Study of Reliability of Power Distribution System and Improvement Options

(Case Study of Awash7 kilo Substation)

Jemal Mohammed Amin

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

Presented in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Electrical Power Engineering

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia

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Approval of Board of Examiners

We, the undersigned, members of the Board of Examiners of the final open defense by Jemal Mohammed have read and evaluated his thesis entitled "**STUDY OF RELIABILITY OF POWER DISTRIBUTION SYSTEM AND IMPROVEMENT OPTIONS**" **(Case Study of Awash7 kilo Substation)** and examine the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Masters of Science in Electrical Power Engineering.

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DECLARATION

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

Jemal Mohammed ________________

Student Name Signature

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ACRONOMYS

A	Ampere
AAC	All Aluminum Conductor
AENS	Average Energy Not Supplied
ALIDI	Average Load Interruption Duration Index
ALIFI	Average Load Interruption Frequency Index
ASAI	Average Service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
DUR	Duration of Interruption
EEA	Ethiopia Electric Agency
EEP	Ethiopia Electric Power
EEU	Ethiopia Electric Utility
EEPCO	Ethiopia Electric Power Corporation
EENS	Expected Energy Not Supplied
ETAPS	Electrical Transient Analysis Program Software
ETB	Ethiopian Birr
ICS	Interconnected System
IEC	International Electro technical Commission
IEEE	Institute of Electrical and Electronics Engineers
KM	Kilometer
KV	Kilo Volt
KVA	Kilo Volt Ampere
KVAr	Kilo Volt Ampere reactive
KWh	Kilowatt hour
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
MVA	Mega Volt Ampere
Rec	Recloser
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
TCC	Time Current Curve

ABSTRACT

Unreliable electric power distribution reduces power consumption, affects daily activity and drags the modern lifestyle. It impacts societal development and individuals' income. Basically, a power distribution reliability has been a major challenge in Awash7 kilo city. The existing substation has encountered frequent power interruptions problems. The interruptions are caused mainly by the short circuit (SC) and earth fault (EF). There are also planned outages for operation and maintenance purpose. The substation's System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) are 414.0 interruptions per customer per year and 319.67 hours per customer per year, respectively. The substation is not reliable by the standard of Ethiopian Electric Agency (EEA) which set SAIFI is equal to 20 interruptions per customer per year and SAIDI which is around 25 hours per customer per year. This reliability gap calls for searching for effective methods for improving the reliability of the distribution system. Thus, the objective of the study is to assess the reliability of the existing distribution system and suggest solutions for reliability improvement in heuristic techniques. To limit the scope of the study, 15 kV Awash7 kilo city feeder of the substation has chosen for reliability improvement measures and also predict the reliability analysis for the future. The historical outage interruption data of years 2015/16-2017/18 G.C has been used as a base year. The study has evaluated four different mitigation scenarios have been assessed using the heuristic method to improve the system reliability. From the mitigation scenarios with the lowest SAIDI, SAIFI and Expected Energy Not Supplied (EENS) at a reasonable cost has been selected. The simulation results have been done with the help of Electrical Transient Analysis Program (ETAP 12.6) software. The result of this thesis work reveals that the reliability of the system has been improved significantly by implementing reliability improvement solutions that are justified economically. The researcher identifies scenario four as the optimum one as comparing the power reliability improvement and the cost. Hence, the overall reliability of Awash7 kilo city feeder has been improved significantly by 86%, 85.4% and 92.94% for SAIFI, SAIDI, and EENS respectively as compared with the existing system. The economic analysis shows that the selected solution results in a cost saving of 556,615.9686 ETB per year from the unsold energy of one feeder only with three years payback period investment. Satisfaction of the society has been considered as a priceless benefit as well.

Keywords: *Distribution System, Power Reliability, Reliability Indices, ETAP Software.*

CHAPTER ONE

INTRODUCTION

1.1 Background

The electric power system is basically set up to supply electricity with little or no interruptions to its customers. The number of interruptions that occur while the system performs its intended function is part of what determines the overall reliability of the system. The other factor that determines its reliability is the quality of electricity delivered. Furthermore, the capability of a power system to continuously deliver quality electricity means that the customers are satisfied and the electricity providers are having favorable returns on their investment as they continue their business of supplying electricity. As electricity consumption has become an important factor that affects the drive needed for the technology to grow and to facilitate the development of modern society. It is very important therefore to take seriously the issue of reliability of an electric power system.

Generation, transmission and distribution are the three subsystems of an electric power system. At the generating station, electricity is generated and transmitted through the high voltage transmission lines to the distribution substations. The distribution substation system considered covers the electrical system between the substation fed by the sub-transmission system and the supply line to the consumers' meters i.e. 15 kV to 0.4 kV transformation [1]. The distribution substations are usually sited relatively near the customers for effective delivery, monitoring and maintenance of the substation and the customer end are usually referred to as secondary distribution substation system. Distribution systems basically serve as the link from the distribution substation to the customer. Reliable and safe transfer of electricity to the customers covered by the distribution area is ensured by this system and is the main subject studied in this thesis.

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

In terms of reliability evaluation and modeling, generating stations have justifiably received more attention than the other systems because they are individually capital intensive. In addition, in the event of generation inadequacy and generation loss, there is usually widespread catastrophic effects on the society and environment. It impacts directly on the whole system and even distribution system will not be able to perform its duty because there will be no electricity to supply to customers. However, based on published research work and studies, distribution systems have begun to receive moderate attention compared to past decades. In most cases, when there is a disturbance in form of failure which results in outages in the distribution system it affects only the localized territory. Only in a few cases does the fault move up into the system largely as a result of protection failure. Analysis of the customer failure statistics of most electricity companies shows that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer [1]. This makes the distribution system to be highly important. The distribution systems account for up to 90% of all customer reliability problems, improving distribution reliability is the key to improving customer reliability [2].

Meanwhile, as the main aim of a power system is to meet the electricity needs of the customers and this can only be achieved when the components making up the system are performing their intended function properly for as long as the system is in operation. It is important that the demand for electricity and its supply be properly viewed and included in setting up the system. Therefore, due to its high impact on the cost of electricity and its corresponding effect on customer satisfaction, distribution reliability is very important. However, as in any other viable engineering system, there are challenges that face power distribution system which tends to make the system unreliable. One of these is the issue of serving its main purpose which is to supply quality electricity with little or no interruptions. This problem is inevitable in power systems across the world but the way they are managed is what makes it different from country to country. For instance, in the United States, there is nearly an uninterrupted delivery of quality electricity to its numerous customers which makes it rank among the most dependable in the world. It is the management of the power systems that reliability evaluation becomes significant. Reliability evaluation does not in any way make a system more reliable but it helps in system planning and identification of weak components.

Thus, the purpose of this thesis is to address the problems that customers face due to the present state of power distribution problems in Awash7 kilo city and come up with proper mitigation techniques for power reliability improvement of the existing system.

1.2 Statement of the Problems

The distribution system is the core part of the power system network, which delivers power to the end user. It connects the customer to the power generation. Reliable power delivery plays a key role in profitability and customer satisfaction. Ethiopia Electric utility has tried to improve the delivery mechanism and quality of supply. But the power distribution system in Awash7 kilo city has remained inadequate to meet customer demand both in required reliability and reduce safety risks of the customers. The power failure impacted to varying degrees, a wide range of critical infrastructure like the industry, the business enterprises and for the residential users. Low system reliability has led to increased outages resulting in more losses to business sectors. Reliability and consistency of electricity supplies are critical to mainly industrial and service activities. The unreliable power supply does not only slow down or damages production or results in shutting down of the plant but also leads to equipment damage, additional maintenance and the industry's reputation for the quality of the product. The power outage has resulted in customer stoppage of production and unavailability of lighting in the major areas of Awash7 kilo city. Achieving reliability of power supply in Awash7 kilo city has a major challenge for the last many years and it will continue to be a challenge in the future if an amicable solution is not found to the problem. How a reliable distribution system can be reconfigured for optimal power reliability improvement of the study area is the main question for this study tries to address. Therefore, the recloser and the tie switch coordination together with substation circuit breaker to achieve the distribution system reliability improvement is studied for its implementation to alleviate this public problem.

1.3 Significance of the Study

The benefit of this study is mainly the residential customers by solving the problem of power interruption in the city of Awash7 kilo. The other benefit of the study is significant economic impact it might bring to the commercial sectors. In addition to this in the utility side, the study has a major role to reduce the interruption cost during power outage.

1.4 Objectives of the Study

The objective of this thesis work can be categorized in to two these are general objective and specific objective.

1.4.1 General objective

The main objective of this thesis work is study the reliability power distribution system and improvement options.

1.4.2 Specific objective

The specific objectives of this study are as follows:

- ✓ Assess Awash7 kilo city power distribution system in terms of its reliability problems.
- ✓ Identify the major causes of power interruptions in the existing system based on historical outage data.
- ✓ Evaluate system reliability indices based on selected base year's interruption data of the city feeder using an available reliability analysis tool (ETAP12.6.0).
- ✓ Propose and evaluate proper power outage mitigation techniques and draw relevant conclusions.

1.5 Scope of the Study

The thesis focuses on studying the current power system reliability problems of the Awash7 kilo substation of the medium voltage feeder connecting to the customers of the city. The customer's equipment, substation equipment's and sub-transmission networks are excluded from this thesis. It is limited to calculate the customer based reliability indices and also the calculation of energy oriented indices. In addition to this, the thesis also studies the improvement of power reliability network topology reconfiguration with protection systems.

1.6 Methodology

Due to the nature of the study, it starts by reviewing literature related to the investigation of the reliability problems of power distribution systems. Recent and unpublished important historical outage data's related to power reliability have been collected from Ethiopian Electric Utility (EEU) at Awash7 kilo district.

Interviews with the respective professional workers at Awash7 kilo substations have been contacted. Previously historical outage data's have been gathered for detail assessment and investigation to come up with a clear solution of the problem at hand.

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

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

- **Assessment of the existing network**: an assessment of the physical system in the case study area, understanding and adopting the system as a whole.
- **Data Collection:** Data collection plays a very crucial role in the statistical analysis. In this thesis work, the primary data type has been used which is collected for the first time by the researcher from the case study area. In this thesis work, the data can be collected through various methods like surveys, observations, personal interviews, telephonic interviews and case study.
  - Three years (2015/16 -2017/18 G.C) the interruption, data has been collected from Awash7 kilo substation which helps to carry out reliability analysis.
  - The rating of Transformers, number of customers and feeder length has been collected from the distribution in Awash7 kilo district.
  - Load of the existing system has been gathered from the district.
  - The collected data has been used to clearly analyze the problems of the Awash7 city feeder.

1.7 Thesis Layout

The thesis is organized into five chapters which are briefly summarized below.

Chapter one**,** presents the introduction, background, objectives, problem statements, scope, the significance of the study and methodology followed in the thesis work. In addition, it provides the outline of the thesis. The second chapter discusses the theoretical frameworks of reliability, protection system and a review of the literature on power reliability and distribution systems. In chapter three of the thesis, the electrical data of Awash7 kilo substation and interruption data's collected has been analyzed. These include the number of customers, the number of distribution transformers, interruption duration and frequency and so on. The collected data is analyzed numerically and reliability indices are calculated. Simulation studies, system modeling and analysis of different mitigation alternatives have been presented in chapter four, and the results are presented with reasonable explanations in this chapter. Finally, the conclusions, recommendations, and future work for researches are discussed in chapter five. The results are obtained from this thesis works are summarized and relevant conclusions have been drawn.

CHAPTER TWO

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

Distribution reliability primarily relates to equipment outages and customer interruptions. In normal working conditions, all material (except standby) and all customers are energized. Schedule and unscheduled activities disrupt normal working conditions and can make to outages and interruptions. The unscheduled situation is caused either due to human error or due to Electrical material failures. The scheduled events are meant for periodic maintenance of the equipment and shall be notified in advance to the customers. Different indicators are used to evaluate reliability in the transmission and distribution system. The Regulation can aim to compensate customers for very long interruptions, keep restoration times under control and create incentives to decrease the total number and duration of interruptions (disincentives to raise them).

Electrical power reliability can be explained 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 desired amount. The reliability of the interconnected bulk power system is defined in two ways.

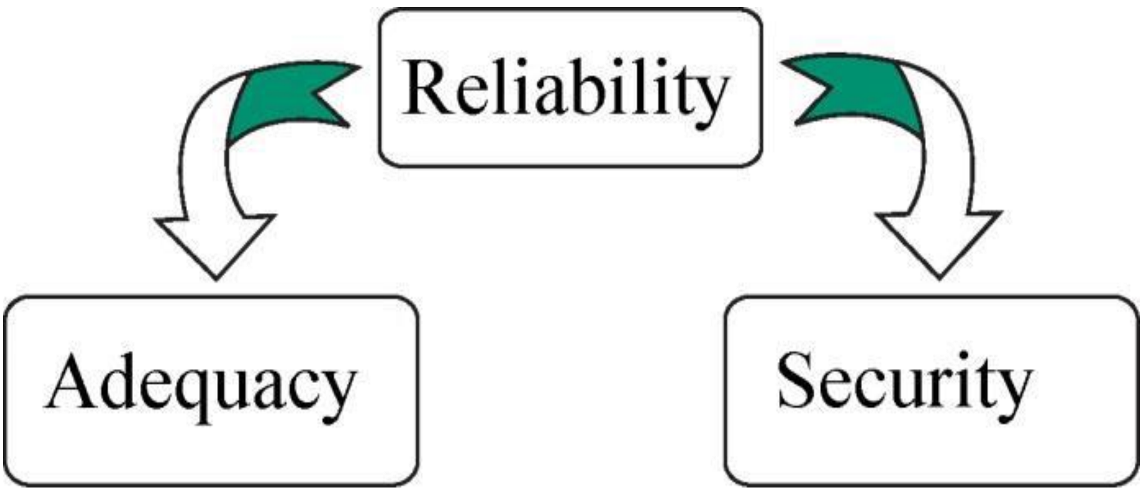


Figure 2.1: Classification of Distribution Reliability [3].

(A) Adequacy: it is the ability of the Electric systems to supply the aggregate Electrical demand and energy requirements of their customers at all times, taking into account scheduled and reasonably expected unscheduled outages of the system elements.

(B) Security: It is the ability of Electrical systems to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements.

In brief, reliability has to do with total Electric interruptions and complete loss of voltage, no just deformations of the Electric sine wave. Power reliability does not cover to sag, swells, impulse or harmonic. Reliability indices typically consider such aspects as [4].

- The number of customers
- The duration of the interruption measures in seconds, minutes, hours or days.
- The amount of Power (KVA) interrupted and
- The frequency of interruptions.

There are many terms and definitions used in Reliability Engineering. Some of the frequently used terms and definitions are presented below [4].

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

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

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

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

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

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

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

$$f = \frac{\text{Number of failures}}{\text{Studied Period x Circut length of Transmission lines or Cables}} \qquad (2.1)$$

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

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

$$f = \frac{1}{MTTF + MTTR} \tag{2.2}$$

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

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

$$Q(t)= 1- R(t) \tag{2.3}$$

Availability (A): It is the probability that the component is normal at an arbitrary time t, given that it was good at a time zero [4].

$$A = \frac{MTTR}{MTTF + MTTR} \tag{2.4}$$

Unavailability (U): It is the probability that the component is down at any arbitrary time t and unable to operate [4].

$$U = \frac{f * MTTR}{8760} \tag{2.5}$$

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

$$U= 1-A \tag{2.6}$$

2.2 Electricity Service Faults

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

Permanent Forced Outage Duration: It is defined as the average time it takes to restore the affected components to service without deliberate delays when the component outage occurrence has been automatically initiated due to a permanent fault with the components [4,5].

Transient Forced Outage Duration: It is defined as the average time it takes to restore the affected components to service without deliberate delays when the component outage occurrence has been automatically initiated due to transient faults with the components [4,5].

2.3 Types of Power Interruption

There are different types of interruption and they are as discussed below.

2.3.1 Momentary Interruption

This is a situation where a customer is without electricity supply from the utility for less than a few minutes. When the power supply is interrupted and restored in less than five minutes, then the customer is said to have experienced momentary interruption according to IEEE 1366-2003 standard. The operation of a circuit breaker or reclosers, which opens the circuit momentarily to clear faults and closes back, brings about this interruption. Momentary interruptions sometimes affect power quality and sometimes lead to voltage sags [15].

2.3.2 Temporary Interruption

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

2.3.3 Sustained Interruption

This is a loss of supply to the customer which is usually more than many hours and can sometimes last for days. A temporary fault can lead to sustained interruption if it does not take care of as soon as possible. However, the sustained interruption could be as a result of transformer failure, insulator failure, damaged wires etc.

2.3.4 Planned Interruption

This happens when deliberate action is taken on a component by removing it from service in order to carry out maintenance work or construction. This interruption usually accompanies scheduled outage. It is usually planned and the customers are aware of the loss of supply that ensues.

2.4 Distribution System Reliability Indices

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

Most reliability indices are average values of a specific reliability characteristic of an entire system, operating region, or feeder. The indices for the power distribution system analysis include customer-oriented indices and energy-oriented indices as defined in IEEE standard 1366-2012 [6].

A. Customer Oriented Indices

1. System Average Interruption Frequency Index (SAIFI)

The index represents the average number of sustained interruptions experienced by a customer in a unit time (generally one year). The definition of the service area is flexible in the sense that the number of customers and the interruptions experienced by them changes with the definition of the enclosed area. For instance, a feeder SAIFI indicates the average number of interruptions a customer serviced by the particular feeder would experience in a year. Similarly, SAIFI reported for a substation or a distribution system encloses the total customers in the service area. It is the total number of customer interruptions per year divided by the total number of customers served [6].

$$\mathrm{SAIFI} = \frac{\text{Total number of Customer Interruptions}}{\text{Total number of Customers served}} = \frac{\sum_i N_i}{\sum_i N_t} \tag{2.7}$$

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

In order to calculate the index, data about individual sustained interruptions in a year are required. For each of these interruptions, the number of customers affected comprises the customer interruptions for the particular outage. The denominator is the total number of customers in the service area under consideration.

The method to improve on the SAIFI levels of a system is by reducing the number of sustained interruptions that occur. This can be achieved through a proper maintenance cycle, for each of the components in the system and through the use of automation and improved protective equipment that sense faults and attempt to clear the same before it turns into a permanent outage.

2. System Average Interruption Duration Index (SAIDI)

The index indicates the average time a customer has an interruption during a time cycle (one year). It is usually specified in customer minutes or customer hours of the interruption per year. SAIDI (system average interruption duration index) is the average interruption duration per customer served as given in Equation (2.8). It is determined by dividing the sum of all customer interruption durations during a year by the number of customers served [6].

$$\text{SAIDI} = \frac{\text{Total Customer Interruptions Durations}}{\text{Total number of Customers served}} = \frac{\sum_i r_i N_i}{\sum_i N_t} \qquad (2.8)$$

Where, N_i is the number of interrupted customers for each interruption event i during the reporting period, N_t is the total number of customers served in the area and r_i is the restoration time for each interruption event i. The number of customers affected and the time it took for the restoration for each interruption event are the parameters required to estimate the system average interruption duration index. The restoration time includes, the time is taken to notice an outage, the time taken to locate and reach the location and the time to repair the fault.

3. Customer Average Interruption Duration Index (CAIDI)

Customer Average Interruption Duration Index (CAIDI) is the average interruption duration for those customers interrupted during a year. It is determined by dividing the sum of all customer interruption duration by the number of customers experiencing one or more interruptions over a one year period.

The index is the ratio of SAIDI to SAIFI as given in Equations (2.9). It represents the average time taken to restore service to the customers when a sustained interruption occurs [6].

$$\text{CAIDI} = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total number of Customer Interruptions}} = \frac{\text{SAIDI}}{\text{SAIFI}} \qquad (2.9)$$

4. Customer Average Interruption Frequency Index (CAIFI)

Customer average interruption frequency index (CAIFI) gives the average frequency of sustained interruptions for those customers experiencing interruptions as given in equation (2.10) [6].

$$\text{CAIFI} = \frac{\text{Total number of Customer Interruptions}}{\text{Total number of Customer Interrupted}} = \frac{\sum_i N_i}{C_n} \qquad (2.10)$$

Where N_i is the total number of customer interruption, C_n is the total number of customers facing an interruption during the reporting period.

SAIFI is the average frequency of interruptions experienced by a customer and includes even the customers that have not experienced an outage, while CAIFI's computation involves only the inclusion of customers that have experienced at least one interruption. Also, the customer is counted once no matter how many times they have been interrupted.

5. Average Service Availability Index (ASAI)

The average service availability index (ASAI) gives the fraction of time the customer has power during the reporting time. Higher ASAI values reflect higher levels of reliability. Equation (2.11) is used to calculate the value of ASAI for a given service area [6].

$$\text{ASAI} = \frac{\text{Customer hours service availability}}{\text{Customer hours service demand}} = \frac{N_t x8760 - \sum_i r_i N_i}{N_t x8760} \qquad (2.11)$$

Where; N_i is the total number of customer interruption, N_t is the total number of customers served and r_i is the restoration time for each interruption event i.

6. Average Service Unavailability Index (ASUI)

This index is the complementary value of the average service availability index (ASAI) [6].

$$\text{ASUI} = 1 - \text{ASAI} \qquad (2.12)$$

B. Load or Energy Oriented Indices

1. Energy Not Supplied Index (ENS): This index represents the total energy not supplied by the system [6].

$$\text{ENS} = \sum_i L_a(i) U_i \qquad (2.13)$$

The unit is $(Watt - Hours)$

Where, La(i) is given by:

$$L_a(i) = L_p(i) x L_F(i) = \frac{E_d(i)}{t} \qquad (2.14)$$

Where, $L_p(i)$ is a peak load demand,

$L_f(i)$ is the load factor and

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

2. Average Energy is Not Supplied (AENS)

This index represents the average energy not supplied by the system [6].

$$\text{AENS} = \frac{\text{Total Energy not suplied}}{\text{Total number of Customers served}} = \frac{\sum_i L_a(i) U_i}{\sum_i N_i} \qquad (2.15)$$

3. Average Customer Curtailment Index (ACCI)

This index represents the total energy not supplied per affected customer by the system [6].

$$\text{ACCI} = \frac{\text{Total Energy not suplied}}{\text{Total number of Customers served}} = \text{ACCI} = \frac{\sum_i L_a(i) U_i}{\sum_i N_o} \qquad (2.16)$$

Where, $L_a(i)$ and U_i respectively, are the average connected load and the average annual outage time at load point i and N_o is the number of customers affected.

In this thesis works, System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI) and Expected Energy Not Supplied (EENS) are used to measure reliability performance of utilities.

2.5 Distribution System Protection

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

The main objectives of distribution system protection are:

- ✓ To minimize the duration of a fault.
- ✓ To minimize the number of consumers affected by the fault.

The secondary objectives of distribution system protection are:

- ✓ To eliminate safety hazards as fast as possible.

- ✓ To limit service outages to the smallest possible segment of the system.
- ✓ To protect the consumers' apparatus.
- ✓ To protect the system from unnecessary service interruptions and disturbances.
- ✓ To disconnect faulted lines, transformers, or other apparatus.

Overhead distribution systems are subject to two types of electrical faults, namely, transient (or temporary) faults and permanent faults. Depending on the nature of the system involved, approximately 75% to 95% of the total number of faults are temporary in nature [8]. 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 the repair crew in terms of:

- ☞ Replacing burned-down conductors, blown fuses, or any other damaged apparatus
- ☞ Removing tree limbs from the line
- ☞ 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 Reclosers located inside the substation [8].

