Reliability Assessment and Its Improvement of Power Distribution systems (Case Study of DireDewa Substation I)

Getinet Umma Getaneh

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
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APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by Getinet Umma have read and evaluated his thesis entitled "**Reliability Assessment and Improvement of Power Distribution System**" **(Case Study of Dire Dewa Substation I)** 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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External Examiner	Signature	Date

DECLARATION

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

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Signature:___________________

This MSc Thesis has been submitted for examination with my approval as thesis advisor/ dissertation Supervisor.

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Signature:__________________

Date of submission:

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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
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
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
PEF	Permanent Earth Fault
PSC	Permanent Short Circuit
Rec	Recloser
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
TCC	Time Current Curve
TEF	Temporary Earth Fault

ABSTRACT

Most of developing country including Ethiopia distribution systems has received considerably less of the attention to reliability modeling and evaluation than have generating and transmitting systems. Unreliable electric power distribution reduces power consumption, affects daily activity and downers the modern lifestyle. It impacts societal development and individuals' income. More or less, a power distribution reliability has been a big simulating task in Dire Dawa 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. This paper focuses on enhancement of distribution system of Dire Dawa distribution network. 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 feeder line (F4) of the substation has chosen for reliability improvement measures and also predict the reliability analysis for the future. The reliability assessment has been done on six feeders of 15kV to assess the performance of the existing system and to predict the reliability analysis for the future. The interruption data of two years 2016/17-2018/19 G.C has been used as a base year. Different alternatives have been assessed using heuristic (trial and error) method and the alternative with low SAIDI, SAIFI and EENS with a reasonable cost has been preferred. From different alternative solutions the reliability of Dire Dawa distribution system could be improved by installation of one tie switch, two reclosers and built new substation near to Dire Dawa at reasonable cost has been selected. The reliability of the Dire Dawa distribution system has been enhanced significantly by implementing reliability improvement solutions that are justified economically. The researcher identifies case four as the optimum one as comparing the power reliability improvement and the cost. Even if the uncertainty of the input data is taken into account, SAIFI has been reduced by 86% as compared with the average reliability indices values of the system in the base years. In the similar way SAIDI and EENS have been decreased by 85% and 93% respectively.

Keywords: Distribution System**,** Assessment of Reliability, EENS, Network Reconfiguration, SAIFIandSAIDI

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Electric power system is the largest and the most complex system made by the mankind. It consists of countless number of structures and facilities, equipment and components, systems and subsystems and the sophisticated connections among all those. The development of power systems goes hand in hand with the proliferation of generation and consumption due to which systems complexity is increased. The use of electrical energy has been on the rise since Electric power system is the largest and the most complex system made by the mankind. It consists of countless number of structures and facilities, equipment and components, systems and subsystems and the sophisticated connections among all those. The development of power systems goes hand in hand with the proliferation of generation and consumption due to which systems complexity is increased. The use of electrical energy has been on the rise since its invention [1].

Fundamental function of electric power system is to transfer electrical energy to it consumers, it is always the priority of utility companies to ensure its consumers gets adequate and secure electric power supply within some economic constraints [2]. Adequacy means the ability of sufficient generation and the capability of transmission and distribution system to meet customer demand. While system security is the capability of the system to counter disturbances or faults which arsis within system. [3].Nowadays Ethiopian Electric Utility (EEU) Power system has 400 kV, 230 kV, 132 kV primary transmission systems and 66 kV, 45 kV as sub-transmission system and 33 kV and 15 kV as a distribution system. Substation power transformers of various ratings like 25/12 /6.3/3 MVA are installed for stepping down the voltage to 15 kV to feed the power to distribution transformers. The outgoing feeders are connected in radial fashion.

Reliable power systems serve consumer loads without interruptions in supply voltage. Generation facilities must generate adequate power to meet consumer demand. Transmission lines must transfer bulk power over long distances and Distribution systems must distribute electricity to each customer. Reliability assessment of a complete system is a significant ability in overall electric power system operation and planning [4].

In the context of Ethiopia, electric power interruption is becoming a day to day phenomenon. Even there are times that electric power interruption occurs several times a day, not only at the low voltage but also at the medium voltage distribution systems. However, utilities across the world are still eager to improve and develop better data gathering schemes and to implement better and efficient statistical methods to improve reliability of electrical power system [5]. Distribution systems account more customer reliability problems. Generation and Transmission systems determine the rest. To make effective improvements in reliability, the emphasis should be placed on the distribution system. Performing distribution system reliability assessment is used to identify the relevant improvement techniques to get better reliability of the system. As different researchers agreed there are different distribution system reliability assessment approaches and techniques [6].

