0	0	28	42.71	281.44	166.5

Appendix F: Frequency and duration of interruption of 2021/2022 G.C

Item No.	Feeder Name	Voltage Level(KV)	Frequency and Duration of Interruption							
			DEF		DSC		TLP		SOL	
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]
1	Tulubolo	15	49	23.27	143	133.45	0	0	0	0
2	Goro	15	44	34.67	73	24.45	0	0	0	0
3	Weliso	15	59	69.83	117	69.03	7	2.76	0	0
4	Acheber	33	49	46.2	116	56.37	0	0	0	0
5	Busa	33	58	56.57	129	153.35	0	0	0	0
6	Kota	33	98	112.51	111	28.16	0	0	0	0
7	Ameya	15	57	41.3	100	67.18	0	0	0	0

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Appendix G: Frequency and duration of interruption of 2021/2022 G.C

No.	Feeder Name	Voltage Level(KV)	Frequency and Duration of Interruption								Frequency of Interruption (No.)	Duration of Interruption (Hr.)
			GUP		DLOL		PTOL		OP			
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]		
1	Tulubolo	15	0	0	0	0	0	0	78	83	270	239.72
2	Goro	15	0	0	0	0	0	0	95	86.02	212	145.14
3	Weliso	15	0	0	0	0	0	0	101	98.43	284	240.05
4	Acheber	33	0	0	0	0	0	0	65	39.33	230	167.57
5	Busa	33	0	0	0	0	0	0	77	26.02	264	235.94
6	Kota	33	0	0	0	0	0	0	65	74.34	274	215.01
7	Ameya	15	0	0	0	0	0	0	97	70.95	254	179.43