2.5.1 Distribution System Protection Devices

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
- Sectionalizers
- Fuses

Reclosers: - A recloser is a device with the ability to detect phase and phase-to-ground overcurrent conditions, to interrupt the circuit if the overcurrent persists after a predetermined time, and then to automatically reclose to re-energize the line. If the fault that originated the operation still exists, then the 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 75 to 95 percent 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 ground-fault units which can also be initiated by externally controlled devices when appropriate communication means are available. The operating time/current characteristic curves of reclosers normally incorporate three curves, one fast and two delayed, designated as A, B, and C, respectively. Figure 2.2 shows a typical set of time/current curves for reclosers. However, new reclosers with microprocessor-based controls may have keyboard-selectable time/current curves which enable an engineer to produce any curve to suit the coordination requirements for both phase and ground-faults. This allows reprogramming of the characteristics to make an arrangement to a customer's specific needs without the need to change components.

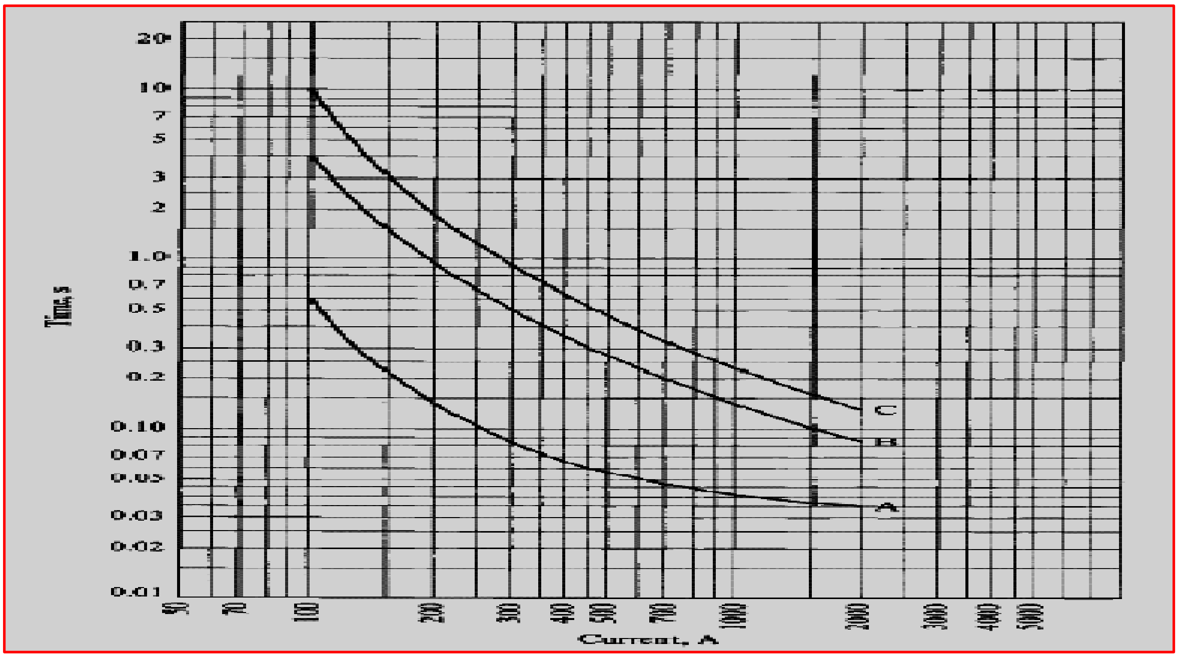


Figure 2.2: Typical set of time/current curves for Recloser [8]

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 2.3. The first shot is carried out in the 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 is disconnected.

Ground 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 residual 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 ground faults.

Reclosers can be classified as follows:

- Single phase and three phase;
- Mechanisms with the hydraulic or electronic operation;

- Oil, vacuum or SF6.

Single phase Reclosers are used when the load is a 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 receive 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 [8].

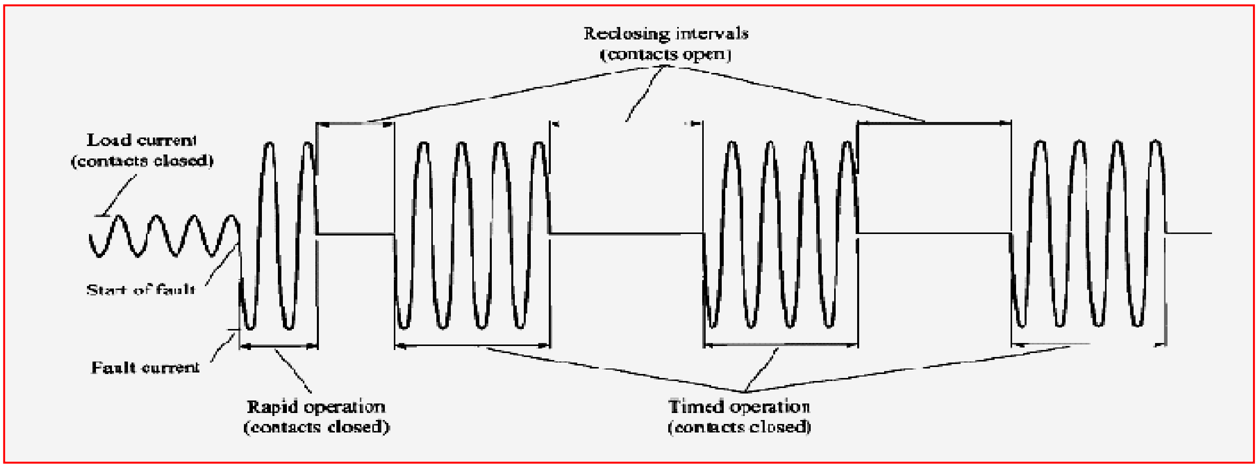


Figure 2.3: Typical sequence for Recloser operation [8]

Reclosers are used at the following points on a Power Distribution System:

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

- In branches or spurs, to prevent the tripping of the main circuit due to faults on the spurs.

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

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

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.

Sectionalizers:- 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 sectionalizers have no capacity to break fault current, they must be used with a backup device that has fault current breaking capacity. Sectionalizers 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 the 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 [8].

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 pretension 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.

The following factors should be considered when selecting a sectionalizer:

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

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.

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 a nominal voltage applied to its terminals, (i.e. no arcing across the fuse element).

The majority of fuses used in distribution systems operates 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 ensures 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.

The following information is required in order to select a suitable fuse for use on the distribution system [8]:

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

The above four factors determine the fuse nominal current, voltage and short circuit capability characteristics.

2.5.2 Coordination of Devices in Distribution System

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

- 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 backup 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.
- Loss of supply caused by permanent faults should be restricted to the smallest part of the system for the shortest time possible.

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

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

- **Sensitivity** applies to the ability of the relay to operate reliably under the actual condition that produces the least operating tendency.
- **Selectivity** is the ability of the relay to differentiate between those conditions for which immediate action is required and those for which no action or a time-delayed

operation is required. The relays must be able to recognize faults on their own protected equipment and ignore, in certain cases, all faults outside their protective area. It is the purpose of the relay to be selective in the sense that, for a given fault condition, the minimum number of devices operate to isolate the fault and interrupt service to the fewest customers possible.

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

On designing protection system coordination it may differ from system to system because of economic considerations, equipment availability, system topology and others. The economic costs and the benefits of a protection device should also be considered to arrive at a suitable balance between the requirements of the scheme and the available financial resources. In most modern relays the time dial settings can start from values as low as 0.1second, and go to as high as 20 seconds. In distribution systems where it is possible to increase the loading on feeders under emergency conditions, the minimum pickup current setting is usually two times the nominal circuit current. And in order to make sure that the relay is able to trip under a fault condition, the maximum pick up current is usually chosen to be half of the smallest single phase to ground fault current [7].

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

$$T_{i,j} = \left(\frac{A_k}{(I_{ij}/I_{pi})^{C_k}-1} + B_k\right) \text{ x TDS}_i \qquad (2.17)$$

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

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

Table 2.1: Constants and exponents for standard characteristics of over current relays.

Characteristics	A	B	C
Moderately Invers	0.0515	0.114	0.02
Very Invers	19.61	0.491	2
Extremely Invers	28.2	0.2117	2

The coordination of different devices used on the distribution systems discussed in the following sections.

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 backup 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 to 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 reclosers will then reenergize 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 sectionalizers.

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 applied before the relay has completely reset, the relay will move towards its operating point from this partially reset position [8].

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

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

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

2.6 Reliability Cost/Worth

When a power is interrupted, both the utility and customers face interruption costs. When a customer faces such interruption, there is an amount of money that the customer is willing to pay to avoid the interruption and this amount is referred to as the customer cost of reliability. Such costs are tangible and intangible types and also there is an opportunity cost. But assessing the interruption cost from the customer side is difficult.

So to maximize the reliability, the utility should balance their reinforcement cost for reliability improvement and the customer cost for poor reliability. Therefore, the optimal level of reliability is said to be achieved when the sum of utility cost and the customer cost are minimum[10].

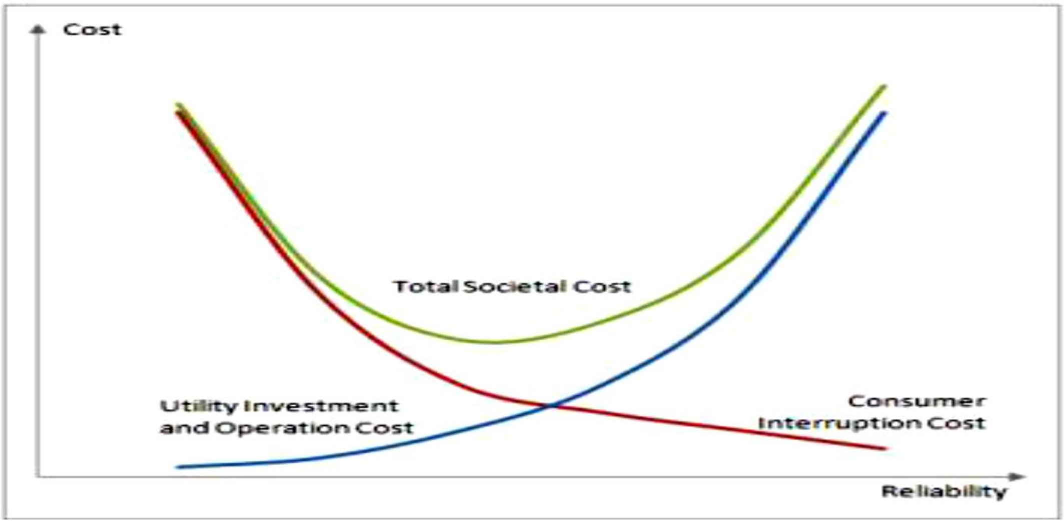


Figure 2.4: Reliability worth and reliability cost [11]

The above Figure 2.4 shows the cost of both customer and utility and it tells us that high reliability achieved by investing high cost.

2.7 Literature Review

Electric power is a vital element in any modern economy. The availability of a reliable power Supply at a reasonable cost is crucial for the economic growth and development of a country. Electric power utilities throughout the world, therefore endeavor to meet customer demands as economically as possible at a reasonable service of reliability. To meet customer demands, the power utility has to evolve and the distribution Substation system has to be upgraded, operated and maintained accordingly [12]. To fulfill and meet customer demands currently the following Researches are going on, on the electric power distribution Substation system some of these listed as follows:

In the paper [13] presents a comparative analysis of distribution reliability improvements that can be achieved by using various outdoor distribution devices. First, it discusses the application of the most common types of devices, including line Reclosers, automatic sectionalizes and manual switches. And analysis the quantifies the reliability improvements that can be achieved by using each or a combination of these devices. The paper concludes all devices offer an improvement in reliability. Switches will improve SAIDI. Midpoint switches also possess significant value for tie-point applications where feeder ties are possible. Sectionalizes and Reclosers perform relatively closely for the various configurations except that the Reclosers offer more improvement for MAIFI. The highest possible across the board improvement is achieved by using single-phase Recloser and single-phase Reclosing loop schemes.

In the paper [14] provides the development of the new reliability and security index that reflects both on direct and indirect characteristics. Direct characteristics deal with the risk to not fully supply load in various contingencies. Indirect characteristics address such undesirable conditions as circuit overloads, voltage problems, low stability margins, area interchange violations, and insufficient generation reserves, unfeasible power flows, etc. Although indirect characteristics do not necessarily cause load losses they nevertheless signal about a reduce security/reliability margin. This reduce margin may lead to sometimes hardly predictable and quantifiable load losses (via remedial actions, islanding and, instability), unforeseen events (cascading outages), sever system failures (voltage collapse) etc. The new index gives a more comprehensive answer regarding the general degree of both reliability and security in the system by combing diverse contributing factors using a fuzzy logic like approach. It is designed to flexibly accommodate various priorities and admittance of power utilities regarding particular characteristics integrated into the index. The existing indices such as unexpected unsaved energy, system minutes, stability margins and others can be linked to or derived from the general index. The index meets the need in practical, flexible and effective security and reliability index.

The paper [15] explains the implementations of reliability improvement solutions to test system have been evaluated from a socio-economical point of view. For each of the alternative solutions implemented in the test system, the average annual supply interruption cost to the customers supplied from the test system has been estimated. Furthermore, the maximum annual capital cost associated with the implementation of each solution has been estimated. Then, a reliability improvement solution is considered justified socio-economically if the capital cost associated with its implementation is less than the resulting reduction in the interruption cost to the customers.

The paper [16] focuses on aging power systems. Aging of components is an important fact in power system reliability assessment. It results from a number of different reasons; deterioration, erosion or damage of equipment. Regardless of reasons, most equipment may develop aging trend over time. As a result, aging may become the cause of load curtailments because of higher system failure probability. So, it is necessary to examine aging characteristics in system reliability or in economic evaluation. Power systems with high reliability at low-cost offer may benefit in competitive. This thesis illustrates the effect of aging on composite power system reliability evaluation.

Paper [17] explain the technique for assessing the reliability of alternative conceptual design architectures. The method is based on the identification of criticality and sensitivity of system components, and the simulation model that incorporates probability and failure rates of individual components such that system level reliability measures can be computed. This analysis at the system level supports decision making early in the design process and assists the designers to evaluate and identify critical elements of different conceptual architectures and to select among or integrate different architectural solutions to ensure improved reliability.

Paper [18] mainly focuses on the reliability problems of the existing power grid of Adama city and the smart grid has been proposed as a solution. Therefore the appropriate components of the smart grid are selected to design the overall system. Smart Reclosers are the key components of the smart grid, which are used for fault detection, isolation and restoration programs in the distribution systems and the result of this fact has been an unprecedented increase of global demand for this product. Smart Reclosers offers a complete design solution with integrated smart grid capabilities offering not only remote control but automation and analog data measurement and logging capabilities to achieve the utility business drivers. The designed system is simulated using the software's Dig-Silent and windmill that are used to analyze the reliability of the overall system. The simulation of the designed model shows that the application of smart Reclosers can improve the reliability of the overall system from 50% to 70%.

The paper [19] presented a basic new restoration methodology for distribution system configurations that maximize the amount of load that can be restored after a grid blackout, substation outage and distribution feeder line section outages and evaluates the cost of load point interruptions considering feeder islanding and substation capacity constraints. Several case studies with restoration procedures are presented and discussed to clearly reveal the impact of distribution system capacity constraints on load point reliability indices and the cost of load point interruptions.

Paper [20] proposed a branch and bound type heuristic method to determine the network configuration to enhance distribution system reliability and for minimum line losses. Its solution scheme starts with a meshed network by initially closing all switches in the network. The switches are then opened one at a time until a new radial configuration is reached. In this process the switch to be opened at each stage is selected in order to enhance distribution system reliability and to minimize line losses of the resulting network.

The paper [21] proposed an evaluation technique for distribution reliability that uses the improved failure rate of all protective devices in a network, depending on the location of the superconducting fault current limiter. As a result, it is expected that the SFCL makes the reliability of adjacent equipment on an existing network improve, and these changes are analyzed.

CHAPTER THREE

DATA COLLECTION AND ANALYSIS

3.1 Introduction

This chapter briefly deals with the methodologies used for data collection and data analysis for the existing system.

Reliability analysis needs interruption duration, interruption frequency, a total number of customers served, customers interrupted, loads connected and so on. So, under this chapter, the collected failure data and basic electrical data of power system equipment which are necessary for reliability analysis are presented. These data are analyzed to identify the current reliability status of the substation and to distinguish the main problems of interruption.

3.2 Description of Awash7 Kilo Substation

Awash7 kilo substation takes electric power through 132 kV transmission lines from Koka power plant that is interconnected system (ICS) and it supplies electric power to Awash7 city and the nearby areas. Ethiopian Electric Power (EEP) and Ethiopia Electric utility (EEU) are a service provider of electric power in the country. A 132 kV transmission line is stretched into the Awash7 substation, then stepped dawn to 66 kV/15 kV with two parallel connected transformers as shown in Figure 3.1. The distribution system in the city has a primary voltage of 15 kV and also, this voltage value is stepped down to 400/220V in three phase and single phase respectively. The network topology Awash7 kilo substation is radial. The bus bar scheme or bus bar layout is parallel to the single bus bar system. The single bus bar scheme has only one three phase but to which the various incoming and outcoming circuits are connected. This has lack of operational flexibility in case of bus fault or circuit breaker failure then, the entire bus has to be de-energized, but it has low cost, simple to operate and requires simple protection of the system. Awash7 kilo substation consists of five outgoing feeders. The nominal voltages of the three feeders are 15 kV and the remaining two feeders are 66 kV. As per the data found from the south-east region billing office, the south-east region has a total of 9,823 customers and from these Awash7 town has approximately 4,819 customers served. From the outgoing feeders, 15 kV feeder city line is serving customers found in the center of the city and is extended to Argoba Wereda and Awash Park, which are at around 35 km away from the Awash7 kilo substation. Commercial areas are served by this feeder. Big hotels, small and micro industries, banks, most administrative offices, telecommunication, schools and a large number of residential customers get electricity from this feeder. City line is represented by L1 as depicted in Figure 3.1. According to the breaker arrangement in the control room (Figure 3.2), Current Transformer (CT) rating of city feeder is 400/5 A. This primary distribution feeder delivers power from the substation to distribution transformers. It begins with the feeder breaker at the distribution substation and exits the substation in a concrete duct bank (feeder get-away) and routed to a nearby pole.

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

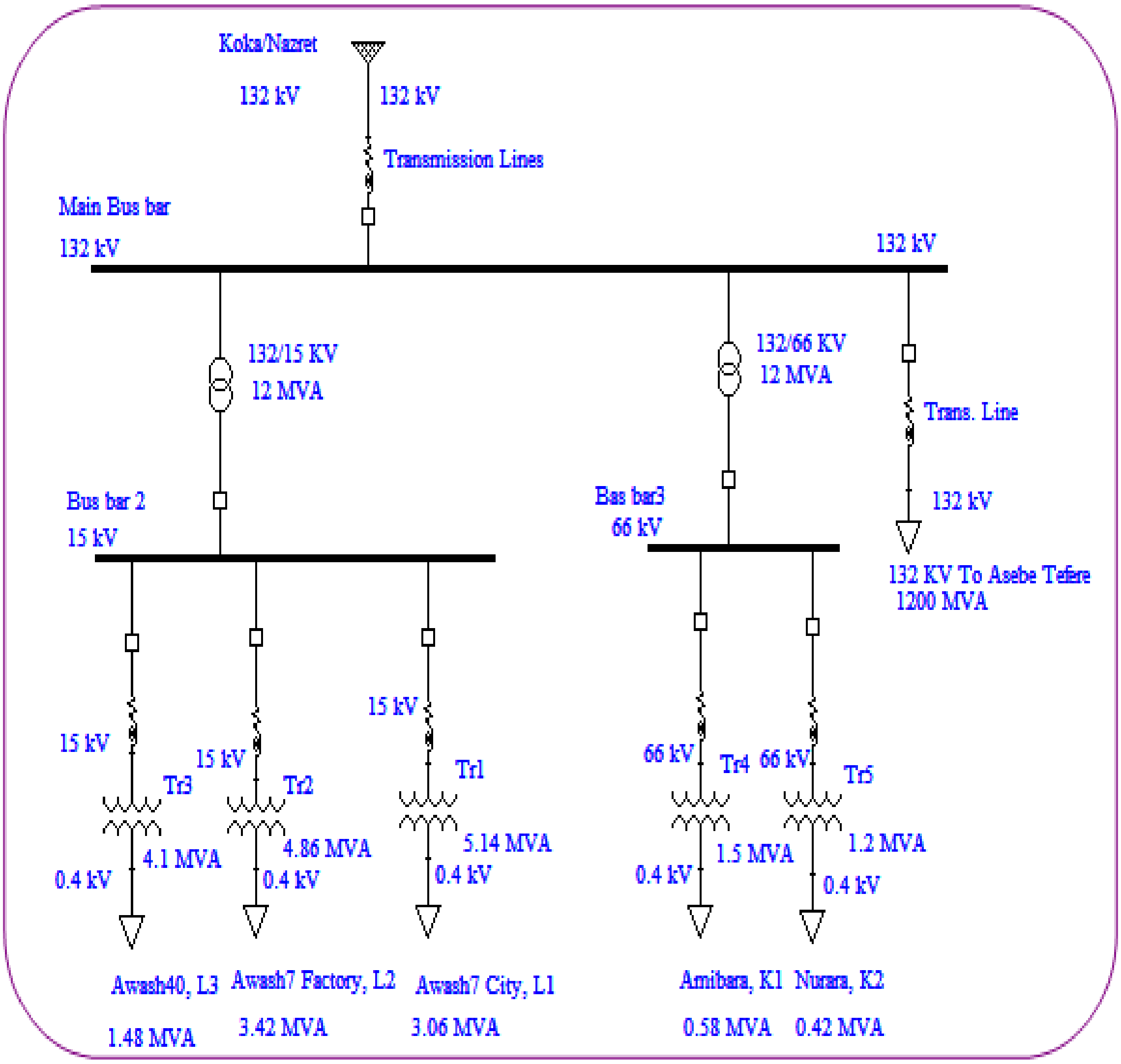


Figure 3.1: Single line diagram of Awash7 kilo Substation [ETAP16.0 software]

Figure 3.2: Partial view of Awash7 kilo Substation Control Room [Source: study area]

Figure 3.3: Awash7 kilo Substation [Source: study area]

Figure 3.4: Awash7 Diesel Substation

3.3 Data Collection

Primary data have been collected by the direct involvement of the researcher and workers of Ethiopia Electric Utility (EEU) from Awash7 kilo.