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

1.2 Statement of the Problem

The purpose of the power system is to provide an adequate electrical supply to its customers as economical as possible with reasonable level of reliability. With growing demand and increasing dependence on electricity supplies, the necessity to achieve an acceptable level of reliability, quality and safety at an economic price, the utility have to evolve and improve the systems continuously depending upon the requirement of the customers. Ethiopia Electric utility has tried to improve the delivery mechanism and quality of supply. But the power distribution system in Dire Dewa city has remained inadequate to meet customer demand both in required reliability and reduce safety risks of the customers. Power interruption becomes a serious problem in the city in everywhere. The number of outages is very high and it takes long time for service restoration. Due to this every aspects of business and non-business activities and day to day lives of the city residents are negatively affected and highly complained with this problem.

There are many factors that contribute to the failure of distribution network system. Reliability is very important issue in dealing with planning and operation of the networks. In distribution system planning, reliability aspects are an important part of the decision base. Thus, to be able to assess and evaluate, reliability is needed in the planning process. The data obtained from Dire Dewa city showed that the distribution network contribute the highest SAIDI and SAIFI for two years from 2010 and 2011.

Therefore, for the purpose of demonstrating appropriate action, the investigation should identify the main constraints in electric power supply to ensure interruption free electric power supply. More specifically, the following research questions need to be addressed:

I. Assessment of the reliability indices of the existing network of Dire Dawa city , analyse major cause of interruptions and to find out the improvement techniques with use of reliability tool (ETAP) and recommend alternatives which could improve the reliability in the system.

II. What are the main causes of power interruptions and

III. How a reliable distribution system can be reconfigured for optimal power reliability improvement of the study area.

1.3 Objectives of the Study

1.3.1 General objective

The main objective of this thesis work is to evaluate and analyze electrical power distribution network in Dire Dawa city distribution system reliability and customer satisfaction; and give improvement options.

1.3.2 Specific objective

The specific objectives of this study are as follows:

- ❖ Identify the major causes of power interruptions in the existing system based on historical outage data.
- ❖ To investigate Dire Dewa city power distribution system in terms of its reliability problems.
- ❖ Evaluate system reliability indices based on selected base year's interruption data of the city feeder using an available reliability analysis tool (ETAP).
- ❖ Propose and evaluate power outage mitigation techniques such as reconnection of the scheme and replacing old components using additional recloser, sectionalize-switches & load break switches in cost effective locations are the main alternatives.

1.4 Significance of the study

The benefit of this study is mainly improve system performance by solving the problem of power interruption in the city of Dire Dewa. The other benefit of the study is significant economic impact it might bring to the commercial sectors. In addition to this in Satisfy regulatory requirements of the utility side, the study has a major role to reduce the interruption cost during power outage.

1.5 Scope of the Study

The thesis focuses on studying the current power system reliability problems of the Dire Dewa 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 Dire Dewa district. Interviews with the respective professional workers at Dire Dewa 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.

- Two years (2010 -2011 E.C) the interruption, data has been collected from Dire Dewa 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 Dire Dewa 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 Dire Dewa 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 Dire Dawa city 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

LITERATURE REVIEW

2.1 Overview on Reliability

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 system have to be upgraded, operated and maintained accordingly. An analysis throughout the world shows that around 90% of all customer reliability problems are due to the problem in distribution system, hence, improving distribution reliability is the key to improving customer reliability [7]. Fundamental function of electric power system is to transfer electrical energy to it consumers, it is always the priority of utility companies to ensure its consumers gets adequate and secure electric power supply within some economic constraints [8]. Adequacy means the ability of sufficient generation and the capability of transmission and distribution system to meet customer demand. While system security is the capability of the system to counter disturbances or faults which arsis within system [9].

Reliable power systems serve consumer loads without interruptions in supply voltage. Generation facilities must generate adequate power to meet consumer demand. Transmission lines must transfer bulk power over long distances and Distribution systems must distribute electricity to each customer. Reliability assessment of a complete system is a significant ability in overall electric power system operation and planning [10].

There are many terms and definitions used in Reliability Engineering. Some of the frequently used terms and definitions are presented below [10] [11].

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

Failure: This is the inability of an item to function within the initially defined guidelines.

Downtime: This 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 state.

Availability: This is the probability that an item is available for application or use when needed. Mean time to failure (exponential distribution): This is the sum of the operating time of given items divided by the total number of failures.

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

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

$$f = \frac{\text{Number of failures}}{\text{Studied period} \times \text{Circuit length of Transmission lines or Cables}} \qquad (2.1)$$

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

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

Then the relationship between the failure frequency and the Mean Time to Failure is:

$$f = \frac{1}{\text{Mean Time To Failure} + \text{Mean Time To Repair}} \qquad (2.2)$$

In above equation, the unit for Mean Time to Failure is years.