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

Table 3.1: Awash7 Diesel Substation Data

Capacity	35 MW
Maximum Load	15 MW
Maximum Load Current	215 A
Feeder Current Transformer Capacities	350 A
Feeder Cable Current Capacities	300 A
Voltage Level	15 KV
Main Line Feeder Capacities Current	340 A

Table 3.2: Data for Awash7 kilo Substation

Name of Substation	Lines			Number of Transformer	Voltage Level (KV)	Transformer Capacity (MVA)	Total Capacity (MVA)
	HV	MV	LV				
Awash7 kilo	0	2	3	2	132/66/15	12	24

Table 3.3: Feeder name and voltage levels of Awash7 kilo Substation outgoing feeders

Feeder Name	Voltage Level in KV	Circuit breaker type	CT ratio
Awash7 city L1	15	Oil Circuit breaker	200-400/5 A
Awash7 Factory L2	15	Oil Circuit breaker	200-400/5 A
Awash40 city L3	15	Oil Circuit breaker	200-400/5 A
Amibara K1	66	Vacuum Circuit breaker	75-150/5 A
Nurara K2	66	Vacuum Circuit breaker	75-150/5 A

Table 3.4 contains the data about 15 KV feeders (bus bar 2) and 66 KV feeders (bus bar 3). In this Table 3.4, L1, L2 and L3 represent the outgoing feeder lines from 15 KV bus bar and K1 and K2 represent the outgoing feeder lines from 66 KV bus bar. In Awash7 kilo city has 34 total distribution transformers with a total capacity 9,900 KVA from the feeder L1 and L2.

Table 3.4: The complied data for Awash7 kilo Substation feeders

Feeder Name	Total No of Distribution Transformer	No of Customers	Total capacities of Distribution Transformer (KVA)	Total Length of Feeders (km)	Conductor Size (mm^2)
Awash7 city L1	26	4,819	4555	35	AL-50 mm^2
Awash7 Factory L2	8	8	5345	0.6	AL-50 mm^2
Awash40 L3	22	2,242	3450	10	AL-50 mm^2
Amibara K1	10	1,405	1680	18	AL-95 mm^2
Nurara K2	12	1,349	1330	16	AL-95 mm^2
Total	76	9,823	16360	79.6	

Table 3.5: Awash7 kilo city line Transformer Data (15 kV feeder L1 and L2)

Number	Specific Areas/Places Name	Transformer Size in kVA
1	High School	200 KVA
2	Farmer Association	100 KVA
3	Budle	315 KVA
4	Afar Health Center	100 kVA
5	Agricultural Office	50 KVA
6	Finance	200 KVA
7	Bus Station	315 kVA
8	Haji Siyum	315 kVA
9	Afar Moot Court	315 kVA
10	Telecommunication Tower 1	25 kVA
11	Afar Milk Process	200 kVA
12	Awash EEU District Office	50 kVA
13	Gumruk Office	315 kVA
14	Elala Sala Tele	50 kVA
15	Telecommunication Tower 2	25 kVA
16	Noke	200 kVA
17	Genet Hotel	200 kVA
18	Water Pump 1	200 kVA
19	Water Pump 2	200 kVA
20	Rail Way Company	100 kVA
21	Megala	315 kVA
22	Telecommunication Tower main Office	100 kVA
23	Kebele Office	315 kVA
24	Maryam Church	50 kVA
25	Water Push	100 kVA
26	Coca-Cola	200 kVA
27	Around Awash 7 Substation Area Factory	100 kVA
28	National Mining Factory 1	1250 KVA
29	National Mining Factory 2	1250 kVA
30	Filer Plant Factory	800 kVA
31	Cotton Factory	315 kVA
32	Hen Production	200 kVA
33	Lucy Cotton Factory	630 kVA
34	Concrete Factory	315 kVA
35	Total	9900 kVA

Table 3.6: shows the annual average energy and power consumption of each feeder bus bar. The annual average energy is calculated using the recorded data from 2015/16 -2017/18 G.C.

Table 3.6 : Annual average energy and Power consumption each feeder

Feeder Name	Average MVA	Average Power Consumption		Average Energy Consumption	
		Average Active Power (MW)	Average Reactive Power (MVAr)	Average Active Energy (KWh)	Average Reactive Energy (KVArh)
Awash7 city L1	3.06	2.448	1.7748	21,444,480	15,547,248
Awash7 Factory L2	3.42	2.736	1.9836	23,967,360	17,376,336
Awash40 L3	1.48	1.184	0.8584	10,371,840	7,519,584
Amibara K1	0.58	0.464	0.3364	4,064,640	2,946,864
Nurara K2	0.42	0.336	0.2436	2,943,360	2,133,936
Total	8.96	7.168	5.1968	62,791,680	45,523,968

Based on Table 3.6, the Power factor (PF) of the substation system can be calculated as;

$$\mathrm{PF} = \mathrm{Cos}(\tan^{-1}(\mathrm{Q}/\mathrm{P})) \qquad (3.1)$$

$$\mathrm{PF}{=}\mathrm{Cos}\ (\tan^{-1}\left(\frac{45{,}523{,}968}{62{,}791{,}680}\right) = 0.8$$

When;

PF= Power factor

Q= Reactive Power in (MVAr)

P= Active Power in (MW)

Table 3.7: Average and Peak Load of the Substation

Feeder Name	Average Demand (MW)	Peak Load (MW)
Awash7 city L1	2.45	5.3
Awash7 Factory L2	2.74	5.6
Awash40 L3	1.18	3.48
Amibara K1	0.46	2.00
Nurara K2	0.34	1.74
Total	7.17	18.12

Table 3.8: Hourly load (MW) each feeder of Awash7 kilo Substation

Feeders / Hours	L1	L2	L3	K1	K2	Total
1	0.52	1.75	0.23	0.13	0.12	2.75
2	0.55	1.75	0.2	0.1	0.12	2.72
3	0.72	1.77	0.23	0.1	0.12	2.94
4	0.97	2.21	0.53	0.13	0.14	3.98
5	1.67	2.05	0.45	0.12	0.14	4.43
6	3.01	2.05	0.45	0.12	0.21	5.84
7	3.01	1.98	0.45	0.12	0.21	5.77
8	3.01	1.86	0.45	0.12	0.21	5.65
9	2.16	3.08	0.87	0.3	0.2	6.61
10	2.06	3.88	0.89	0.34	0.25	7.42
11	1.79	3.95	0.91	0.34	0.25	7.24
12	2.93	3.5	0.76	0.27	0.28	7.74
13	1.67	3.71	1.25	0.43	0.42	7.48
14	3.23	3.75	1.32	0.43	0.42	9.15
15	3.19	3.52	0.35	0.43	0.34	7.83
16	2.98	3.51	0.3	0.39	0.21	7.39
17	2.75	3.27	0.28	0.35	0.18	6.83
18	2.3	3.34	1.31	0.44	0.24	7.63
19	2.73	3.23	1.56	0.65	0.31	8.48
20	2.8	3.15	1.78	0.66	0.31	8.7
21	2.55	4.11	1.61	0.7	0.45	9.42
22	1.5	2.42	0.91	0.64	0.52	5.99
23	1.25	2.32	0.87	0.61	0.42	5.47
24	1.47	2.41	1.05	0.39	0.38	5.7

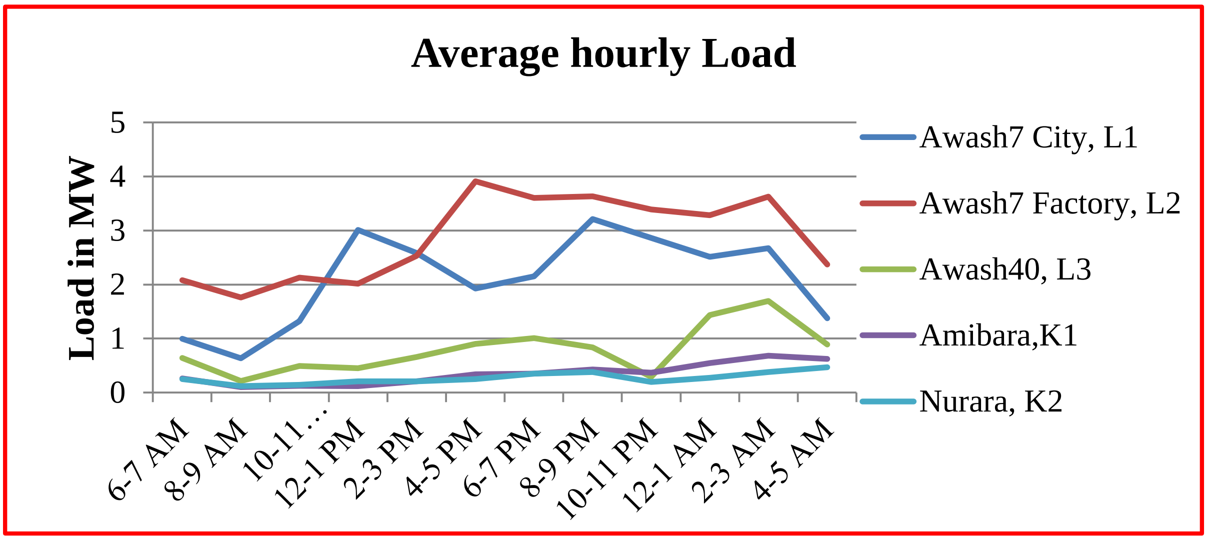


Figure 3.5: Average hourly loads of Awash7 kilo Substation

As shown from the hourly load of Figure 3.5, the maximum and minimum loads of the feeders are 3.92 MW and 0.12 MW respectively. The maximum load is observed during the night time in the range of 4:00 PM to 5:00 PM. The minimum load is observed during the day time in the range of 8:00 AM to 9:00 AM.

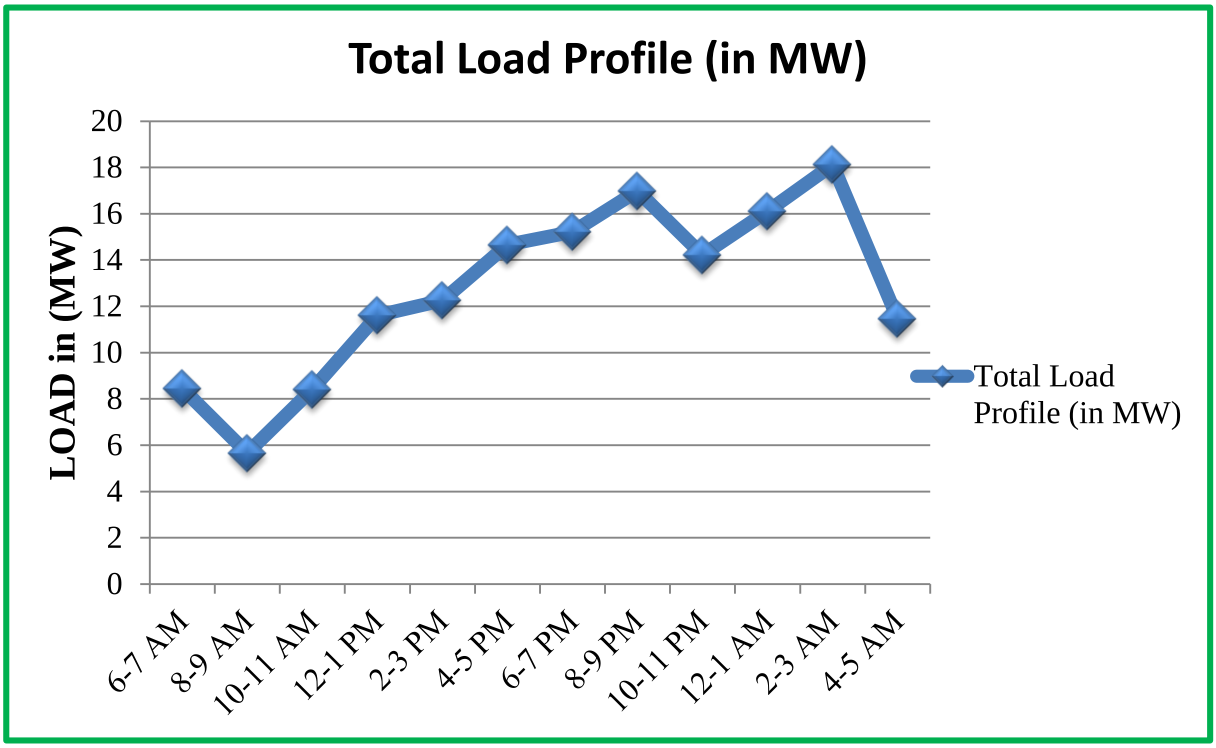


Figure 3.6: Total load profile (MW) of Awash7 kilo Substation

Figure 3.5 and Figure 3.6 shows the load measured during 24 hours of a day. Hourly load denotes a load measured during that corresponding time and overall load is the total sum of a load of each feeder. So the maximum overall load of the system is observed from 12:00 AM to 3:00 AM day time (due to the desert area most customers, which are used to Air condition and ventilator) which is 18.12 MW.

3.3.1 Reliability Related Data's of Awash7 Kilo Substation

This section contains the compiled power reliability related data's that are collected from Awash7 kilo substation. Table 3.9 contains the frequency of interruptions due to non-momentary (unplanned) and momentary (planned) interruptions from 2015/2016 G.C (2008 E.C) to 2017/2018 G.C (2010 E.C). In the case study area throughout the year mostly the planned interruption is carried out due to the ongoing network maintenance, construction, upgrade works and whenever possible. Sometimes however we need to temporarily disconnect power supplies while this work takes place.

Table 3.9: Frequency Interruptions from 2015/16 G.C to 2017/18 G.C

Feeder	2015/2016 G.C			2016/2017 G.C			2017/2018 G.C		
	Unplanned	Planned	Total	Unplanned	Planned	Total	Unplanned	Planned	Total
L1	198	183	381	245	165	410	288	163	451
L2	125	78	203	98	128	226	130	95	225
L3	285	165	450	191	108	299	270	115	385
K1	213	155	368	245	125	370	188	175	363
K2	182	155	337	141	128	269	158	112	270
Total	1,003	736	1,739	920	654	1,574	1,034	660	1,694

Table 3.10, refers to the duration of interruptions due to non-momentary (unplanned) and planned interruptions in the existing Awash7 substation system from 2015/2016 G.C to 2017/2018 G.C.

Table 3.10: Duration Interruptions from 2015/16 G.C to 2017/18 G.C

Feeder	2015/2016 G.C			2016/2017 G.C			2017/2018 G.C		
	Unplanned	Planned	Total	Unplanned	Planned	Total	Unplanned	Planned	Total
L1	171	141	312	181	127	308	187	152	339
L2	18	65	83	62	73	135	31	84	115
L3	168	82	250	132	112	244	128	110	238
K1	105	110	215	176	79	255	105	89	194
K2	128	145	273	87	168	255	153	102	255
Total	590	543	1,133	638	559	1,197	604	535	1,141

Table 3.11: Average Frequency Interruptions and Average Duration Interruptions per year

Feeder	Frequency Interruption (Int/year) 2015/16 to 2017/18 G.C			Duration Interruption (Hour/year) 2015/16 to 2017/18 G.C		
	Unplanned	Planned	Total	Unplanned	Planned	Total
L1	243.67	170.3	413.97	179.67	140	319.67
L2	117.67	100.3	217.97	37	74	111
L3	248.7	129.3	378	142.7	101.3	244
K1	215.33	151.67	367	128.7	92.67	221.37
K2	160.33	131.67	292	122.7	138.3	261
Total	985.7	683.24	1,668.94	610.77	546.27	1,157.04

3.4 Causes of Power Interruption in Awash7 Kilo Substation

At Awash7 kilo substation, major faults occurring frequently are short circuit, earth fault, blackout, distribution line overload, under frequency. And there are planned outages for operational and maintenance purpose. The major faults occurring can either a temporary or permanent type. Permanent or sustained interruptions are long-duration interruptions which last longer than five minutes, whereas interruptions with a duration of fewer than five minutes are termed momentary interruptions [22]. Usually, only data on sustained interruptions is reported to the regulatory authority in the study area. Many of the distribution problems are temporary and mainly caused by tree, animal contact, and weather condition. They can easily be solved with little or no intervention from the system. Then by simply reclosing, the system will be re-energized. But permanent faults can't be restored by simple re-energizing. Permanent faults can be caused by equipment malfunction, cable failure, down line or persistent tree contact [23].

Permanent (Sustained) interruptions can be classified as planned and unplanned interruptions [22]. Planned interruptions (operational outages) occur mainly for the purpose of construction, preventative maintenance or repair. A planned interruption occurs at a selected time less inconvenient for the customers and the customers have been notified beforehand of the interruption. On the other hand, if the occurrence time of the interruption has not been selected, then the interruption is unplanned. An unplanned interruption occurs, for example, due to fault clearing, the unwanted operation of the protection system or due to inadvertent initiation of opening operation of a switching device by a human.

According to the data collected from the Awash7 kilo substation, the causes of non-momentary (unplanned) interruptions are; Distribution Permanent Earth Fault (DPEF), Distribution Permanent Short Circuit (DPSC), Distribution Temporary Earth Fault (DTEF) and Distribution Temporary Short Circuit (DTSC). The reason for these unplanned interruption are basically as a result of faults and failures which makes a component to be unavailable to perform its function. In addition, the two major factors that affect the reliability of power distribution system are capacity shortages and Faults and failures

Distribution Permanent Earth fault (DPEF):-This fault occurs when there is a conducting connection between any electrical 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 [23]. 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 to the electrical installations and above all may jeopardize people; as a matter of fact, people could get in touch with an exposed-conductive-part not normally live but which, due to the fault, might have a dangerous potential to ground.

Distribution Permanent Short Circuit (DPSC):-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 [24]. 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 accidentally 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 the 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.

Power Transformer Overload:-Overloaded transformers are found in the industry as a result of a combination of factors. Often times rapid plant expansion without adequate capacity planning can lead to overloaded transformers. This combined with the poor power factor and high harmonic currents generated by inductive loads can cause a transformer to become heavily loaded.

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. The 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. [24]

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 purposes.

Table 3.12: Average interruption duration and frequency of different faults of 2015/16 to 2017/18 G.C

Feeder	DPEF		DPSC		DTEF		DTSC		OPR	
	DUR	FER	DUR	FER	DUR	FER	DUR	FER	DUR	FER
L1	42.5	60	60.5	70	35.5	90	41.5	24	140	170.3
L2	9	25	12.75	39	5	29	10.25	20	74	100.3
L3	25	52	40.75	64	20	78	27.25	20	101.3	129.3
K1	22.25	44	42.25	26	24	85	20	15	92.67	151.67
K2	20.75	30	40.75	45	20	35	21.2	15	138.3	131.67
Total system	119.5	211	197	244	104.5	317	120.2	94	546.27	683.24

In Table 3.12, where; DPEF is a distribution permanent earth fault, DPSC is a distribution permanent short circuit, OPR is operational interruptions, FRE is frequency interruption and DUR is duration interruptions. Based on the above table, it is possible to analyze the percentage contributions of each cause of interruptions for the total frequency and duration of interruptions of each feeder and the overall system.

Table 3.13: Percentage of the cause of average duration and frequency interruptions of different fault

Feeder	DPEF		DPSC		DTEF		DTSC		OPR	
	%DUR	%FER	%DUR	%FER	%DUR	%FER	%DUR	%FER	%DUR	%FER
L1	13.29	14.49	18.93	16.91	11.11	21.74	12.98	5.8	41.1	43.8
L2	8.11	11.47	11.49	17.89	4.50	13.30	9.23	9.18	46	66.7
L3	10.25	13.76	16.70	16.93	8.2	20.63	11.17	5.29	34.2	41.5
K1	10.05	11.99	19.09	7.08	10.84	23.16	9.03	4.09	41.3	41.86
K2	7.95	10.27	15.61	15.41	7.66	11.99	8.12	5.14	45	52.99
Average	10.33	12.64	17.03	14.62	9.01	18.99	10.39	5.63	47.21	40.94

Table 3.14 and Table 3.15; shows as the percentage of each of the cause of fault in Awash7 Substation.

Table 3.14: Percentage average interruption duration of each type of fault

Causes	DPEF	DPSC	DTEF	DTSC	Operational	Others
%Dur(Hr.)	10%	17%	9%	10%	47%	7%

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

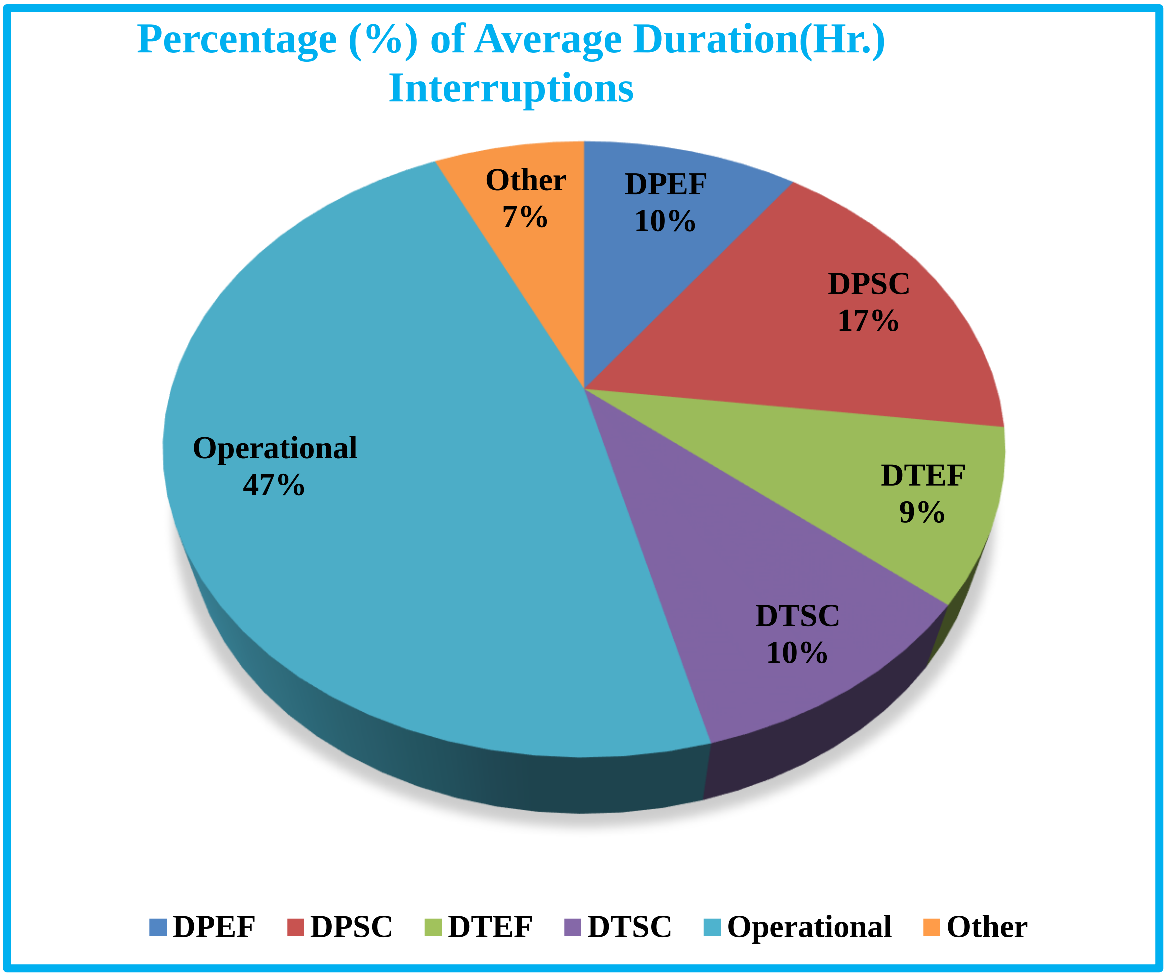


Figure 3.7: Percentage of average duration interruptions of overall system of Awash7 Substation

From the above pie chart in Figure 3.7, 47% (Hr.) of the interruption duration of the overall system are due the operation and maintenance, 10% is due to a distribution permanent earth fault, 17% is due to distribution permanent short circuit and the remaining other faults account for around 7% (include Power Transformer overload, Transmission line fault etc.).