Failure Probability (Q (t)): The failure probability is the probability that, under stated conditions, the system or component fails within a stated period. It is identical to unreliability, which is denoted as (F (t)

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

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

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

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

$$A = \frac{MTTF}{MTTF + MTTR} = \frac{f \times MTTR}{8760} \qquad (2.5)$$

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

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

2.2 Distribution System Reliability Indices

Power system reliability indices are used as a means of measuring the reliability of the individual as well as the overall system. Reliability indices typically consider such aspects as the number of customers; the connected load;the duration of the interruption measured in seconds, minutes, hours, or days; the amount of power (kVA) interrupted; and the frequency of interruptions. The indices for the power distribution system analysis include customer-oriented indices and energy-oriented indices as defined in IEEE standard 1366-2012 [12].

2.2.1.Customer Oriented Indices

System Average Interruption Frequency Index (SAIFI)

It is the average frequency of sustained interruptions per customer over a predefined area.

It is the total number of customers interruptions divided by the total number of customers served.

$$SAIFI = \frac{Total\ number\ of\ Customer\ Interruptions}{Total\ number\ of\ Customer\ Served} = \frac{\sum \lambda_i N_i}{\sum N_i} \qquad (\ 2.7)$$

Where λi is the failure rate and Ni is the number of customers of load point i.

System Average Interruption Duration Index, (SAIDI) is commonly referred to as customer minutes of interruption or customer hours, and is designed to provide information about the average time that the customers are interrupted:

$$\text{SAIDI} = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total Number of Customer Served}} = \frac{\sum U_i N_i}{\sum N_i} \qquad (\ 2.8)$$

where Ui is the annual outage time and Ni is the number of customers of load point i. **Customer Average Interruption Duration Index (CAIDI)** is the average time needed to restore service to the average customer per sustained interruption:

$$\text{CAIDI} = \frac{\text{Sum of Customer Interruption Duration}}{\text{Total Number of Customer Interruptions}} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} = \frac{\text{SAIDI}}{\text{SAIFI}} \qquad (2.9)$$

Where λi is the failure rate, Ui is the annual outage time and Ni is the number of customers of load point i.

Customer Average Interruption Frequency Index (CAIFI) is designed to show trends in customers interrupted and helps to show the number of customers affected out of whole customer base.

$$\text{CAIFI} = \frac{\text{Total Number of Customer Interrupted}}{\text{Number of Customer affected}} = \frac{\sum \text{U}N_i}{\text{N}} \qquad (2.10)$$

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

$$\text{ASAI} = \frac{\text{Customer hours ofAvailable Service}}{\text{Customerhours demanded}} = \frac{\sum_{\text{i}} N_i \times 8760 - \sum_{\text{i}} U_i N_i}{\sum_{\text{i}} N_i \times 8760} \qquad (2.11)$$

Average Service Unavailability Index (ASUI): This index is the complementary value to the average service availability index (ASAI).

$$ASUI = 1 - ASAI = \frac{Customer\ hour\ of\ Unavailable\ Service}{Customer\ hours\ demanded} = \frac{\sum_i U_i N_i}{\sum_i Ni \times 8760} \qquad (2.12)$$

Load or Energy-Oriented Indices

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

$$ENS = \sum_i L_a(i)\, U_i \qquad (2.13)$$

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

$$L_a(i) = L_P(i) \times L_F(i) \;=\; \frac{E_d(i)}{t} \qquad (2.14)$$

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

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

$$AENS \;=\; \frac{Total\ energy\ not\ supplied}{Total\ number\ of\ customers\ served} \;=\; \frac{\sum_i L_a(i)U_i}{\sum_i N_i} \qquad (2.15)$$

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

$$ACCI \;=\; \frac{Total\ energy\ not\ supplied}{Total\ number\ of\ customers\ served} \;=\; \frac{\sum_i L_a U_i}{\sum_i N_o} \qquad (2.16)$$

where: La (i) is the average load, No 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.

2.3 Reliability Cost/Worth

When an interruption is experienced by a customer, there is an amount of money that the customer is willing to pay to evade the interruption and this amount is referred to as the customer cost of reliability'. These costs include both tangible and intangible cost and also the opportunity cost. As such, to maximize the reliability, 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 [13] [14].

2.4 Electrical fault

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

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 need repairs by the repair team in terms of Replacing burned-down conductors, blown fuses, or any other damaged apparatus, Removing tree limbs from the line and 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 [15].

2.5 Types of Power Interruption

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

2.5.1 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. [16].

2.5.2 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 [16].

2.5.3 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 [17].

2.5.4 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 [18].

2.6 Distribution System Protection

Protection coordination is performed among protection devices to prevent unwanted operation of the equipment for a fault occurred on the system [19] [20].