Table 3.15: Percentage average frequency interruption of each type of fault

Causes	DPEF	DPSC	DTEF	DTSC	Operational	Others
%Frequency (Int/year)	13	15	19	6	41	6

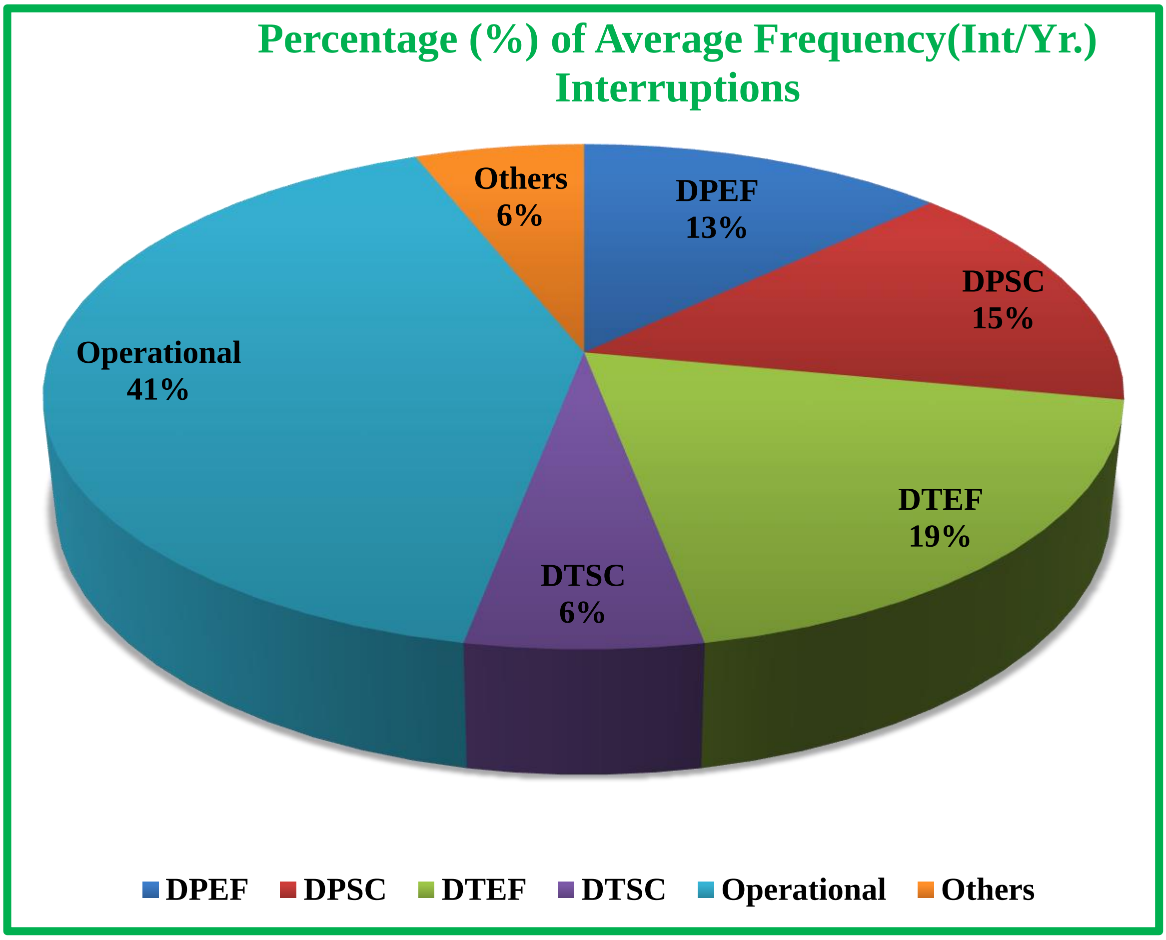


Figure 3.8: Percentage of average frequency interruptions of overall system of Awash7 Substation

Figure 3.8 shows that 41% of the interruption frequency is due the operation and maintenance, and 19% are due to a distribution temporary earth fault, 15% a distribution permanent short circuit, 6% is others (include under frequency).

3.5 Distribution Reliability Indices Calculation

The reliability indices of the existing substation can be calculated using equations (2.7) to (2.15), which are given in chapter two. Based on the data given in Table 3.9 and Table 3.10, we can calculate the reliability indices for 2015/16 to 2017/2018 G.C and the average of the three years. Therefore, Table 3.16, Table 3.17, Table 3.18 and Table 3.19 shows the calculated reliability indices in the year of 2015/16, 2016/17, 2017/18 G.C and the average system respectively.

Table 3.16: Calculated reliability indices of 2015/16 Awash7 kilo Substation

Feeder	SAIFI	SAIDI	CAIDI	ASAI	ASUI	EENS (MWh)	AENS
L1	381	312	0.819	0.964	0.036	763.776	0.158
L2	203	83	0.409	0.99	0.01	227.088	0.189
L3	450	250	0.556	0.971	0.029	296	0.132
K1	368	215	0.584	0.975	0.025	99.76	0.071
K2	337	273	0.81	0.969	0.031	91.728	0.068
Average	347.8	226.6	0.6356	0.9738	0.0262	1,478.35	0.618

Table 3.17: Calculated reliability indices of 2016/17 Awash7 kilo Substation

Feeder	SAIFI	SAIDI	CAIDI	ASAI	ASUI	EENS (MWh)	AENS
L1	410	308	0.751	0.965	0.035	753.984	0.156
L2	226	135	0.597	0.985	0.015	369.36	0.308
L3	299	244	0.816	0.972	0.028	288.896	0.129
K1	370	255	0.689	0.971	0.029	118.32	0.084
K2	269	255	0.948	0.971	0.029	85.68	0.064
Average	314.8	247.5	0.755	0.972	0.028	1,616.24	0.741

Table 3.18: Calculated reliability indices of 2017/18 Awash7 kilo Substation

Feeder	SAIFI	SAIDI	CAIDI	ASAI	ASUI	EENS (MWh)	AENS
L1	451	339	0.752	0.961	0.039	829.872	0.172
L2	225	115	0.511	0.987	0.013	314.64	0.262
L3	385	238	0.618	0.973	0.027	281.792	0.126
K1	363	194	0.534	0.978	0.022	90.016	0.064
K2	270	255	0.944	0.971	0.029	85.68	0.0635
Average	338.8	237.83	0.688	0.973	0.027	1,602.003	0.6875

Table 3.19: Calculated reliability indices the average of three years at Awash7 kilo Substation

Feeder	SAIFI	SAIDI	CAIDI	ASAI	ASUI	EENS (MWh)	AENS
L1	414	319.67	0.772	0.963	0.037	782.544	0.162
L2	218	111	0.506	0.987	0.013	303.696	0.253
L3	378	244	0.663	0.972	0.028	288.896	0.1287
K1	367	221.3	0.602	0.975	0.025	102.699	0.0733
K2	292	261	0.901	0.970	0.030	87.696	0.0648
Average	333.8	237.31	0.698	0.973	0.027	1,565.539	0.6822

In this thesis, focus is given only on Awash7 kilo city feeder line one (L1). Because, as per data of Awash7 kilo substation, the city feeder has more frequency and duration interruptions than other feeders in the existing substation.

Table 3.20: Calculated reliability indices of Awash7 kilo city feeder for year 2015/16-2017/18 G.C

Feeder Name	Reliability Indices	2015/16 G.C	2016/17 G.C	2017/18 G.C	Average
Awash7 kilo City Feeder line, L1	SAIFI	381	410	451	414.0
	SAIDI	312	308	339	319.67
	CAIDI	0.819	0.751	0.752	0.772
	ASAI	0.964	0.965	0.961	0.963
	ASUI	0.036	0.035	0.039	0.037
	EENS	763.776	753.984	829.872	782.552
	AENS	0.158	0.156	0.172	0.162

3.5.1 Comparison of the Calculated values of Reliability Indices with benchmarks

In the Table 3.21 bellow, shows the calculated Reliability indices values of Awash7 kilo city feeder line L1 compared with Ethiopia Electric Agency standard and other country benchmark values most commonly used reliability indices. This thesis also focuses on the customer oriented reliability indices and energy oriented indices.

Table 3.21: Comparisons of SAIFI and SAIDI values with different countries [21]

Countries	SAIFI (Int./Year/Customer)	SAIDI (Hr./Year/Customer)
United States of America	1.5	4
Italy	2.2	0.967
France	1.0	1.03
Denmark	0.5	0.4
Australia	0.9	1.2
Spain	2.2	1.73
Canada	3.4	6.9
United Kingdom	0.8	1.5
Germany	0.5	0.383
Netherland	0.3	0.55
Ethiopia	20	25
Awash7 kilo city Feeder, L1	414.0	319.67

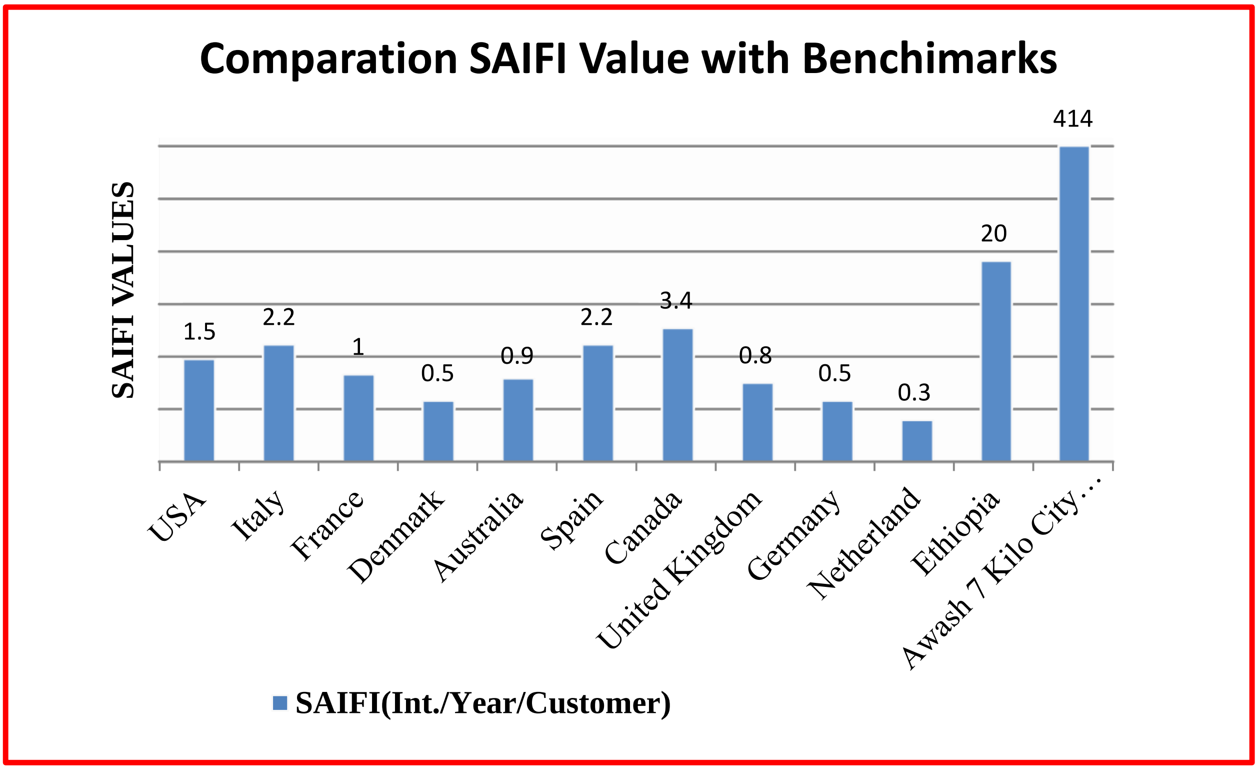


Figure 3.9: Comparison of SAIFI value with different countries standards

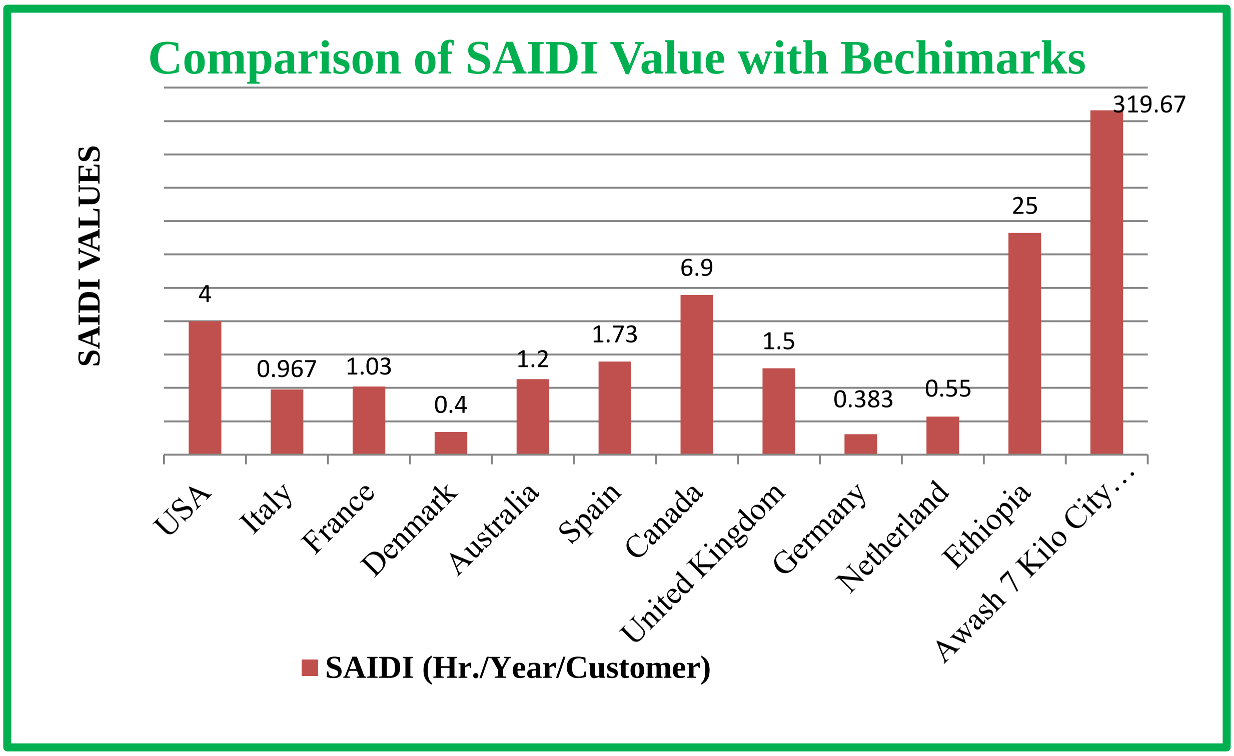


Figure 3.10: Comparison of SAIDI value with different countries standards

3.6 Outage Cost Evaluation of Awash7 Kilo City Feeder Line

Power interruption costs both the utility and the customer sides. The size of the economic losses due to interruption depends largely on the composition of the customers that experience interruptions. Customers in the Awash7 city are roughly divided into three categories: residential, commercial, and small industrial customers. On the utility side power interruption cost is estimated based on customer data, interruption data, and cost per outage data.

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

In the case study area, Awash7 kilo city, power interruptions data are usually recorded in the form of interruption duration, interruption frequency and load (MW) reading of each feeder on each hour. From these data, it is easy to know the reliability indices, System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI) and Expected Energy Not Supplied (EENS) of sustained interruptions experienced by customers of each feeder in a year. By using the recording Mega Watt (MW) load before the interruption on each hour, SAIDI and SAIFI data unsold energy (MWH) will be calculated. Energy is a very important term to estimate the interruption cost of the system for a typical year.

Table 3.22: Ethiopia electricity tariff (Birr/KWh) since July 8, 2006 (1998 E.C)

	Monthly Consumption (KWh)	Price Rate (Birr/KWh)
Residential	Equivalent Flat Rate	0.4735
	0-50	0.2730
	51-100	0.3564
	101-200	0.4993
	201-300	0.5500
	301-400	0.5666
	401-500	0.5880
	Above 500	0.6943
Commercial	Equivalent Flat Rate	0.6723
	0-50	0.6088
	Above 500	0.6943
Low Voltage Time of Day Industry @15 KV		
Equivalent Flat Rate		0.5778
Peak		0.7426
Off Peak		0.5354
High Voltage Industry @132 KV		
Peak		0.4736
Off Peak		0.3664

Based on Table 3.22, the interruption cost in the study area that is in Awash7 kilo substation can be calculated using the formula below;

$$\text{Interruption Cost} = \text{Unsupplied Energy (in kWh)x } 0.4409\,\frac{\text{ETB}}{\text{kWh}} \qquad (3.2)$$

Where, the tariff 0.4409 is taken from the average of the first block tariffs of residential and commercial customers, which most Ethiopian electricity customers are assumed to be grouped [16].

For Awash7 kilo city feeder (L1) in the year 2015/16 has 763.776 MWh unsupplied Energy from Table 3.20; then, Interruption cost is calculated as:

Interruption costs =763.776 kWh x1000 x0.4409 ETB/ kWh=336,748.8384 ETB

By the same procedure the interruption cost for the 3 years, that is, from 2015/16 to 2017/18 G.C is calculated and summarized in Table 3.23. Based on the exchange rate of the Commercial Bank of Ethiopia (CBE) on 05-May-2018, (l $= 27.5151 ETB).

Table 3.23: Summary of estimated interruption cost from 2015/16 to 2017/18 G.C in Awash7 kilo city feeder line

Years	EENS (MWh)	Interruption Cost (ETB)	Interruption Cost (USD)
2015/2016 G.C	763.776	336,748.8384	12,238.69
2016/2017 G.C	753.984	332,431.5456	12,081.79
2017/2018 G.C	1358	598,742.2	21,760.5
Max.	1358	598,742.2	21,760.5

The maximum of the three year's interruption cost due to the unsold energy of the Awash7 kilo city feeder line is 598,742.2 ETB or 21,760.5 USD per year.

3.7 Data Analysis

Based on the data collected from Awash7 kilo substation we can summarize the power reliability indices of the Awash7 kilo city feeder line L1 in the following manner.

- ☞ SAIFI of the overall system as shown in Table 3.19 is 414 int. /yr. As per Ethiopian Electrical Agency's (EEA's) standard, SAIFI should not exceed 20 interruptions per customer per year, which indicates that the current value is above the acceptable value by a large margin. And also, when we compare the calculated SAIFI value with Denmark standard, it is much greater than the maximum limit [25]. This clearly indicates that there is serious reliability problem in the existing Awash7 kilo city feeder line, L1.
- ☞ SAIDI of the overall system from Table 3.19 is 319.67 hours per customer per year. This shows that every customer experiences 319.67 Hr. interruption per year. This indicates that there is great reliability problem in the existing Awash7 kilo city feeder line, L1. As per the Ethiopian Electrical Agency's (EEA), the SAIDI value should not exceed 25 hours per customer per year [26]. The permissible SAIDI value in Denmark is 0.4 hours per customer per year [26].
- ☞ ASAI: It is the average service availability index which shows the fraction of time that a customer has received power during the reporting period. From the Table 3.19 the power supply of the overall system for Awash7 kilo city feeder, L1 is 0.963 (96.3%) available. However, this value is still not good enough since the ASAI value should be greater than 99.98% as per Ethiopian Electrical Agency's standard [26].

- ENS: It shows the unsupplied energy or unsold energy of each feeder. From the Table 3.23 the maximum unsold energy for Awash7 kilo city feeder, L1 was 1,358.4 MWh per year.
- AENS: This index shows the average energy not supplied per customer by the system. From the Table 3.19 the overall system for Awash7 kilo city feeder, L1 has an AENS value of 0.162 MWh per customer.
- Due to power interruption per year for the Awash7 kilo city feeder, L1 the average cost of unsold energy is 598,742.2 ETB has been lost. This amount of money has a negative impact on the economic growth of our country.

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

- The power reliability of the Awash7 kilo city feeder line, L1 does not meet the requirements set by the Ethiopian Electric Agency (EEA).
- The power reliability indices of Awash7 kilo city feeder line, L1 is not a good performance as compared to the international reliability indices of best-experienced countries.
- In the study area of city feeder line, L1 has high unavailability of services in the system.
- The impact of planned and unplanned outages in the existing power grid of Awash7 kilo city feeder line, L1 has more loss of unsupplied energy.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

This chapter presents the explanation of the modeling and simulation of the existing system with different mitigation alternative scenarios to improve the system reliability of the Awash7 kilo city feeder line at a reasonable cost. Different scenarios have been analyzed by ETAP 12.6 Software simulation. The simulation focuses on evaluating the impact of using reclosers and reconfiguration of the feeder on the reliability of the system.

Recloser is a device that is used in overhead distribution systems to interrupt the circuit to clear faults. Automatic reclosers have electronic control sensors and vacuum interrupters that automatically reclose to restore service if a fault is temporary. There are several attempts that may be made to clear and energize the circuit and if the fault still exists the recloser locks out. In this thesis three-phase Reclosers are used for enhancement of power distribution reliability. The Reclosers incorporated protective relaying equipment can be set to trip at specific overcurrent conditions and reclose at specific time intervals. After a circuit trip and settled time delay, the Recloser automatically re-energizes the circuit. Reclosers are typically set to trip and reclose two or three times before a lockout condition occurs. The Lockout means that a person working on the line must manually reset the recloser for power to be restored. If the fault condition clears before the recloser locks-out, the protective relaying resets back to the start of the sequence. Reclosers can also be tripped manually. This allows the recloser to be used as a load-break switch [27].

Recloser allows utilities to implement automatic back feed restoration (loop automation), fault finding and fault isolation. The device is also equipped with precise timing parameters allowing protection coordination time between devices to be minimized. Automatic circuit reclosers are designed for use on overhead distribution lines as well as distribution substation applications for different voltage classes like 15 KV, 27 KV and 38 KV [27]. In this thesis a 15 KV Recloser has been selected based on the capacity of the Awash7 city feeder line.

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

In this study, a Nu-Lec 15 KV outdoor pole mounted automatic circuit Recloser is selected for simulation. The Recloser allows protection coordination with other devices and is applicable in the real world. Nu-Lec industries are Schneider electric core business unit for recloser technology [28].

4.2 Procedure for Distribution Reliability Analysis by ETAP Software

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

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

4.3 System Modeling

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

To predict the reliability indices of Awash7 kilo distribution system, values of failure rates and mean time to repair for each component of static loads are necessary. To estimate the failure rate of the line per kilometer, the total number of outages should be divided by the feeder length (kilometers) as indicated in equation (4.1). The average mean time to repair (MTTR) each failure is computed using equation (4.2).

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

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

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

μ_A= 414/105= 3.94 (Int./km.year) and MTTR= 319.67/414 = 0.77 (Hr./Int.)

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

The Awash7 kilo city feeder (15 KV) has been constructed by 50 mm^2, seven stranded, Aluminum Conductor (ALC). This almost equals with ICEA three phase AL Conductor or Code AL 50 mm^2, which is found in ETAP Library. The overhead three-phase line mounted on wooden poles of height 12 meters with a triangular configuration. All the distribution transformers are pole mounted, liquid fill type and Oil Natural Air Natural (ONAN) classes.

In order to modeling the existing city distribution line and to analyze the current distribution reliability status, the following assumptions have been considered as an input in ETAP 16.0 software.

- The city line data,
- Cable length,
- Number of customers,
- The connected load
- Number of the transformer for each load point with the rating,
- Active Failure rate
- Duration of interruption in hours
- Frequency of interruption

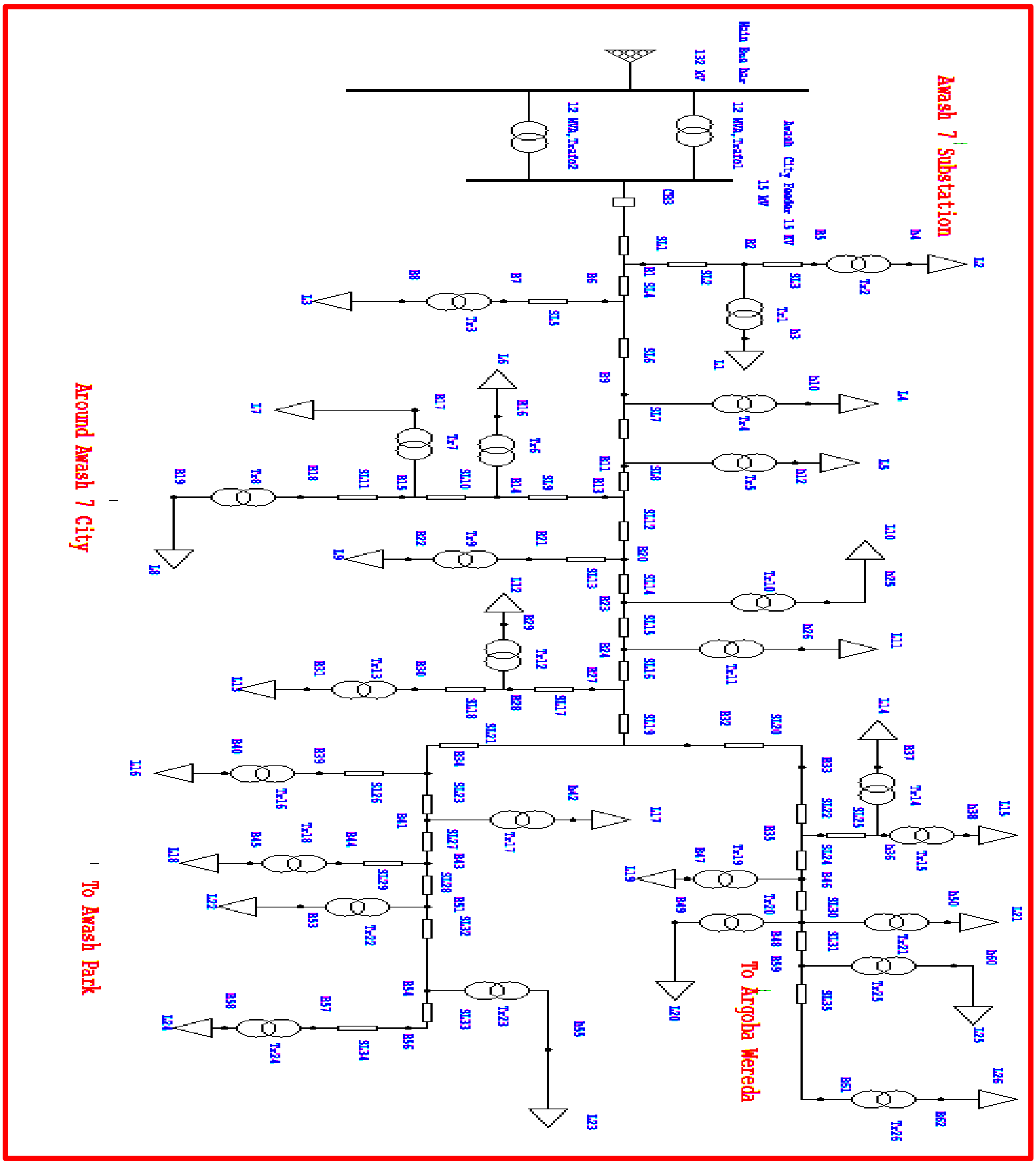


Figure 4.1: System modeling of the Awash7 kilo city feeder line, L1

Legends

SL1-SL35= Segmented Line of the Feeder

L1-L26= Load Points on each Transformers

T1-T26= Transformers

CB1= Circuit breaker

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

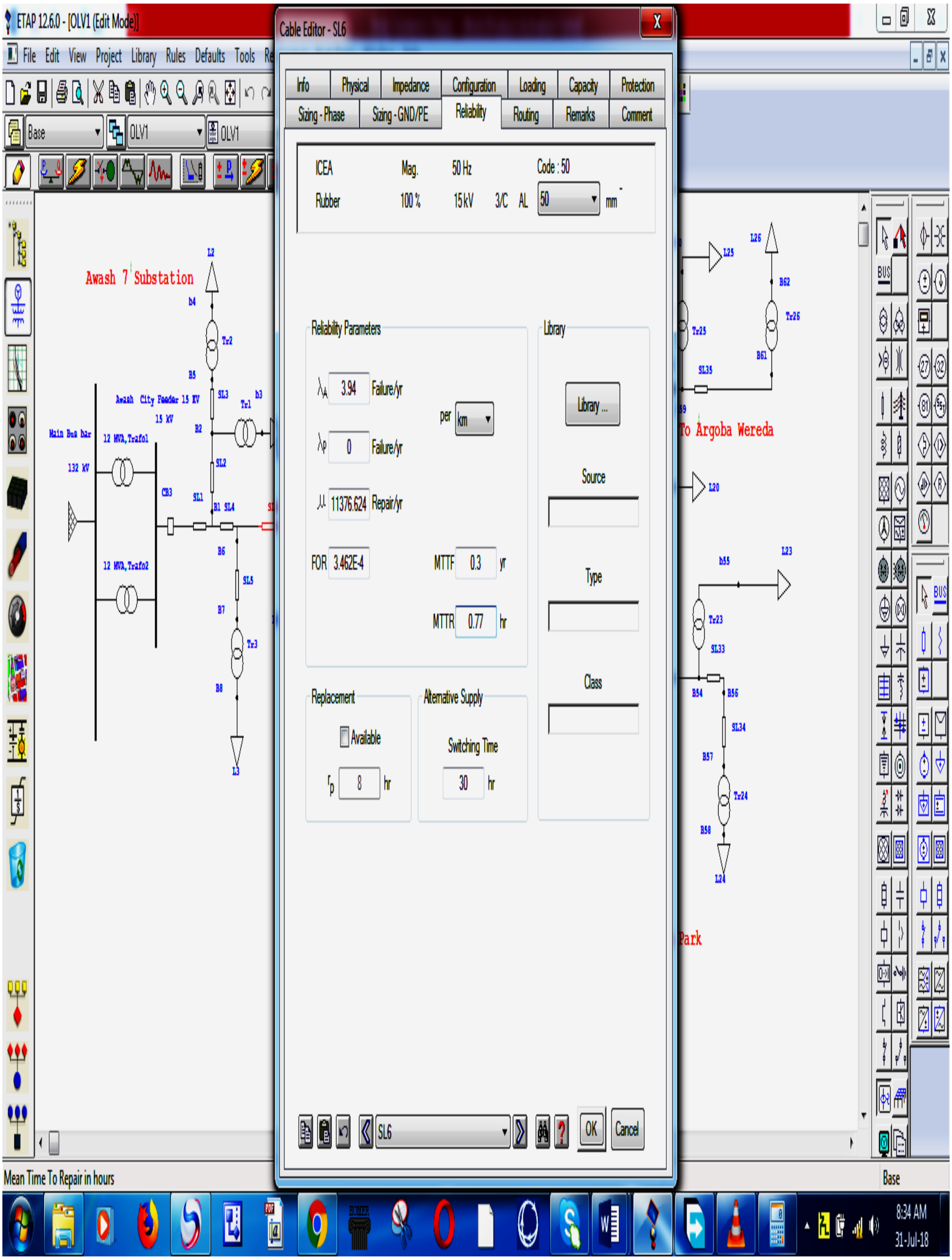


Figure 4.2: Window of ETAP 12.6 software existing system of reliability page opened

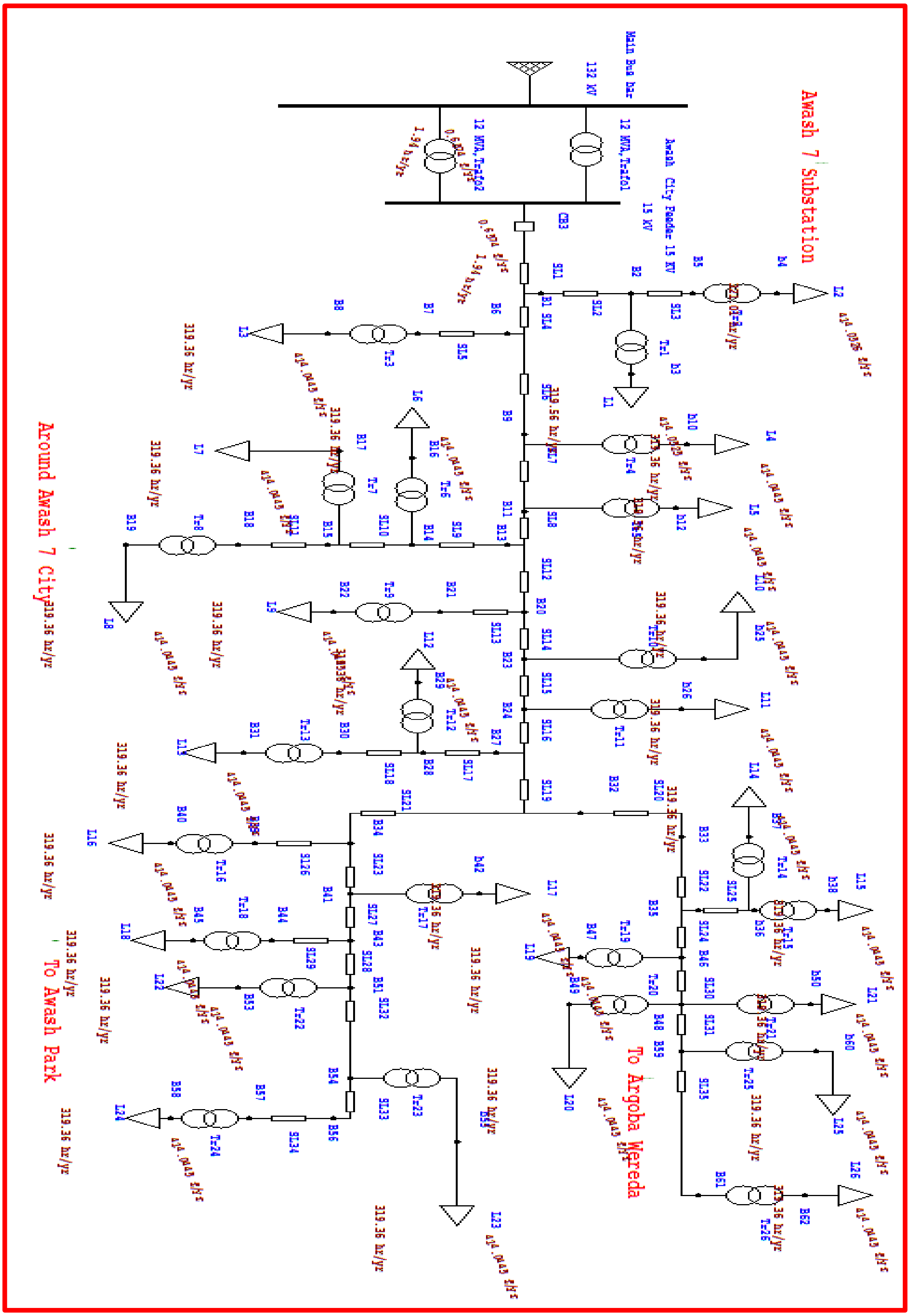


Figure 4.3: Awash7 kilo city feeder line with existing SAIFI and SAIDI values

Table 4.1: Simulation result of reliability indices for existing system

Project: Power Reliability Improvement	ETAP	Page: 1
Location: Awash7 Kilo, Afar, Ethiopia	12.6.0H	Date: 15-04-2018
Contract: 0914352253		SN:
Engineer: Jemal Mohammed Amin	Study Case: Existing RA	Revision: Base
Filename: Awash City		Config. Normal

SUMMARY

System Indexes

SAIFI 414.0447 f / customer.yr

SAIDI 320.2055 hr / customer.yr

CAIDI 0.771 hr / customer interruption

ASAI 0.9635 Pu

ASUI 0.03646 Pu

EENS 1358.4 MW hr / yr

SAIFI System Average Interruption Frequency Index

SAIDI System Average Interruption Duration Index

CAIDI Customer Average Interruption Duration Index

ASAI Average service Availability Index

ASUI Average Service Unavailability Index

EENS Expected Energy Not Supplied

Table 4.1 shows that the designed system has given the similar reliability indices output values as found from the average of three years interruption data of Awash7 kilo city. The two basic reliability indices, system average interruption frequency index and system average interruption duration index are 414.0 and 320.2 respectively.

4.4 Simulation and Result Analysis of Feeder Reconfiguration for Awash7

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

4.4.1 Scenario- 1: Using one Recloser on the Distribution line

Every necessary parameter (connected load, number of customers, cable length and active failure rate are the major ones) used for distribution system reliability analysis is entered in the ETAP software. The interruption, data of years from 2015/16 to 2017/18 G.C are used as a base year. As per the data found from the customer service center, a total number of customers currently connected to the Awash7 city feeder are about 4,819. The Recloser R1 has been placed on the line (SL19) as shown in Figure 4.4.

Table 4.2: Input Reliability parameters to ETAP Software for Scenario-1

Substation component	Source	Type	Active Failure Rate (f/yr.)	Passive Failure Rate (f/yr.)	MTTR (hr.)	Switch Time (hr.)	Replace Time (hr.)
Transformer1	IEEESd493-1990	Liquid Fill 15 KV	0.0130	0.0130	367.00	367.00	71.50
Transformer2	IEEESd493-1990	Liquid Fill 15 KV	0.0130	0.0130	367.00	367.00	71.50
Circuit Breaker	IEEESd493-1997	Fixed	0.0030	0.0045	54.20	54.20	3.90
Recloser 1	IEEESd493-1997	3phase Oil Fill 15 KV	0.0037	0.003	149.3	34	10

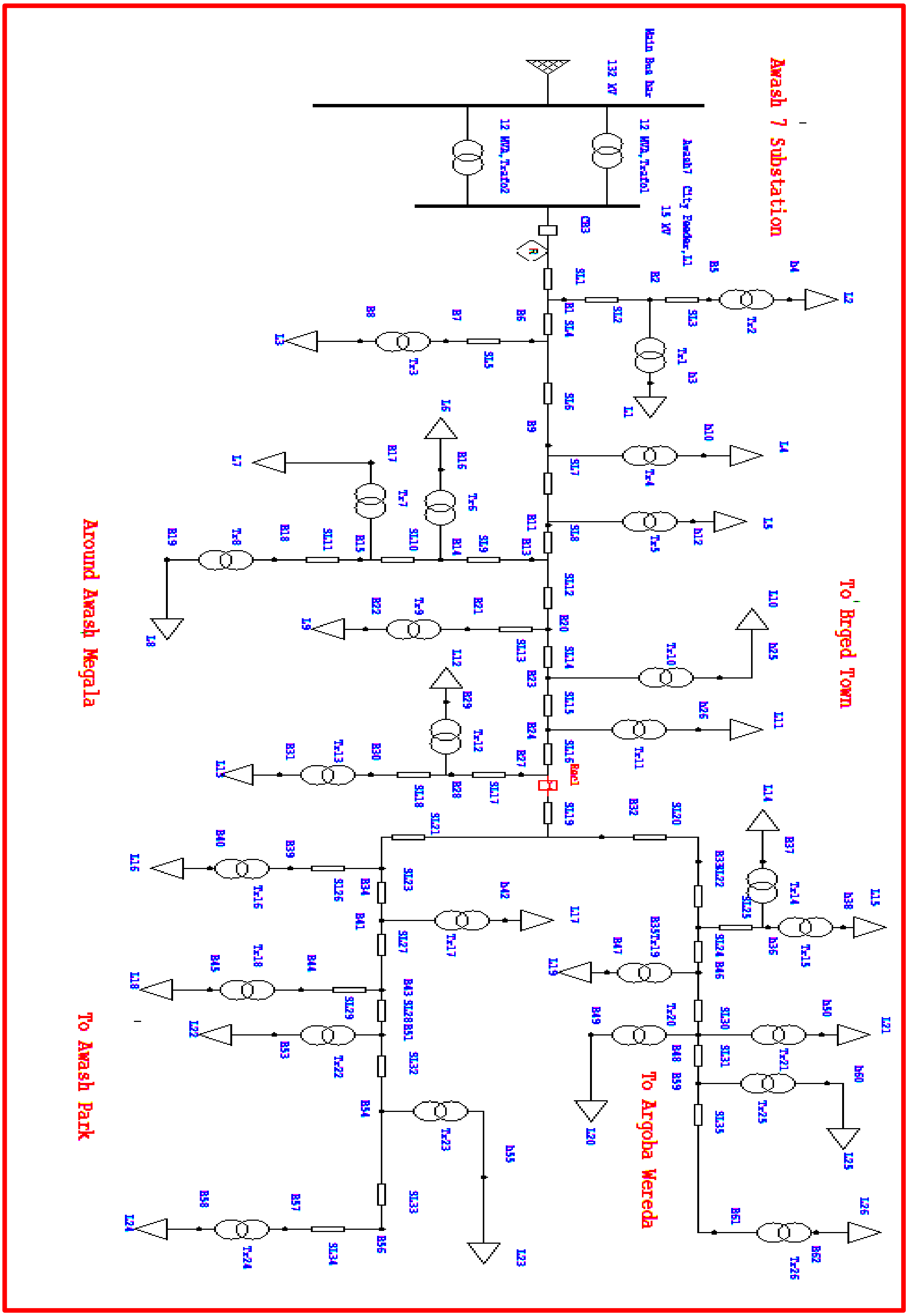


Figure 4.4 Single line diagram using one Recloser on Distribution line for Scenario -1

Table 4.3: Simulation result of reliability indices for Scenario-1

Project: Power Reliability Improvement	ETAP	Page: 1
Location: Awash7 Kilo, Afar, Ethiopia	12.6.0H	Date: 26-05-2018
Contract: 0914352253		SN:
Engineer: Jemal Mohammed Amin	Study Case: Scenario 1; RA	Revision: Base
Filename: Reliability		Config.: Normal

SUMMARY

System Indexes

SAIFI	234.0079 f / customer.yr
SAIDI	229.6079 hr / customer.yr
CAIDI	0.981 hr / customer interruption
ASAI	0.9738 Pu
ASUI	0.02621 Pu
EENS	554.470 MW hr / yr

SAIFI System Average Interruption Frequency Index

SAIDI System Average Interruption Duration Index

CAIDI Customer Average Interruption Duration Index

ASAI Average service Availability Index

ASUI Average Service Unavailability Index

EENS Expected Energy Not Supplied

Table 4.3 (Scenario -1), is the screenshot for a model with one Recloser in the feeder. As can be seen from the table, the Recloser together with the substation breaker significantly improves the reliability of the system. The expected number of outages per year has been reduced from 414.00 to 234.0079 (43.47% system reliability has improved), the annual outage duration has been reduced from 319.67 to 229.6079 hours (28.2% reduction in outage duration) as compared with the existing system. In scenario-1 the reliability of Awash7 city feeder is improved by 43.47%, 28.2% and 59.2% for SAIFI, SAIDI and EENS respectively. And also the interruption energy cost for (Scenario-1) can be calculated as, Interruption cost =554.470 MWh x 1000 x 0.4409 ETB/ kWh = 244,465.823. Therefore the interruption energy cost has been decreased from 598,766.4 to 244,465.823 ETB per year.

4.4.2 Scenario- 2: Using Two Recloser on the Distribution line

In this particular Scenario, the effect of using two Reclosers on the distribution system has been presented. One of the two Reclosers has been placed on the line (SL19) as revealed in Scenario-1, and second Recloser (R2) has been placed in the existing Awash7 kilo city to Argoba Wereda line (SL30) which is 15 Km far away from the substation and power reliability problem is serious for this line.