The main objectives of distribution system protection and coordination 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.

Electrical fault is an abnormal condition, caused by equipment failures such as transformers and rotating machines, human errors and environmental conditions. Theses faults cause interruption to electric flows, equipment damages and even cause death of humans, birds and animals.

2.6.1 Distribution Protection Equipment

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:

- ✓ Reclosers
- ✓ Sectionalizers
- ✓ Fuses
- ✓ Overcurrent relays

2.6.2 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 per cent of the faults are of a temporary nature and last, at the most, for a few cycles or seconds. Thus, the recloser, with its opening/closing characteristic, prevents a distribution circuit being left out of service for temporary faults. Typically, reclosers are designed to have up to three open-close operations and, after these, a final open operation to lock out the sequence. One further closing operation by manual means is usually allowed. The counting mechanisms register operations of the phase or ground-fault units which can also be initiated by externally controlled devices when appropriate communication means are available [21]. 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 1 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.

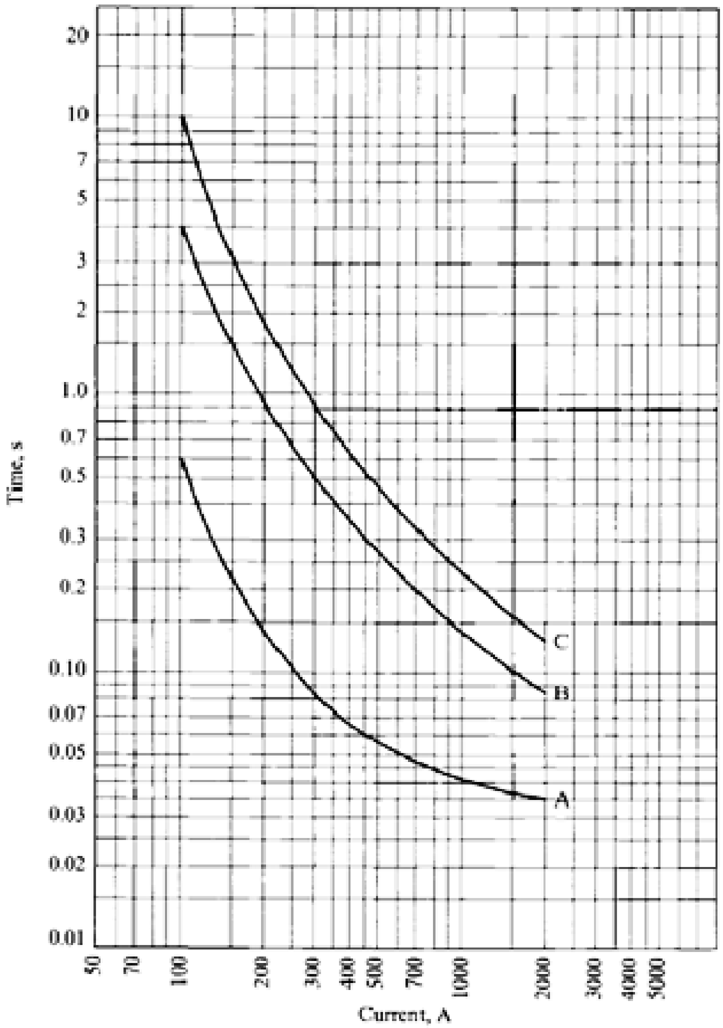

Figure 2.1: Time/Current curves for Recloser [21].

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 minimise 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. The first shot is carried out in instantaneous mode to clear temporary faults before they cause damage to the lines. The three later ones operate in a timed manner with predetermined time settings. If the fault is permanent, the time-delay operation allows other protection devices nearer to the fault to open, limiting the amount of the network being disconnected. 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 residually so that the resultant residual current under normal conditions is approximately zero. The recloser should operate when the residual current exceeds the setting value, as would occur during ground faults.

Reclosers can be classified as follows:

- Single-Phase and Three-Phase
- Mechanism with hydraulic or electronic operation
- Oil, Vacuum or SF_6

Single-phase reclosers are used when the load is predominantly single-phase. In such a case, when a single-phase fault occurs the recloser should permanently disconnect the faulted phase so that supplies are maintained on the other phases. Three-phase reclosers are used when it is necessary to disconnect all three phases in order to prevent unbalanced loading on the system. Reclosers with hydraulic operating mechanisms have a disconnecting coil in series with the line. When the current exceeds the setting value, the coil attracts a piston that opens the recloser main contacts and interrupts the circuit. The time characteristic and operating sequence of the recloser are dependent on the flow of oil in different chambers. The electronic type of control mechanism is normally located outside the recloser and receives current signals from a CT-type bushing. When the current exceeds the predetermined setting, a delayed shot is initiated that finally results in a tripping signal being transmitted to the recloser control mechanism. The control circuit determines the subsequent opening and closing of the mechanism, depending on its setting. Reclosers with electronic operating mechanisms use a coil or motor mechanism to close the contacts. Oil reclosers use the oil to extinguish the arc and also to act as the basic insulation. The same oil can be used in the control mechanism. Vacuum and SF6 reclosers have the advantage of requiring less maintenance.