Table 4.4: Input Reliability parameters to ETAP Software for Scenario-2

Substation component	Source	Type	Active Failure Rate (f/yr.)	Passive Failure Rate (f/yr.)	MTTR (hr.)	Switch Time (hr.)	Replace Time (hr.)
Transformer1	IEEESd493-1990	Liquid Fill 15 KV	0.0130	0.0130	367.00	367.00	71.50
Transformer2	IEEESd493-1990	Liquid Fill 15 KV	0.0130	0.0130	367.00	367.00	71.50
Circuit Breaker	IEEESd493-1997	Fixed	0.0030	0.0045	54.20	54.20	3.90
Recloser 1	IEEESd493-1997	3phase Oil Fill 15 KV	0.0037	0.003	149.3	34	10
Recloser 2	IEEESd493-1997	3phase Oil Fill 15 KV	0.0037	0.003	149.3	34	10

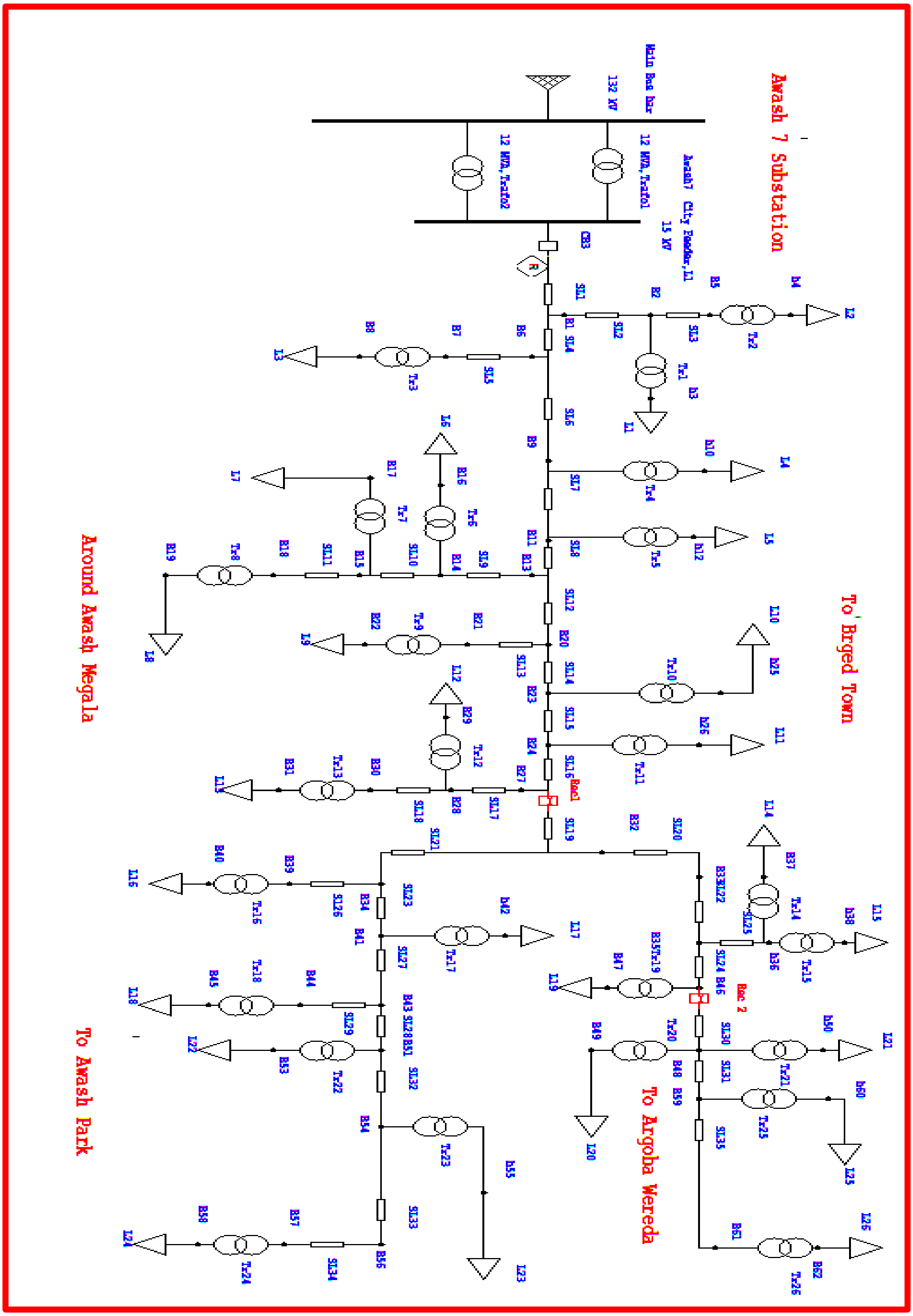


Figure 4.5: Single line diagram using two Reclosers on Distribution line for Scenario -2

Table 4.5: Simulation result of reliability indices for Scenario-2

Project: Power Reliability Improvement	ETAP	Page: 1
Location: Awash7 Kilo. Afar. Ethiopia	12.6.0H	Date: 26-05-2018
Contract: 0914352253		SN:
Engineer: Jemal Mohammed Amin	Study Case: **Scenario-2; RA**	Revision: Base
Filename: Scenario 2		Config.: Normal

SUMMARY

System Indexes

SAIFI 187.0951 f / customer.yr
SAIDI 170.8294 hr / customer.yr
CAIDI 0.913 hr / customer interruption
ASAI 0.9805 Pu
ASUI 0.01950 Pu
EENS 412.657 MW hr / yr
SAIFI System Average Interruption Frequency Index
SAIDI System Average Interruption Duration Index
CAIDI Customer Average Interruption Duration Index
ASAI Average service Availability Index
ASUI Average Service Unavailability Index
EENSExpected Energy Not Supplied

Table 4.5 (Scenario -2), shows the reliability improvement of using two Reclosers in the feeder. As can be seen from the Table 4.5, the two Reclosers together with the substation breaker significantly improve the reliability of the system. The expected number of outages per year has been reduced from 414 to 187.0951 (54.81% SAIFI has been improved), and the annual outage duration has been reduced from 319.67 to 170.8294 hours (46.56% SAIDI and 69.6% EENS) has been improved as compared to base years' average. The interruption energy cost for (scenario-2) can be estimated as;

Interruption cost = 412.657 MWh x 1000 x 0.4409 ETB/ kWh = 181,940.4713. Therefore the interruption energy cost has been decreased from 598,766.4 to 181,940.4713 ETB per year.

4.4.3 Scenario-3: System Reconfiguration using Tie Switch

In this Scenario, Awash7 kilo city feeder is reconfigured with diesel generator substation using normally open tie switch. The Tie Switch paves the way to transfer the load from the diesel generator to the Awash7 city feeder in case of power outage on the supply of the city. The diesel generator operates for emergency cases (in case of the power outage of Awash7 city feeder line) due to natural disasters or high power demands are increasingly common. Emergency backup electrical generators powered by diesel engines provide reliable, immediate and full strength electric power when there is a failure of the primary power supply system on the city feeder, minimizing losses from these events. Thus, diesel-powered generator provides the most power reliable form of emergency backup power on Awash7 city feeder line. The capacity of Awash7 diesel generator substation is assumed to be 15% (5.3/35*100%=15%) of the peak demand of the Awash7 city. Furthermore, increasing power reliability on the city feeder line the recloser R1 has been placed on the outgoing line of the Awash7 city to Argoba Woreda and this has been reduced the impact of transient faults on the distribution reliability of the system.

Table 4.6: Simulation result of reliability indices for Scenario-3

Project: Power Reliability Improvement
Location: Awash7 Kilo, Afar, Ethiopia
Contract: 0914352253
Engineer: Jemal Mohammed Amin
Filename: Scebario-3

ETAP
12.6.0H

Study Case: Scenario-3; RA

Page: 1
Date: 01-06-2018
SN:
Revision: Base
Config. Normal

SUMMARY

System Indexes

SAIFI 115.3246 f / customer.yr
SAIDI 87.5822 hr / customer.yr
CAIDI 0.759 hr / customer interruption
ASAI 0.9900 Pu
ASUI 0.01000 Pu
EENS 212.657 MW hr / yr
SAIFI System Average Interruption Frequency Index
SAIDI System Average Interruption Duration Index
CAIDI Customer Average Interruption Duration Index
ASAI Average service Availability Index
ASUI Average Service Unavailability Index
EENS Expected Energy Not Supplied

In Scenario-3, as shown clearly in Table 4.6 the expected number of outages per year is reduced from 414.00 to 115.3246 (72.14% SAIFI has been improved). And also the annual outage duration has been reduced from 319.67 to 87.5822 hours (72.6% SAIDI and 84.35% EENS) has been improved. The interruption energy cost for (scenario-3) can be estimated as, Interruption cost =212.657 MWh x1000 x 0.4409 ETB/ kWh = 93,760.4713. Therefore the interruption energy cost has been decreased from 598,766.4 to 93,760.4713 ETB per year.

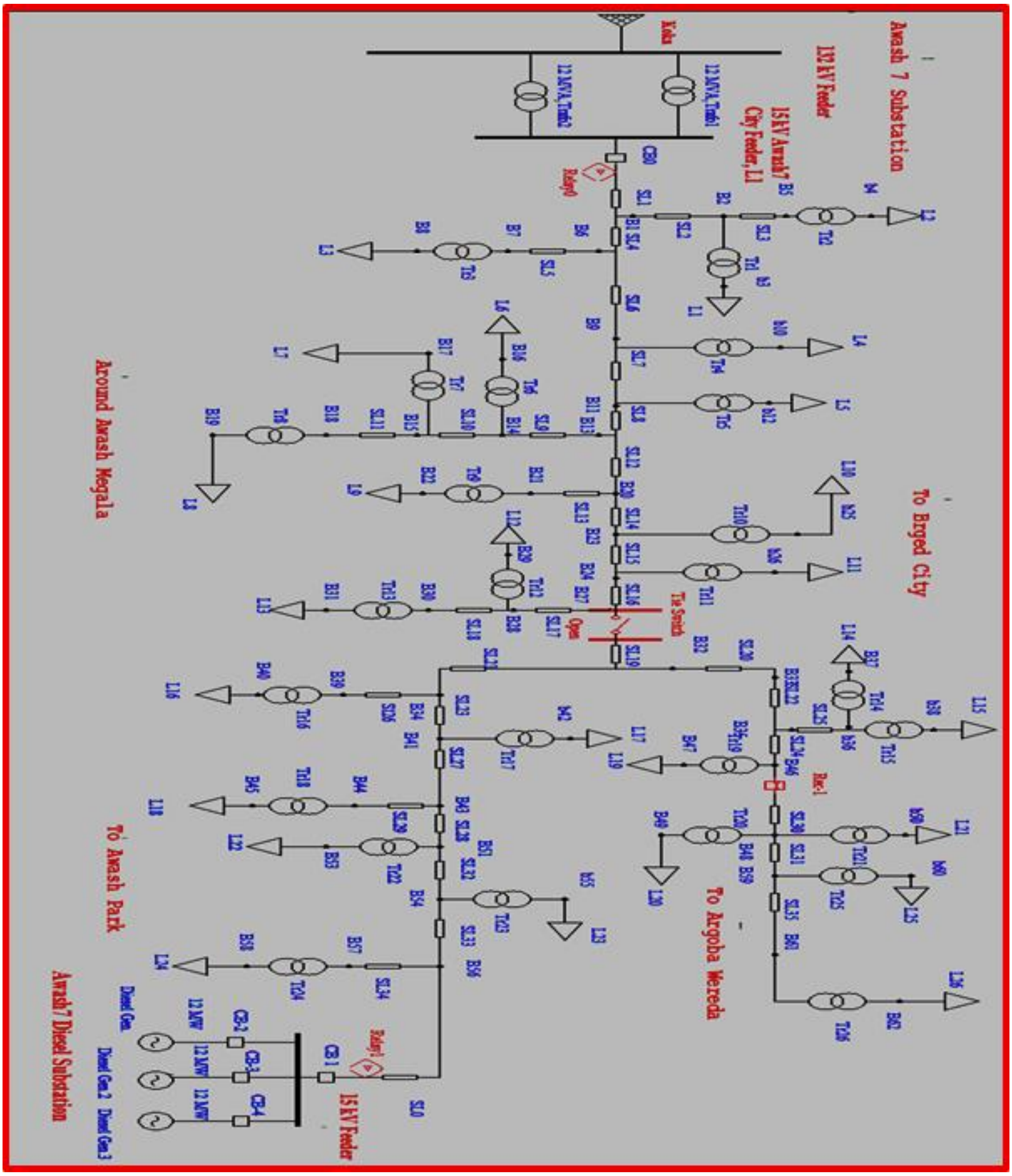


Figure 4.6: Single line diagram for Scenario -3

4.4.4 Scenario-4: Using Two Recloser on the Distribution line, Tie Switch and Isolated Argoba Woreda Line

In Scenario-4, use two Recloser with the normally open tie switches are placed on the distribution line by considering the length of the feeder, the number of customers and criticality of the location. Recloser (Rec2) has been placed at most at midpoint by considering the length and number of customers to the Awash7 diesel substation. The same thing considered for Recloser (Rec-1) which has been placed at Awash7 kilo substation city feeder line side. In this scenario (Figure 4.7) as clearly shown below, the long line runs to Argoba woreda has been permanently isolated from the existing city feeder at the exit of the Awash7 kilo city. The two substation circuit breakers Awash7 kilo substation (CB-0) and Awash7 kilo diesel substation (CB-01) and the normally open tie switch have been coordinated and interlocked together.

In scenario-4, very important thing is isolating the 15 KV power line goes to Argoba woreda from the existing system and replacing it with 66 KV power line. Isolating Argoba line increases the reliability of the feeder in Awash7 city. With the emergence of small villages and increment of electricity demand, replacing 15 KV by 66 KV may also solve the reliability problems in the Argoba woreda. For long distances, the power transfer capability of the 66 KV power line is better than 15 KV power lines. Argoba woreda Line, which consists of currently four transformers (2 with 315KVA and 2 with 200 KVA ratings) and covers about 15 km outside of Awash7 city, should change and connect to the Amibara feeder 66 KV line. The Amibara 66 KV line is one of the two outgoing 66 KV lines from Awash7 Kilo substation. Its capacity is 4.0 MW, but the actual peak load of the feeder is 2.0 MW, which is only about 50% of its capacity. Its exit from Awash7 city to Amibara woreda is in the same direction with the exit to Argoba woreda.

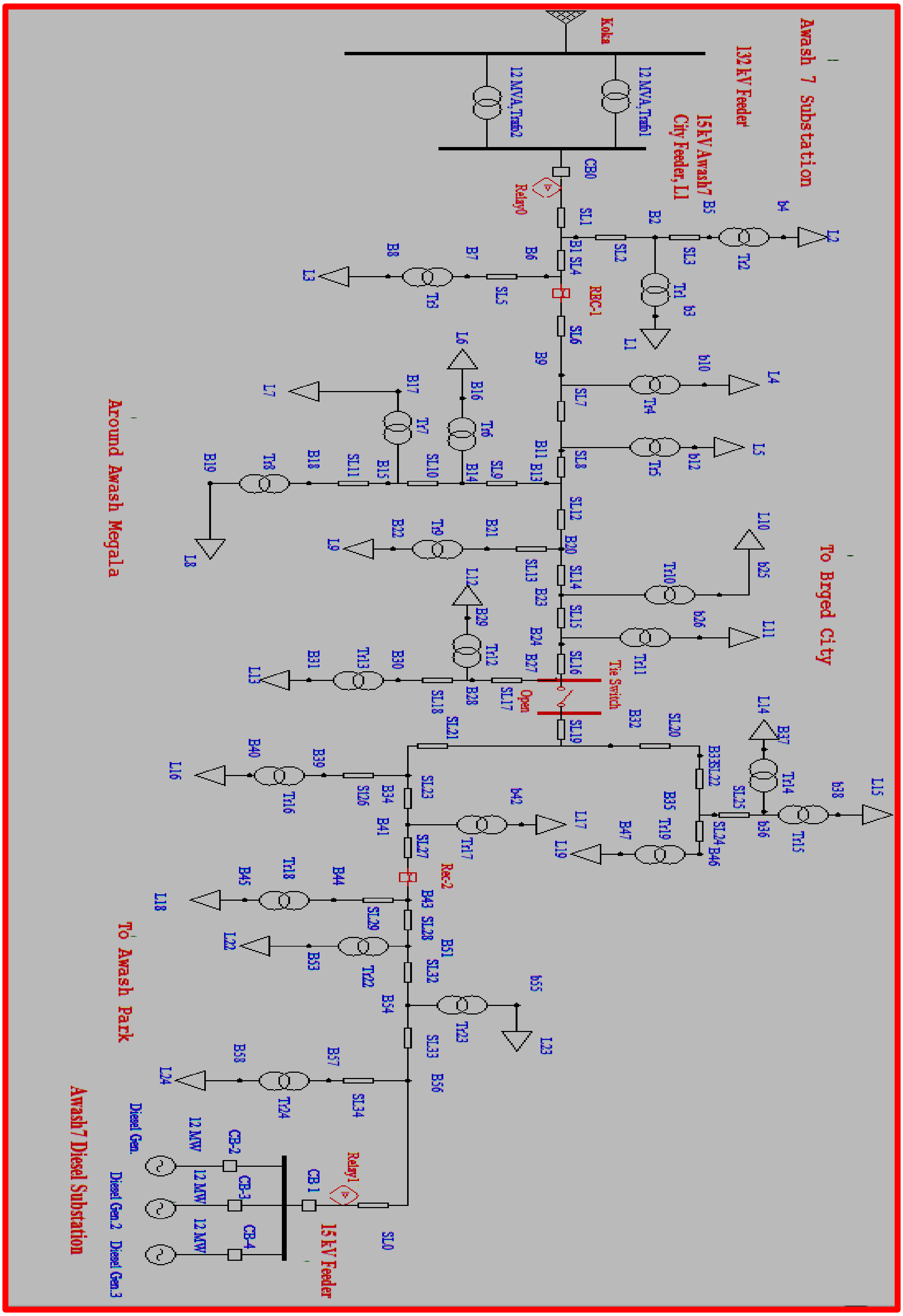
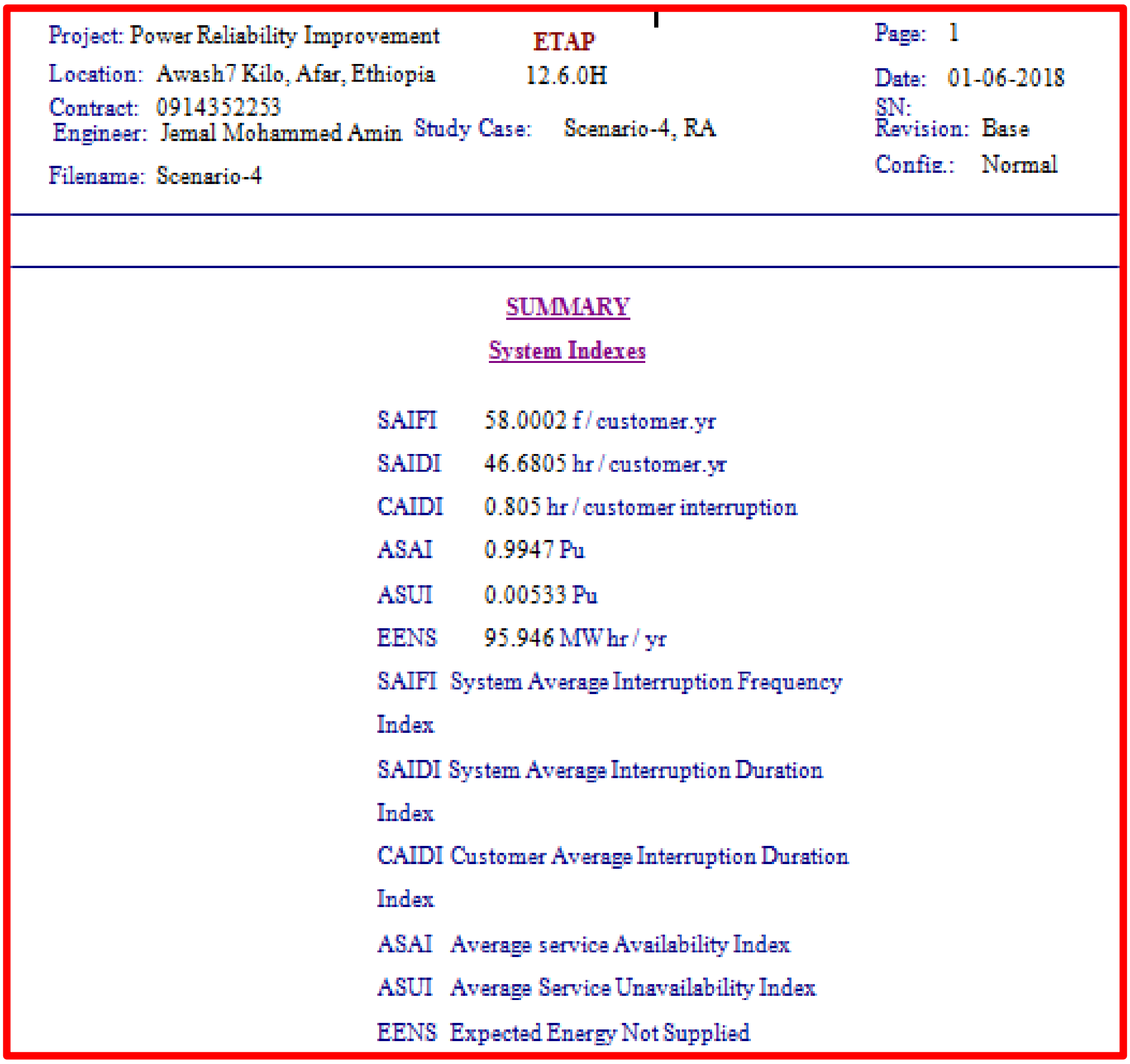


Figure 4.7: Single line diagram for Scenario -4

Table 4.7: Simulation result of reliability indices for Scenario-4



Project: Power Reliability Improvement	ETAP	Page: 1
Location: Awash7 Kilo, Afar, Ethiopia	12.6.0H	Date: 01-06-2018
Contract: 0914352253		SN:
Engineer: Jemal Mohammed Amin	Study Case: Scenario-4, RA	Revision: Base
Filename: Scenario-4		Config.: Normal

SUMMARY

System Indexes

SAIFI	58.0002 f / customer.yr
SAIDI	46.6805 hr / customer.yr
CAIDI	0.805 hr / customer interruption
ASAI	0.9947 Pu
ASUI	0.00533 Pu
EENS	95.946 MW hr / yr

SAIFI System Average Interruption Frequency Index
SAIDI System Average Interruption Duration Index
CAIDI Customer Average Interruption Duration Index
ASAI Average service Availability Index
ASUI Average Service Unavailability Index
EENS Expected Energy Not Supplied

As can be seen from the Table 4.7, the two Reclosers together with the tie switch enhanced significantly the reliability of the system. The expected number of outages per year per customer has been reduced from 414.0 to 58.0002 (86% SAIFI has been improved), and the annual outage duration has been reduced from 319.67 to 46.6805 hours (85.4% SAIDI and 92.94%) has been improved as compared with the selected base years. In the same case the interruption energy cost for (scenario-3) can be estimated as, Interruption cost = 95.946 kWh x1000 x0.4409 ETB/ kWh = 42,302.5914. Therefore the interruption energy cost has been decreased from 598,766.4 to 42,302.5914 ETB per year.

Table 4.8: Summary of the results of reliability improvement for all Scenarios

Customer Oriented Reliability Indices	**Scenarios**				
	Existing System	**Scenario-1**	**Scenario-2**	**Scenario-3**	**Scenario-4**
SAIFI (f/customer/yr)	414.0	234.0079	187.0951	115.3246	58.0002
SAIDI (hr/customer/yr)	319.67	229.6079	170.8294	87.5822	46.6805
CAIDI (hr/customer/Int.)	0.772	0.981	0.913	0.759	0.805
ASAI (Pu)	0.963	0.9738	0.9805	0.9900	0.994
ASUI (Pu)	0.037	0.02621	0.01950	0.01000	0.00533
% Reduction in SAIFI	0	43.47%	54.81%	72.14%	86.0%
% Reduction in SAIDI	0	28.2%	46.56%	72.6%	85.4%

From the above Table 4.8, it was determined and concluded that the most effective alternative (Scenario-4) for improving the power reliability of the study area was installing two Reclosers with tie switch at critically selected locations and permanently isolating the long and faulty line goes to Argoba woreda from the Awash7 city feeder.

Table 4.9: Summary of the result of system energy oriented reliability improvement for all Scenarios

Energy-Oriented Reliability Indices	**Scenarios**				
	Existing System	**Scenario-1**	**Scenario-2**	**Scenario-3**	**Scenario-4**
EENS (MWhr/yr)	1358.4	554.470	412.657	212.657	95.946
ECOST (USD/yr)	21,766.9	8,884.788	6,612.386	3,407.601	1,537.432
% Reduction in EENS	0	59.18%	69.62%	84.35%	92.94%
% Reduction in ECOST	0	59.18%	69.62%	84.35%	92.94%

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

4.5 Protection Coordination Devices and Short Circuit Current Analysis

This part describes the important of distribution system protection coordination device (Recloser and relay) are used to protect the system from unnecessary service interruptions and disturbance. This can be implemented with the help of protection coordination devices for line and ground faults analysis separately.

In this thesis, the protection coordination has been performed using the star view page in ETAP software. Star is a fully integrated system protective device coordination and selectivity module within ETAP. Star offers the state-of-the-art tool for performing device coordination, protection, and testing. This is achieved by utilizing intelligent one-line diagrams, comprehensive device libraries, and an integrated multi-dimensional database. A time-overcurrent relay characteristic is generally plotted as a single line curve. Curves for specific relays and Reclosers are provided with log-log paper and include the available range of time delay (or time dial) and current settings. 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 [29].

In this thesis, the protection devices (the Relay and the Recloser) have been designed to sense the minimum fault current from the operational rush current in the system. Short circuit analysis has been evaluated by creating a fault at different potential locations in the Awash7 city feeder and short circuit current values used for coordination have been identified. To obtain selectivity over wide ranges of short-circuit currents and tripping times a relay and a recloser whose time current curves have the same degree of Inverness have been selected. As the magnitude of the short circuit current flowing through any of the protection devices in the modeled system is dependent mainly upon the location of the fault, and only slightly or not at all upon the generation in service, to obtain a faster clearing a very inverse time overcurrent characteristic has been selected for both the Relay and the Reclosers.

Table 4.10 below, show short-circuit current values for a fault occurred at a different location in the Awash7 kilo distribution line. In this Table 4.10, the buses B24 and B56 are locations found in the upstream (to the source side) from the Recloser.

Table 4.10: Short circuit Analysis for Scenario-1

Project:	Power Reliability Improvement	ETAP	Page:	1
Location:	Awash7 Kilo, Afar, Ethiopia	12.6.0H	Date:	05-06-2018
Contract:	0914352253		SN:	
Engineer:	Jemal Mohammed Amin	Study Case: Scenario-1SC	Revision:	Base
Filename:	Reliability		Config.:	Normal

Short-Circuit Summary Report

1/2 Cycle - 3-Phase, LG, LL, & LLG Fault Currents

Prefault Voltage = 100 % of the Bus Nominal Voltage

Bus		3-Phase Fault			Line-to-Ground Fault			Line-to-Line Fault			*Line-to-Line-to-Ground		
ID	kV	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.
B9	15.00	3.482	-2.726	4.423	2.699	-1.311	3.001	2.361	3.016	3.830	-3.411	-2.637	4.312
B24	15.00	2.039	-0.875	2.219	1.310	-0.377	1.363	0.758	1.766	1.922	-1.235	-1.657	2.067
B34	15.00	1.548	-0.550	1.643	0.963	-0.237	0.992	0.476	1.341	1.423	-0.823	-1.271	1.514
B46	15.00	1.342	-0.436	1.411	0.843	-0.198	0.866	0.377	1.162	1.222	-0.683	-1.103	1.297
B56	15.00	1.105	-0.326	1.152	0.672	-0.143	0.687	0.282	0.957	0.998	-0.523	-0.914	1.053

All fault currents are symmetrical momentary (1/2 Cycle network) values in rms kA

* LLG fault current is the larger of the two faulted line currents

In this thesis work protection coordination for line and ground faults has been analyzed separately. Figure 4.8, demonstrates the coordination between the Awash7 substation Relay and the Recloser (Rec1) in Scenario-1 (Figure 4.4) for line faults. The minimum line fault current for faults occurred in the area between the source and the Recloser is 1,922A (at B24). In Figure 4.8 below, the blue colored time-current curve shows as the Relay (Rly1) trips the minimum line fault current (1,922A) in less than one second. The coordination has been implemented in between Relay (Rly1) and Recloser (Rec1) for faults occurred downstream of the recloser. For the minimum line to line fault current (998A) at the far end of the feeder at the bus (B56). The Recloser is provided with one, two, three or four operations depending upon the adjustment in an attempt to clear the fault. After the fourth operation, if the fault is still on the line, the Recloser should be locked. However, since a permanent fault will still be on the line at the end of these operations, it must be cleared away by the substation breaker. The Relay has been designed to trip 998A after total operations of the recloser.

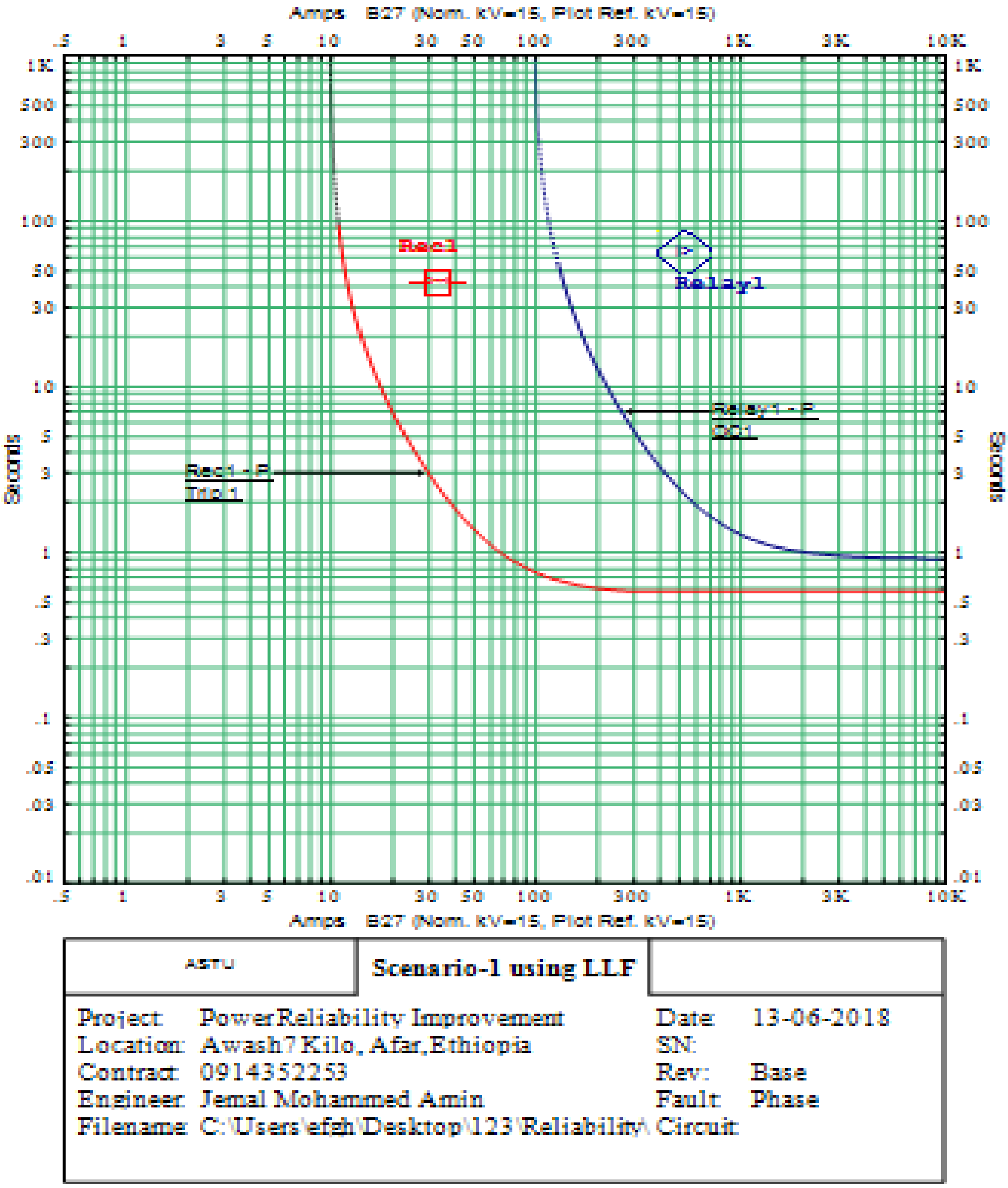


Figure 4.8: Recloser 1 and Relay 1 coordination for line faults in Scenario-1

Figure 4.9 below shows the Time Current Curve Coordination of Rly-1 and Rec1 for ground faults. The minimum line to ground fault current (1,363 A) upstream of the Recloser interrupts Rly-1 in less than one second. The minimum line to ground fault current (687A) for a fault occurred at downstream of the Recloser is designed to trip Recloser (Rec1). If the fault is not cleared after the last operation of the recloser, the substation breaker should trip the Awash7 city feeder from the source.

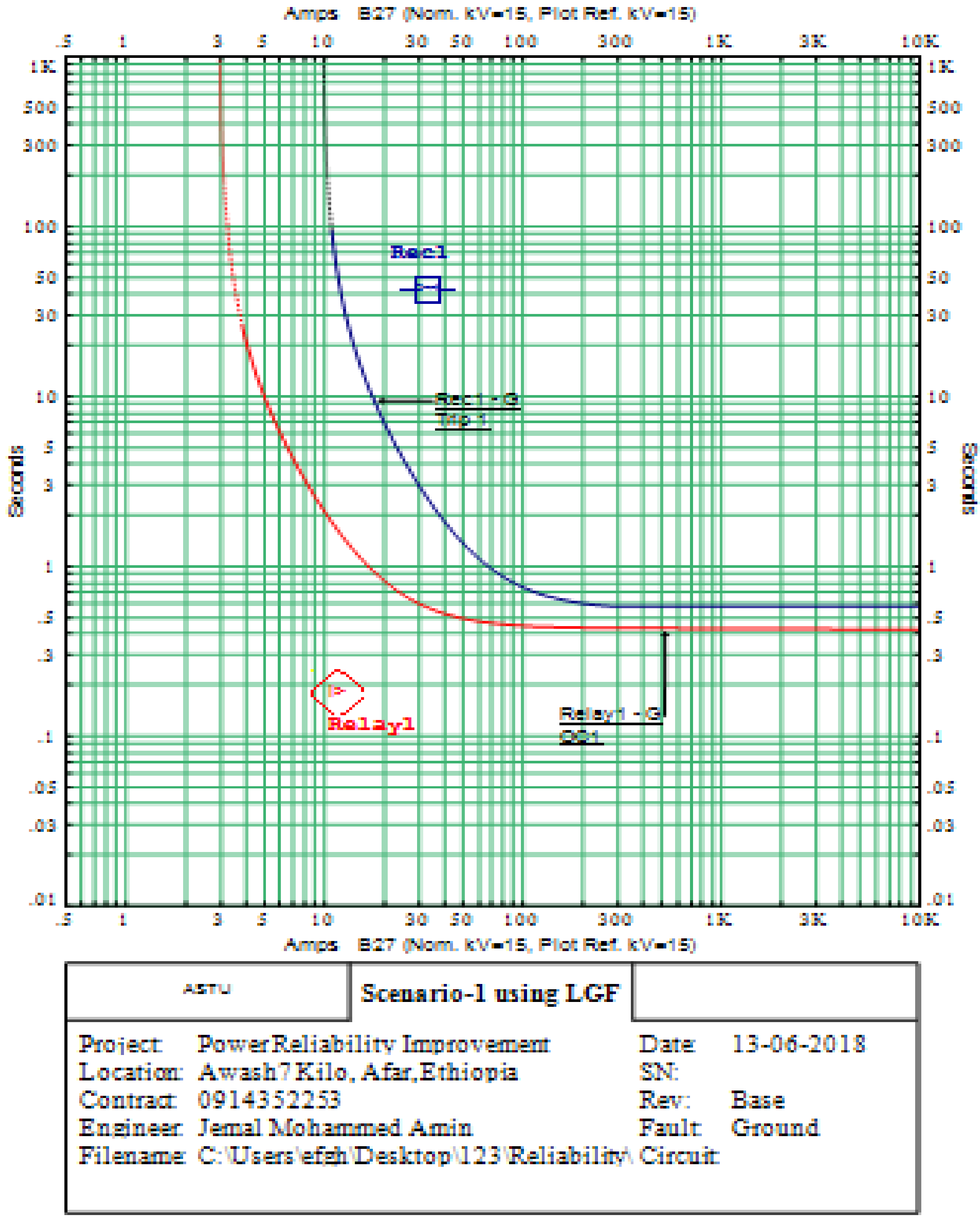


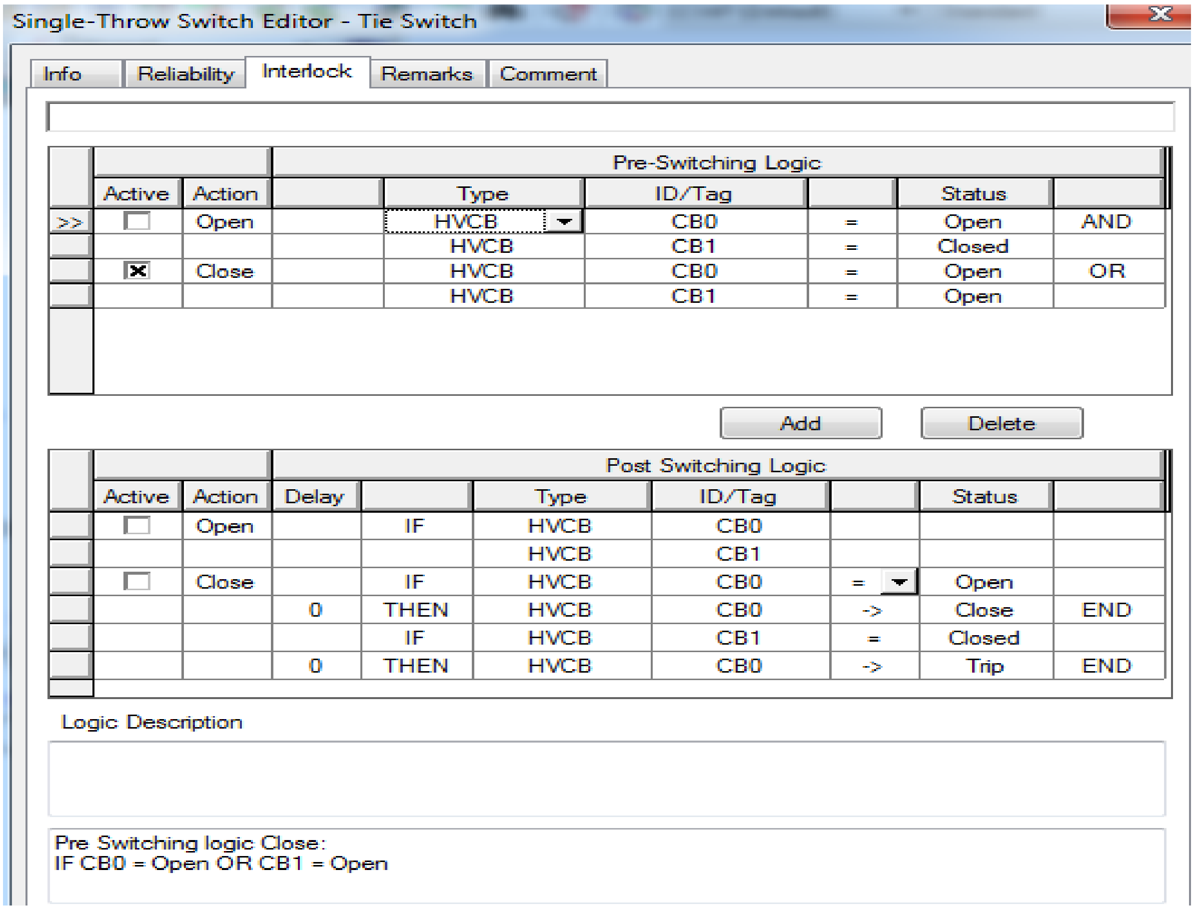
Figure 4.9: Recloser 1 and Relay 1 coordination for ground faults in Scenario-1

4.6 Interlocking and Switching Sequence Operation of Protective Devices

Interlocking among protection devices may be implemented mechanically, electrically or in other ways. These are mainly used to keep service continuity and maintain the overall safety of the system.

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

Table 4.11: Interlocking between CB0, CB1 and Tie switch



Single-Throw Switch Editor - Tie Switch

Info | Reliability | Interlock | Remarks | Comment

Pre-Switching Logic

	Active	Action		Type	ID/Tag		Status	
>>	☐	Open		HVCB	CB0	=	Open	AND
				HVCB	CB1	=	Closed	
	☒	Close		HVCB	CB0	=	Open	OR
				HVCB	CB1	=	Open	

Add | Delete

Post Switching Logic

	Active	Action	Delay		Type	ID/Tag		Status	
	☐	Open		IF	HVCB	CB0			
					HVCB	CB1			
	☐	Close		IF	HVCB	CB0	=	Open	
			0	THEN	HVCB	CB0	->	Close	END
				IF	HVCB	CB1	=	Closed	
			0	THEN	HVCB	CB0	->	Trip	END

Logic Description

Pre Switching logic Close:
IF CB0 = Open OR CB1 = Open

From the Table 4.11, it is clearly observed that the interlocking among the two substation circuit breakers (CB-0 and CB-01) and the Tie switch; so that the tie switch should not close unless one of the two breakers are open. This implies that the three switches never be closed at the same time as the two substations are not synchronized to feed the same load at a time.

Table 4.12: Switching sequence for different operation of CB0, CB1 and Tie switch

Switch Sequence

ID Sequence1 ☑ Save Last Config Normal

Action #	Group #	Active	Device/Logic: Type	Device/Logic: ID	Operation: Delay T (H:M:S)	Operation: Action	Operation: Crew	Operation: Remarks	Operation: Cost ($)	Modification: Name	Modification: Date	Modification: Time
1	1	☑	HV CB	CB0	0:00:00.000	Open			0.00	efgh	06-17-2018	4:41:10
2	2	☑	Switch	Tie Switch	0:00:00.000	Close			0.00	efgh	06-17-2018	4:47:42

Switch Sequence

ID Sequence2 ☑ Save Last Config Normal

Action #	Group #	Active	Device/Logic: Type	Device/Logic: ID	Operation: Delay T (H:M:S)	Operation: Action	Operation: Crew	Operation: Remarks	Operation: Cost ($)	Modification: Name	Modification: Date	Modification: Time
1	1	☑	HV CB	CB 1	0:00:00.000	Open			0.00	efgh	06-17-2018	4:49:33
2	1	☑	Switch	Tie Switch	0:00:00.000	Close			0.00	efgh	06-17-2018	4:49:45

Switch Sequence

ID Sequence3 ☑ Save Last Config Normal

Action #	Group #	Active	Device/Logic: Type	Device/Logic: ID	Operation: Delay T (H:M:S)	Operation: Action	Operation: Crew	Operation: Remarks	Operation: Cost ($)	Modification: Name	Modification: Date	Modification: Time
1	1	☑	Switch	Tie Switch	0:00:00.000	Open			0.00	efgh	06-17-2018	4:55:34
2	1	☑	HV CB	CB0	0:00:00.000	Close			0.00	efgh	06-17-2018	4:56:00

Switch Sequence

ID Sequence4 ☑ Save Last Config Normal

Action #	Group #	Active	Device/Logic: Type	Device/Logic: ID	Operation: Delay T (H:M:S)	Operation: Action	Operation: Crew	Operation: Remarks	Operation: Cost ($)	Modification: Name	Modification: Date	Modification: Time
1	1	☑	Switch	Tie Switch	0:00:00.000	Open			0.00	efgh	06-17-2018	4:50:57
2	1	☑	HV CB	CB 1	0:00:00.000	Close			0.00	efgh	06-17-2018	4:52:03

Table 4.12 explains the switching sequences intended to be experienced by the three devices (CB- 0, CB-01 and the Tie switch) under different situations. Four different conditions have been demonstrated as shown in sequences -1, 2, 3 and -4 in the table. In Sequence-1, the high

voltage circuit breaker (CB-0) must be opened before making the Tie switch. Sequence-4 reveals that the Tie switch should be opened before closing CB-01.

4.7 Economical Cost Analysis

In this thesis, an economical cost analysis has been done based on the interruption cost only related to the utility side by using Expected Energy Not Supplied (EENS) of each Scenario. For Scenario -1, annual average unsold energy is reduced from 1,358.4 to 554.470 MWh per year as shown in Table 4.9. Therefore, the revenue saved due to reliability improvement can be estimated as follows.

The Revenue loss before improvement due to unsold energy is:

1,358,400KWh/year x 0.4409 ETB/KWh = 598,918.56 ETB/year

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

$$\frac{[1358400 - 554470]\text{KWh}}{\text{year}} \text{ x } 0.4409 \frac{\text{ETB}}{\text{KWh}} = 354{,}452.737 \text{ ETB}$$

The investment cost can be calculated by using the cost of one outdoor high voltage recloser used to design the system in Scenario-1. The average cost of one Recloser is 15,000 (USD) [29]. Based on the exchange rate of the Commercial Bank of Ethiopia (CBE) on 05-May-2018, (l USD= 27.5151 ETB), the cost of one 15 KV, 800A pole mounted outdoor Recloser is: 15,000 x 27.5151 = 412,726.5 ETB.

The Payback period is used as an important factor to evaluate the economic competiveness of the respective Scenarios. The Payback period is the period or length of time required to recoup the cost expended in an investment. It is the ratio of the cost of investment to the annual saving by using that investment.

$$\text{Payback period} = \frac{\text{Investment Cost}}{\text{Annual Revenue Saved Cost}} \tag{4.3}$$

Thus, For Scenario-1; the payback period is:

$$\text{Payback period} = \frac{412{,}726.5 \text{ ETB}}{354{,}452.737 \text{ ETB/year}} = 1.16 \text{ years payback time}$$

Hence, the payback period indicates that it takes 1.16 years to get back the investment cost. In this Scenario-1, the reliability indices SAIFI and SAIDI have been reduced by about 43.47% and 28.2% respectively.

For Scenario-2: Annual Revenue saved cost after improvement is

$$= \frac{[1358400 - 412657]\text{KWh}}{\text{year}} \text{ x } 0.4409 \frac{\text{ETB}}{\text{KWh}} = 416{,}978.0887 \text{ ETB/year}$$

Investment cost= 2 x 15,000 x 27.5151= 825,453 ETB

$$\text{Payback period} = \frac{825{,}453 \text{ ETB}}{416{,}978.0887 \text{ ETB/year}} = 1.98 \text{ years Payback time}$$

In Scenario-2, the payback period shows that it takes 1.98 years to get back the investment cost and the reliability indices SAIFI and SAIDI have been reduced by 54.81% and 46.56% respectively.

For Scenario- 3 and Scenario-4, including the cost of Reclosers, tie-switch and feeder line cost that connects to the Argoba Woreda line should be considered.

For Scenario-3: Annual Revenue saved cost after improvement is:

$$= \frac{[1{,}358{,}400 - 212{,}657]\text{KWh}}{\text{year}} \text{ x } 0.4409 \frac{\text{ETB}}{\text{kWh}} = 505{,}158 \text{ ETB/year}$$

In Scenario-3 the investment cost is the diesel fuel costs is considered in addition to the tie-switch costs. The diesel generator operates for emergency cases has a capacity 3.06 MVA which is equal to 2,448 KW when the power factor is 0.8.

Hence, the diesel generator operates for emergency case has fuel capacity 963.7 Litter/hr. For the price of diesel, which is equal to 0.59 USD/Litter (Petro prices in Ethiopia, June-18-2018). Then, 963.7 x 0.59 USD = 568.583 USD. According to the exchange rate of Commercial Bank of Ethiopia (CBE) on 05-May-2018, (l USD= 27.5151 ETB), the cost of diesel generator operates per hour is; 568.583 x 27.5151= 15,645 ETB. In Scenario-3 the designed system also used one recloser and Tie-switch. Their costs, which are equal to 2 x 15, 000 USD = 30,000 USD (30,000 x 27.5151= 825453ETB) because of the cost of Tie- Switch similar to the Recloser cost [29]. Then the total investment cost is: 15,645 ETB + 825,453 ETB = 841,098 ETB.

$$\text{Payback period} = \frac{841{,}098 \text{ ETB}}{505{,}158 \text{ ETB/year}} = 1.7 \text{ years Payback time}$$

Hence, the payback period is 1.7 years. In this Scenario-3, the reliability of the system has been improved by 72.14%, 72.6% and 84.35% for SAIFI, SAIDI and EENS respectively.