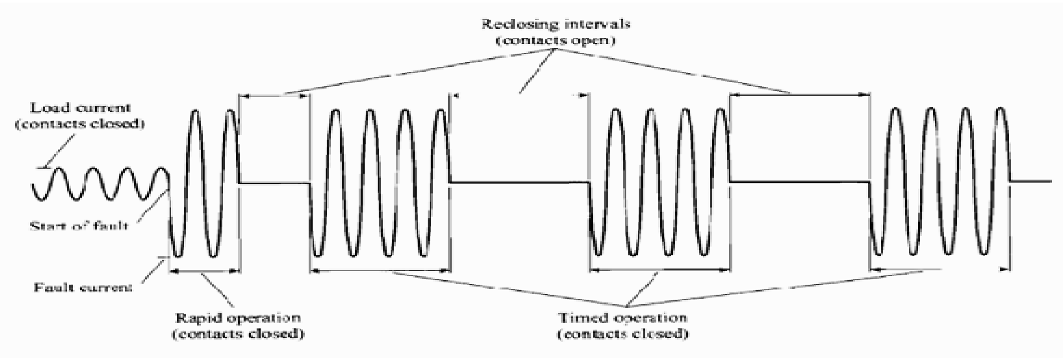

Figure 2.2: Typical sequence for Recloser operation [21].

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

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

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

I. System voltage.

II. Short - circuit level.

III. Maximum load current.

IV. Minimum short – circuit current within the zone to be protected by the recloser.

V. Coordination with other mechanisms located upstream towards the source, and downstream towards the load.

VI. 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.

2.6.3 Sectionalyzers:- 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 back-up 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 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 [22] [23].

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

Sectionalizers with hydraulic operating mechanisms have an operating coil in series with the line. Each time an overcurrent occurs the coil drives a piston that activates a counting mechanism when the circuit is opened and the current is zero by the displacement of oil across the chambers of the sectionalizer. After a prearranged number of circuit openings, the sectionalizer contacts are opened by means of pretensioned springs. This type of sectionalizer can be closed manually. Sectionalizers with electronic operating mechanisms are more flexible in operation and easier to set.

The load current is measured by means of CTs and the secondary current is fed to a control circuit which counts the number of operations of the recloser or the associated interrupter and then sends a tripping signal to the opening mechanism. This type of sectionalizer is constructed with manual or motor closing.

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

The majority of fuses used in distribution systems operate on the expulsion principle, i.e. they have a tube to confine the arc, with the interior covered with de-ionizing fiber, and a fusible element. In the presence of a fault, the interior fiber is heated up when the fusible element melts and produces de-ionizing gases which accumulate in the tube. The arc is compressed and expelled out of the tube; in addition, the escape of gas from the ends of the tube causes the particles that sustain the arc to be expelled. In this way, the arc is extinguished when current zero is reached. The presence of de-ionizing gases, and the turbulence within the tube, 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 [24]:

- 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.

2.6.4 Coordination

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 [25].

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

$$T_{i,j} = \left(\frac{A_k}{\left({I_{ij}}/{I_{pi}}\right)^{C_{k-1}}} + B_k\right) \times TDS_i \qquad (2.17)$$

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 [26].

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

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

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

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

2.6.2.2 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 [27]

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 [23].

2.6.2.3. Recloser - Sectionalizer Coordination: Since the sectionalizers have no time/current operating characteristic, their coordination does not require an analysis of these curves.

The coordination criteria in this case are based upon the number of operations of the back-up recloser. These operations can be any combination of rapid or timed shots as mentioned previously, for example two fast and two delayed. The sectionalizer should be set for one shot less than those of the recloser, for example three disconnections in this case. If a permanent fault occurs beyond the sectionalizer, the sectionalizer will open and isolate the fault after the third opening of the recloser. The recloser will then re-energize 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 [28].

2.7 Literature Review of Current Research Papers

Power systems across the globe are built with the intent of providing for the energy needs of the modern times. Hence, it is understood that meeting the needs of the customers is the most important reason why a power system is established, with the profit coming along while doing the business.

The significance of a reliable distribution is hinged on the fact that even if the generation and transmission of a power system are highly reliable, an unreliable distribution system will mean that there will be poor supply of energy to the customers. Hence, to meet customer demands, the power utility has to evolve and the distribution Substation system has to be upgraded, operated and maintained accordingly [29]. 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:

[30]The main contribution of this paper is presenting the benefits of implementing energy management at the substation level to improve smart grid reliability and stability across the distribution system. The paper provides a brief overview of the recent approaches used to implement management and control decisions in the smart grid.

In [31] Atinafu Alemu (2012) his thesis the reliability assessment of Bahir Dar city distribution system on 15 kV selected four feeders is done. Monte Carlo simulation systems and ETAP software is used to assess and simulate the overall behavior of the distribution system reliability indices. The researcher also recommend that the improvement techniques such as reconnection of the scheme and replacing old components are economical alternatives for further improvement using additional recloser, sectionalize-switches & load break switches in cost effective locations are the main alternatives.

In [32] Seema Saxena Tripta has also assessed the overall performance of Indian distribution utilities. This paper presents the measurement of technical efficiency for performance evaluation of electricity distribution utilities in India after the implementation of EA 2003.

Paper [33] 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 [34] 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 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.

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 Dire Dewa Substation

Dire Dewa substation takes electric power through 230 kV transmission lines from Koka power plant that is interconnected system (ICS) and it supplies electric power to Dire Dewa 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 Hnaz substation, then stepped dawn to 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 Dire Dawa substation one (Hnaz) 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 out coming 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. Dire Dewa substation consists of seven outgoing feeders. The nominal voltages of the six feeders are 15 kV and the remaining one feeder is 132 KV transmission line. As per the data found from the eastern region billing office, the Dire Dawa Customer Service Center one, two and three has a total of approximately 54, 616 customers served. From the outgoing feeders, F4 feeder city line is serving customers found in the center of the city and is extended to Biyawalle and Wahil, which are at around 40 km away from the Dire Dawa substation I. 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 F1-F6 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 800/5 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.