For Scenario-4: The new 1.8 km feeder line cost mainly consists of material cost, labor cost, and transportation cost. The line should be 15 kV, 12 meter concrete pole, and three phase 95 mm^2 AAC conductor with overhead triangular configuration. By dividing the total length (1800 meter) to the span length (50 meters) the total number of concrete poles are estimated to be about 36 (8 Concrete poles for 12 meters and 28 Concrete poles for 11 meters).

Table 4.13: Labor and Transport cost of MV line construction (EEU price list, 2008 E.C)

Distance	Labor cost (ETB)	Transport cost (ETB)	Total (ETB)
for 1km line construction	10,725.12	1,643.76	12,368.88
for 1.8 km line construction	19,305.216	2,958.768	22,263.984

From the Table 4.13, the sum of labor and transport cost to construct 1.8 km medium voltage line is 22,263.984 ETB.

Table 4.14: Summary of materials needed to construct the new line and their costs (EEU price list, 2008 E.C)

Stock No	Materials	Unit	Unit Price (ETB)	Amount	Total Cost (ETB)
03-01-000	Insulator HT 18/5 mm^2 15 KV	Each	382.00	108	41,256
03-01-200	Insulator pin 18/5 for H.T 15 KV	Each	51.85	108	5,599.8
04-04-920	AAC. All Aluminum Conductor 95 mm^2	MT	21.91	5,400	222,534
09-01-480	Concrete Pole 11A (11M Pole)	Each	3,844.80	28	107,654.4
09-01-600	Concrete Pole 12 M	Each	4,574.13	8	36,593.04
09-03-670	15 KV Tie Stamp	Each	56.11	72	4,039.92
09-03-020	Cross arm Type 4-48/202	Each	142.5	36	5,130
09-03-390	Big Collar	Each	64.69	144	9,315.36
12-04-860	Long Bolt Galvanized 5/8" 40 cm	Each	66.13	4	264.52
Total Material Cost					**432,387.04**

As per the Ethiopian Electric Utility price List version 2008 E.C, the total materials cost needed to construct the new MV line (1.8 km) as shown in Table 4.14, is 432,387.04 ETB.

For Scenario-4: Annual Revenue saved cost after improvement is:

$$= \frac{[1{,}358{,}400 - 95{,}946]\mathrm{kWh}}{\mathrm{year}} \text{ x } 0.4409 \frac{\mathrm{ETB}}{\mathrm{kWh}} = 556{,}615.9686 \text{ ETB/year}$$

$$\text{Payback period} = \frac{1{,}708{,}475.524 \text{ ETB}}{556{,}615.9686 \text{ ETB/year}} = 3 \text{ year}$$

Table 4.15: Summary of estimated payback period for all Scenarios

Scenarios	Existing	Scenario-1	Scenario-2	Scenario-3	Scenario-4
EENS (MWh)	1358.4	554.470	412.657	212.657	95.946
Interruption Cost (ETB)	598,918.56	244,465.823	181,940.4713	93,760.4713	42,302.5914
Investment Cost (ETB)	0	412,726.5	825,453	841,098	2,173,943.824
Annual Revenue Saved (ETB)	-	354,452.737	416,978.0889	505,158	556,615.9686
Payback Period (year)	0	1.16	1.98	1.7	3

Table 4.15, clearly shows that the payback period of Scenario-1 (1.16 year) is smallest compared with the other Scenarios, but as clearly shown in Table 4.8, the percentage reduction for SAIFI (43.47%) and SAIDI (28.2%) compared with the selected base years is minimum. In Scenario-2 (54.81% for SAIFI) and Scenario-3 (72.14% for SAIFI), the system reliability enhancement is not good enough as compared to Scenario Four (86.0% for SAIFI). But Scenario-2 and Scenario-3 the payback periods are less compared with Scenario-4. Scenario four has a bit better reliability indices but the payback period is only 3 years. For maintenance system or to isolate faulted areas in case of permanent faults, recloser can manually operate to use as load breaker. And this prevents frequently opening and closing of the substation breaker. Comparing the improvement in reliability improvement and the cost, the researcher identifies Secenario-4 as the optimum one.

Table 4.16 below shows the comparison of the most commonly used reliability indices (SAIFI and SAIDI) of Awash7 city feeder, with the requirements of the Ethiopian Electric Agency (EEA) and the best-experienced countries in the world. As it is observed from Table 4.16, the SAIFI and the SAIDI have been improved by 86% and 85.4% respectively as compared with the base year's values.

Table 4.16: Summary and comparison of reliability indices values with benchmark country

Country		SAIFI (f/Customer/year)	SAIDI (hr/Customer/year)
USA		1.5	4
Italy		2.2	0.967
France		1.0	1.03
Denmark		0.5	0.4
Australia		0.9	1.2
Spain		2.2	1.73
Canada		3.4	6.9
United Kingdom		0.8	1.5
Germany		0.5	0.383
Ethiopia		20	25
Awash7 kilo city Feeder	Existing	414.0	319.67
	Scenario-1	234.0079	229.6079
	Scenario-2	187.0951	170.8294
	Scenario-3	115.3246	87.5822
	Scenario-4	58.0002	46.6805

CHAPTER FIVE

CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK

5.1 Conclusions

In this thesis work, evaluation of power reliability and improvement techniques for Awash7 kilo city feeder has been conducted.

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

The study clearly identified that the reliability of the Awash7 kilo city feeder does not meet the requirements set by the Ethiopia Electric Agency (EEA). The average frequency of the interruptions the city feeder is 414.0 interruptions per customer per year (SAIFI). And also the average duration of the interruption is 319.67 hours per customer per year (SAIDI). This shows that there is huge loss of unsupplied energy due to planned and unplanned outages. The average of unsupplied energy is 1,358.4 MWh per year. This results in a loss of around 598,918.43 ETB per year from Ethiopia Electric utility (EEU).

In this thesis, the system modeling and simulation studies are carried out on one of 15 kV Awash7 kilo city feeder to evaluate its reliability performance for the existing feeder and also for predicting the reliability performance for the proposed improvement techniques.

In this thesis work, four different Scenarios have been proposed and analyzed for the implementation of reliability improvement in the study area. As the simulation result shows all Scenarios have different reliability improvement contribution on the city feeder with 1.16 to 3 years payback period investment cost. All Scenarios are tolerable in terms of the investment cost. But, to improve city power reliability indices more Scenario-4 is highly proposed.

Replacing 15 KV power line goes to Argoba woreda by 66 KV power line have done in this thesis work. Due to this, for long power transfer capability of the 66 KV power line is better than 15 KV power line. Not only this, it should be effective for reliability enhancement and better solutions for overloading problems and temporary faults.

By implementing Scenario-4 the overall reliability of the Awash7 kilo city feeder is improved by 86%, 85.4% and 92.94% for SAIFI, SAIDI and EENS respectively.

The proposed solution has the potential to save around 556,615.9686 ETB per year from the unsold energy of the city feeder with 3 years payback period for the technology investment made to improve the reliability. Satisfaction of the society has also been considered as the priceless advantage.

Finally, the protection system has been evaluated for the right coordination between the Circuit Breaker, Relay and Recloser. Short circuit analysis has been done on the feeders.

5.2 Recommendations

Based on this thesis work the following recommendations are drawn.

- It is highly recommended that EEU has to look at the various technologies evaluated in this research for improving the reliability of distribution systems.
- For better power reliability improvement of Awash7 city feeder, it is also recommended to consider the use of underground cables for low voltage feeders.
- It is also important to give more attention to preventive maintenance to improve random power interruption, sustainability of equipment and to deliver reliable power to the customer.
- Awash7 kilo substation has little experience in the documentation of the performance data for the outgoing feeders. It is, therefore, strongly recommended that the data collection and documentation are improved at EEU.

5.3 Future Works

Here the thesis work is done for the reliability improvement with only Awash7 city feeder line. The reliability assessment can be extended to:

- The reliability assessment of the whole part of the outgoing feeders.
- Technical and non-technical losses.
- Maintenance optimization of the distribution system.
- On the design aspect of the distribution system.
- Distribution automation separately by different researchers.

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APPENDIX A

Table1: Awash7 kilo city Line Data

Line Name	Length of Line		
	From	To	Km
SL1	B0	B2	0.75
SL2	B2	B1	0.45
SL3	B5	B2	0.42
SL4	B6	B1	0.72
SL5	B6	B7	0.61
SL6	B9	B6	0.6
SL7	B11	B9	0.65
SL8	B13	B11	0.95
SL9	B13	B14	0.52
SL10	B14	B15	0.63
SL11	B15	B18	0.6
SL12	B20	B13	0.65
SL13	B21	B20	0.55
SL14	B23	B20	0.6
SL15	B24	B23	0.52
SL16	B27	B24	0.73
SL17	B27	B28	0.71
SL18	B28	B30	0.85
SL19	B32	B27	0.7
SL20	B33	B32	0.65
SL21	B32	B34	0.75
SL22	B35	B33	0.83
SL23	B41	B34	0.58
SL24	B46	B35	3
SL25	B36	B35	0.6
SL26	B34	B39	0.6
SL27	B43	B41	0.65
SL28	B51	B43	0.63
SL29	B43	B44	0.62
SL30	B48	B46	4
SL31	B59	B48	4
SL32	B54	B51	0.68
SL33	B56	B54	0.61
SL34	B56	B57	0.65
SL35	B61	B59	4
Total			35.06

Table 2: Peak Load and Minimum Load Data of Awash7 kilo Substation

Transformer Capacities, Tr1=12 MVA and Tr2= 12 MVA

Feeder Name	Peak Load				Minimum Load				
	MW	Current (A)	Date	Time	MW	Current (A)	Date	Time	Current Transformer Ratio
Nazereit Incoming	35	183	23-11-09	18:00	1	42	21-11-09	9:00	400-800/1A
Asseb Teferi Outgoing	9	49	20-11-09	19:00	0	19	13-11-09	15:00	
Amibara	6	59	20-11-09	19:00	1	6	13-11-09	14:00	50/5 A
Nurara	2	23	21-11-09	21:00	0.1	2	15-11-09	14:00	50/5A
Awash 7 Kilo	2	75	20-12-09	12:00	1	34	30-12-09	12:00	400/5 A
Awash 40	1.1	54	20-12-09	12:00	0.7	31	30-12-09	7:00	400/5 A
Factory	0.5	28	20-12-09	22:00	0.1	8	17-12-09	14:00	400/5 A

Table 3: Sample feeder fault types in Awash7 kilo Substation for year 2010 E.C

Feeder Name	Date	Int. Time	Rec. Time	Dur. Time	Dur.(Hr.)	Fault Type	Reason
L-1	01-07-10	8:22	8:25	0:03	0.05	Transient	Short Circuit
K-2	01-07-10	8:22	8:24	0:02	0.033	Transient	Earth fault
L-2	01-07-10	8:35	8:45	0:10	0.16	Operational	By request
L-1	01-07-10	9:05	10:25	1:20	1.33	Permanent	Earth fault
K-1	01-07-10	12:00	12:20	0:20	0.33	Transient	Earth fault
L-3	01-07-10	14:30	15:40	1:10	1.17	Permanent	Short Circuit
L-1	01-07-10	17:50	17:52	0:02	0.033	Transient	Earth fault
K-2	02-07-10	7:20	7:28	0:08	0.133	Transient	Earth fault
L-1	02-07-10	7:20	7:28	0:08	0.133	Transient	Earth fault
L-3	02-07-10	10:58	10:60	0:02	0.033	Transient	Short Circuit
K1	02-07-10	12:00	12:30	0:30	0.5	Permanent	Earth fault
L-1	02-07-10	12:00	12:50	0:50	0.833	Permanent	Earth fault
L-3	02-07-10	12:00	12:50	0:50	0.833	Permanent	Earth fault
K-2	02-07-10	12:00	12:55	0:55	0.917	Permanent	Earth fault
K-1	02-07-10	15:00	15:45	0:45	0.75	Permanent	Earth fault
L-3	02-07-10	15:55	15:58	0:03	0.05	Transient	Short Circuit
L-1	02-07-10	21:30	23:50	2:20	2.333	Permanent	Earth fault
K-2	03-07-10	7:55	7:58	0:03	0.05	Transient	Short Circuit
K-1	03-07-10	10:00	10:05	0:05	0.083	Transient	Short Circuit
L-3	03-07-10	10:40	11:05	0:25	0.417	Operational	By request
L-1	03-07-10	14:30	16:20	1:50	1.833	Permanent	Earth fault
K-1	03-07-10	14:55	15:00	0:05	0.0833	Transient	Short Circuit
L-2	03-07-10	16:05	16:08	0:03	0.05	Transient	Short Circuit
L-1	03-07-10	16:30	16:34	0:04	0.0667	Transient	Earth fault
K-2	04-07-10	8:10	8:25	0:15	0.25	Operational	By request
L-2	04-07-10	9:25	9:35	0:10	0.16	Operational	By request
L-1	04-07-10	10:30	10:32	0:02	0.033	Transient	Short Circuit
K-1	04-07-10	12:45	13:00	0:15	0.25	Transient	Short Circuit
L-1	04-07-10	13:55	15:00	1:05	1.0833	Operational	By request
L-3	04-07-10	14:06	14:09	0:03	0.05	Transient	Short Circuit
K-1	04-07-10	16:01	16:05	0:04	0.067	Transient	Short Circuit
L-2	05-07-10	1:30	1:45	0:15	0.25	Transient	Short Circuit
L-1	05-07-10	8:50	9:25	0:35	0.583	Permanent	Earth fault
K-2	05-07-10	14:43	15:33	0:50	0.833	Permanent	Earth fault
L1	06-07-10	2:30	4:00	1:30	1.5	Operational	By request
K-1	06-07-10	5:30	5:48	0:18	0.3	Transient	Short Circuit
L-3	06-07-10	8:25	8:50	0:25	0.42	Operational	By request
L-2	06-07-10	14:03	14:05	0:02	0.333	Transient	Earth fault

K-2	06-07-10	16:05	16:10	0:05	0.0833	Transient	Earth fault
L-1	06-07-10	16:32	16:34	0:02	0.333	Transient	Short Circuit
K-1	07-07-10	2:03	2:10	0:07	0.117	Transient	Short Circuit
K-2	07-07-10	3:02	3:07	0:05	0.0833	Transient	Earth fault
L-1	07-07-10	9:30	9:45	0:15	0.25	Permanent	Earth fault
L-2	07-07-10	16:35	16:47	0:12	0.2	Transient	Earth fault
L-3	08-07-10	8:00	8:03	0:03	0.05	Transient	Short Circuit
K-1	08:07-10	8:05	8:07	0:02	0.333	Transient	Short Circuit
L-1	08-07-10	10:04	10:42	0:38	0.633	Permanent	Earth fault
L-2	08-07-10	14:08	14:20	0:12	0.2	Transient	Earth fault
K-2	08-07-10	15:03	15:06	0:03	0.05	Transient	Earth fault
L-2	08-07-10	16:05	16:33	0:28	0.467	Transient	Short Circuit
L-1	08:07-10	21:00	21:35	0:35	0.583	Permanent	Earth fault
K-1	09-07-10	1:35	2:43	1:08	1.133	Permanent	Earth fault
K-2	09-07-10	2:30	4:05	1:35	1.583	Operational	By request
L-3	09-07-10	9:38	9:42	0:04	0.0667	Transient	Earth fault
L-1	10-07-10	7:15	7:18	0:03	0.05	Transient	Earth fault
L-2	10-07-10	9:00	10:05	1:05	1.0833	Operational	By request
K-2	10-07-10	12:30	12:37	0:07	0.117	Transient	Short Circuit
K-1	11-07-10	8:25	8:27	0:02	0.333	Transient	Short Circuit
L-3	11-07-10	11:05	11:08	0:03	0.05	Transient	Short Circuit
L-2	11-07-10	16:25	16:30	0:05	0.0833	Transient	Earth fault
L-1	12-07-10	2:40	3:55	1:15	1.25	Operational	By request
K-2	12-07-10	7:55	7:57	0:02	0.333	Transient	Short Circuit
L-3	12-07-10	14:25	14:28	0:03	0.05	Transient	Short Circuit
K-2	13-07-10	1:25	1:35	0:10	0.167	Transient	Earth fault
L-1	13-07-10	5:33	6:05	0:31	0.52	Permanent	Earth fault
L-2	13-07-10	16:05	16:08	0:03	0.05	Transient	Short Circuit
L-2	14-07-10	9:02	10:05	1:03	1.05	Permanent	Earth fault
L-1	14-07-10	11:05	12:28	1:23	1.383	Operational	By request
K-1	14-07-10	16:37	16:40	0:03	0.05	Transient	Earth fault
K-2	15-07-10	10:25	10:27	0:02	0.333	Transient	Short Circuit
L-3	15-07-10	11:07	11:15	0:08	0.133	Transient	Short Circuit
L-1	15-07-10	14:02	15:32	1:30	1.5	Permanent	Earth fault

APPENDIX B

Table 1: Load Flow Result Analyzer from ETAP Software

ID	Type	kW Flow	KVAr Flow	Amp Flow	% PF	% Loading	% Voltage Drop	kW Losses	KVAr Losses
12 MVA,Trafo1	Tr.2W	769	1470	7.258	46.36	13.8	1.07	1.488	19.344
12 MVA,Trafo2	Tr.2W	621	-253	26.08	92.63	5.6	1.07	0.251	3.264
Cable1	Cable	70.847	53.135	146.3	80	2.3	4.03	0.0914	1.198
Cable2	Cable	69.898	52.423	145.3	80	2.3	3.98	0.023	1.182
SL0	Cable	851	433	36.74	89.14	3.1	2.33	0.0130	3.745
SL1	Cable	1389	1198	71.37	75.7	2.5	0.38	0.0162	1.325
SL2	Cable	162	113	7.728	82.07	5.9	0.03	0.057	0.009
SL3	Cable	81.184	56.981	3.875	81.85	3.05	0.01	0.013	0.002
SL4	Cable	1218	1084	63.69	74.7	5.2	0.32	6.24	1.013
SL5	Cable	89.034	65.227	4.325	80.67	3.3	0.02	0.024	0.004
SL6	Cable	1123	1018	59.38	74.09	45.5	0.25	4.521	0.734
SL7	Cable	1033	953	55.21	73.49	42.3	0.25	4.234	0.687
SL8	Cable	948	890	51.22	72.9	39.2	0.16	2.522	0.409
SL9	Cable	263	193	12.85	80.62	9.8	0.05	0.183	0.03
SL10	Cable	176	129	8.588	80.67	6.6	0.02	0.021	0.003
SL11	Cable	87.757	64.293	4.294	80.67	3.3	0.02	0.023	0.004
SL12	Cable	683	697	38.5	69.97	29.5	0.17	2.058	0.334
SL13	Cable	87.545	64.138	4.289	80.67	3.3	0.02	0.022	0.004
SL14	Cable	593	633	34.27	68.4	26.2	0.14	1.506	0.244
SL15	Cable	519	574	30.62	67.12	23.5	0.1	1.042	0.169
SL16	Cable	432	510	26.47	64.65	20.3	0.12	1.093	0.177
SL17	Cable	166	125	8.256	79.96	6.3	0.01	0.021	0.0025
SL18	Cable	86.893	63.657	4.273	80.67	3.3	0.02	0.028	0.004
SL19	Cable	264	385	18.51	56.66	14.2	0.06	0.425	0.069
SL20	Cable	576	432	28.59	79.98	21.9	0.13	1.083	0.153
SL21	Cable	312	47.865	12.53	98.85	9.6	0.07	0.211	0.034
SL22	Cable	575	432	28.59	79.93	21.9	0.13	1.1	0.179
SL23	Cable	399	111	16.4	96.31	12.6	0.08	0.333	0.054
SL24	Cable	423	313	20.95	80.41	16	0.09	0.563	0.091
SL25	Cable	151	119	7.64	78.45	5.9	0.03	0.075	0.012
Sl26	Cable	86.046	63.415	4.24	80.5	3.2	0.02	0.023	0.004
SL27	Cable	485	175	20.42	94.07	15.6	0.11	0.579	0.094
SL28	Cable	573	239	24.53	92.3	18.8	0.13	0.81	0.131
SL29	Cable	86.378	63.66	4.248	80.5	3.3	0.02	0.024	0.004
SL30	Cable	337	250	16.73	80.35	12.8	0.07	0.359	0.058
SL31	Cable	168	125	8.345	80.29	6.4	0.04	0.095	0.015
SL32	Cable	658	302	28.58	90.88	21.9	0.16	1.187	0.193
SL33	Cable	747	367	32.8	89.78	25.1	0.16	1.402	0.228
SL34	Cable	80.563	62.129	4.009	79.19	3.1	0.02	0.022	0.004

SL35	Cable	85.1	62.718	4.216	80.5	3.2	0.02	0.024	0.004
Tr1	Tr.2W	81.146	56.064	3.853	82.27	49.3	3.11	1.154	1.731
Tr2	Tr.2W	81.17	56.979	3.875	81.85	49.6	3.74	2.249	3.373
Tr3	Tr.2W	89.009	65.223	4.325	80.66	55.2	1.34	0.889	1.334
Tr4	Tr.2W	85.402	63.958	4.192	80.04	33.9	4.1	2.631	3.947
Tr5	Tr.2W	80.665	62.221	4.012	79.18	50.9	7.86	4.822	7.233
Tr6	Tr.2W	86.902	64.06	4.261	80.49	54	2.08	1.36	2.04
Tr7	Tr.2W	87.768	64.313	4.295	80.66	93.8	1.33	0.877	1.315
Tr8	Tr.2W	87.734	64.289	4.294	80.66	34.5	1.33	0.877	1.315
Tr9	Tr.2W	87.524	64.135	4.289	80.66	34.4	1.33	0.874	1.312
Tr10	Tr.2W	72.439	58.854	3.693	77.61	80.5	14.54	8.172	12.259
Tr11	Tr.2W	86.266	63.591	4.246	80.49	53.6	2.07	1.35	2.025
Tr12	Tr.2W	79.532	61.348	3.984	79.18	86.6	7.81	4.755	7.132
Tr13	Tr.2W	86.866	63.653	4.273	80.66	34.2	1.32	0.868	1.302
Tr14	Tr.2W	78.948	60.897	3.969	79.18	86	7.78	4.72	7.079
Tr15	Tr.2W	71.574	58.151	3.671	77.61	79.5	14.45	8.075	12.112
Tr16	Tr.2W	86.023	63.412	4.24	80.49	53.4	2.07	1.346	2.019
Tr17	Tr.2W	86.196	63.539	4.244	80.49	53.5	2.07	1.349	2.023
Tr18	Tr.2W	86.354	63.656	4.248	80.49	53.6	2.07	1.351	2.027
Tr19	Tr.2W	85.312	62.888	4.222	80.49	53	2.06	1.335	2.002
Tr20	Tr.2W	82.93	62.107	4.13	80.04	89.3	4.04	2.555	3.833
Tr21	Tr.2W	86.029	63.039	4.252	80.66	33.9	1.32	0.86	1.289
Tr22	Tr.2W	84.323	63.15	4.165	80.04	90.8	4.07	2.598	3.897
Tr23	Tr.2W	87.755	64.304	4.294	80.66	34.5	1.33	0.877	1.315
Tr24	Tr.2W	80.54	62.125	4.009	79.18	87.7	7.86	4.815	7.222
Tr25	Tr.2W	82.862	62.056	4.129	80.04	89.2	4.03	2.553	3.83
Tr26	Tr.2W	85.077	62.715	4.216	80.49	52.8	2.06	1.331	1.997