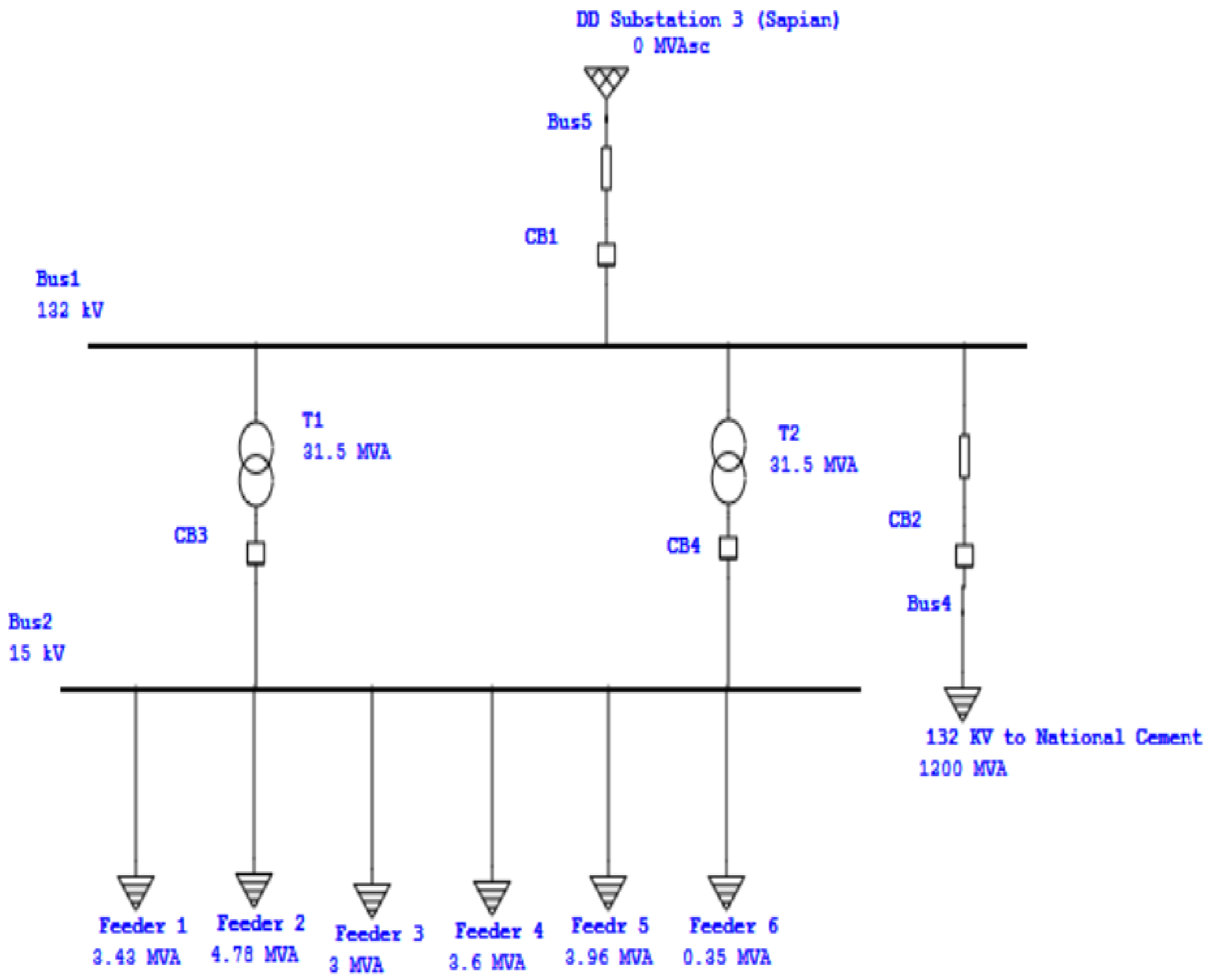

Figure 3.1: Single line Diagram of Dire Dawa Substation I [ETAP 16.0 software]

Figure 3.2 Partial View of DD Substation I Control Room [Source: Study Area]

Figure 3.3: Dire Dewa Substation I [Source: Study Area]

3.3 Data Collection

Primary data have been collected by the direct involvement of the researcher and workers of Ethiopia Electric Utility (EEU) from Dire Dewa. 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: Data for Dire Dewa Substation I

Name of Substation	Lines			Transformer Quantity	Voltage Level (KV)	Transformer Capacity (MVA)	Total Substation Capacity (MVA)
	HV	MV	LV				
DD Substation I	1	0	6	2	132/15	31.5	63

Table 3.2: Name and voltage levels of Dire Dewa substation I outgoing feeders

Feeder Name	Voltage Level in KV	Circuit Breaker Type	CT Ratio	Peak Load in MW,2018
Feeder 1	15	Vacuum	800/5 A	5.14
Feeder 2	15	Vacuum	800/5 A	4.5
Feeder 3	15	Vacuum	800/5 A	4.63
Feeder 4	15	Vacuum	800/5 A	9.3
Feeder 5	15	Vacuum	800/5 A	5.4
Feeder 6	15	Vacuum	800/5 A	0.23

Table 3.3: The Consummate Data for Dire Dewa Substation I Feeders

Feeder Name	Total No of Distribution Transformer	Total Length of Feeders (KM)	Total No.- of Customer	Total Capacities of Distribution Transformer (MVA)	Conductor Size (mm^2)
Feeder I	48	31.75	10408	7.481	AAC -50 mm^2
Feeder 2	76	24.68	10046	7.221	>>
Feeder 3	120	72.9	8640	6.21	>>
Feeder 4	95	90.9	16840	12.104	>>
Feeder 5	52	21.9	7736	5.56	>>
Feeder 6	2	2	946	0.68	>>
Total	393	244.13	54616	39.256	>>

Table 3.4 shows the annual average energy and power consumption of each feeder bus bar. The annual average energy is calculated using the recorded data from 2016/17-2018/19 G.C.

Table 3.4: 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 (MWH)	Average Reactive Energy(MVArh)
Feeder 1	3.403	2.895	1.789	25360.2	15671.64
Feeder 2	4.78	4.07	2.507	35653.2	21961.32
Feeder 3	3	2.56	1.564	22425.6	13700.64
Feeder 4	3.55	3.02	1.866	26455.2	16346.16
Feeder 5	3.96	3.37	2.080	29521.2	18220.8
Feeder 6	0.35	0.3	0.180	2628	1576.8
Total	19.043	16.215	9.986	142043.4	87477.36

Based on Table 3:4, The Power Factor of the Substation can be calculated as:

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

$PF = \text{Cos}\,(\tan^{-1}(87477.36/142043.4) = 0.85$

where:

PF = Power factor

Q = Reactive Power in (MVAr)

P = Active Power in (MW)

Table 3:5 Average and Peak load of the substation

Feeder Name	Average Load (MW)	Peak Load (MW)
Feeder I	2.90	5.99
Feeder 2	4.07	5.78
Feeder 3	2.56	4.97
Feeder 4	3.02	9.68
Feeder 5	3.37	4.48
Feeder 6	0.30	0.54
Total	16.22	31.44

Table 3:6 Hourly Load (MW) each Feeder of Dire Dewa Substation I

Feeder→ Hour↓	Feeder I	Feeder 2	Feeder 3	Feeder 4	Feeder 5	Feeder 6	Total
1	2.13	2.76	2.01	0.76	0.41	0.1	8.17
2	2.15	2.78	2.02	0.78	0.41	0.1	8.24
3	1.67	2.93	1.84	0.79	0.41	0.25	7.89
4	1.68	2.94	1.86	0.78	0.56	0.35	8.17
5	1.91	3.2	2.22	0.75	0.56	0.35	8.99
6	1.93	3.22	2.25	0.76	0.51	0.46	9.13
7	2	2.54	1.86	0.46	0.51	0.51	7.88
8	2	2.54	2.02	0.75	0.61	0.46	8.38
9	2.17	2.75	2.14	0.44	0.66	0.46	8.62
10	2.17	2.78	2.28	0.41	0.71	0.15	8.5
11	2.78	7.26	2.8	0.4	0.77	0.25	14.26
12	2.76	3.8	7.44	0.57	0.57	0.87	16.01
13	2.72	3.62	3.08	0.55	0.52	0.52	11.01
14	2.59	3.01	2.57	0.41	0.77	0.46	9.81
15	2.57	2.07	2.78	0.41	0.77	0.46	9.01
16	2.52	2	2.76	0.42	0.77	0.46	8.93
17	1.71	1.77	1.74	0.76	0.71	0.71	7.4
18	1.68	1.75	1.37	0.76	0.66	0.56	6.78
19	1.21	1.2	1.14	0.49	0.66	0.66	5.36
20	1.21	1.19	1.12	0.48	0.66	0.46	5.12
21	1.15	1.29	1.17	0.41	0.61	0.31	5.09
22	1.2	1.19	1.28	0.79	0.61	0.46	5.53
23	1.27	2	1.54	0.4	0.61	0.61	6.43
24	1.17	3.18	2.16	0.57	0.66	0.2	7.94

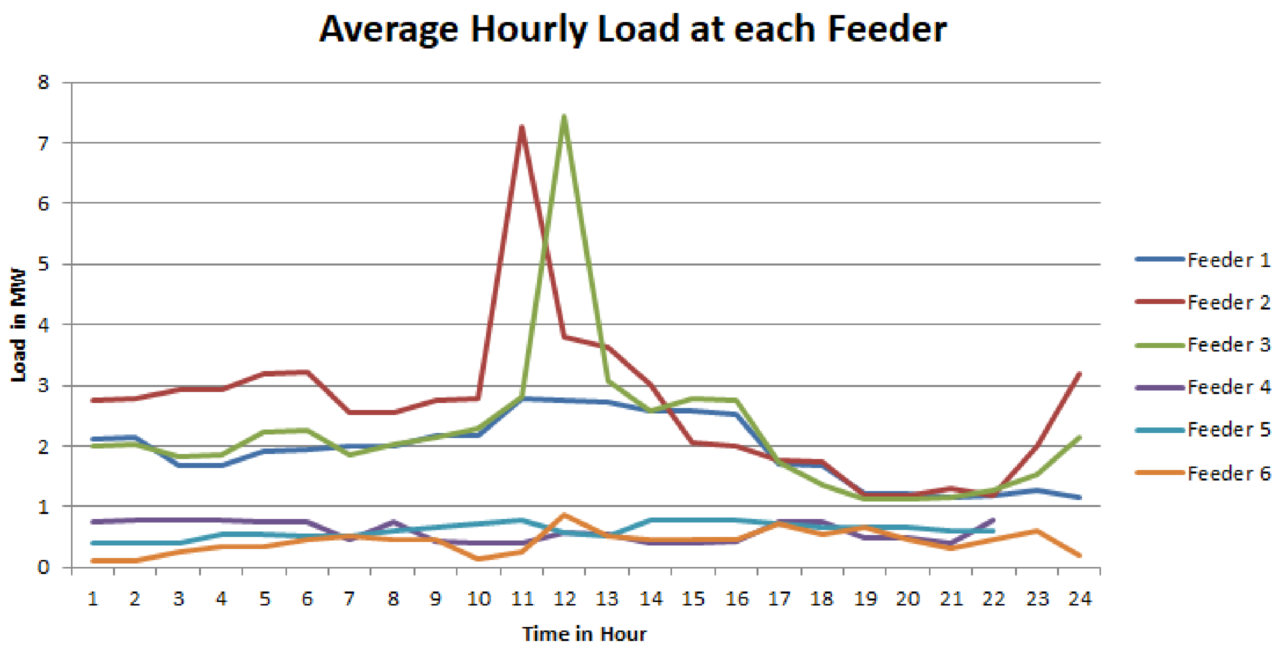

Figure 3.4 Average Hourly Loads of Dire Dewa Substation

As shown from the hourly load of Figure 3.4, the maximum and minimum loads of the feeders are 7.44 MW and 0.1 MW respectively. The maximum load is observed during the day time in the range of 11:00 AM to 13:00 PM. The minimum load is observed during the night time in the range of 1:00 AM to 2:00 AM.

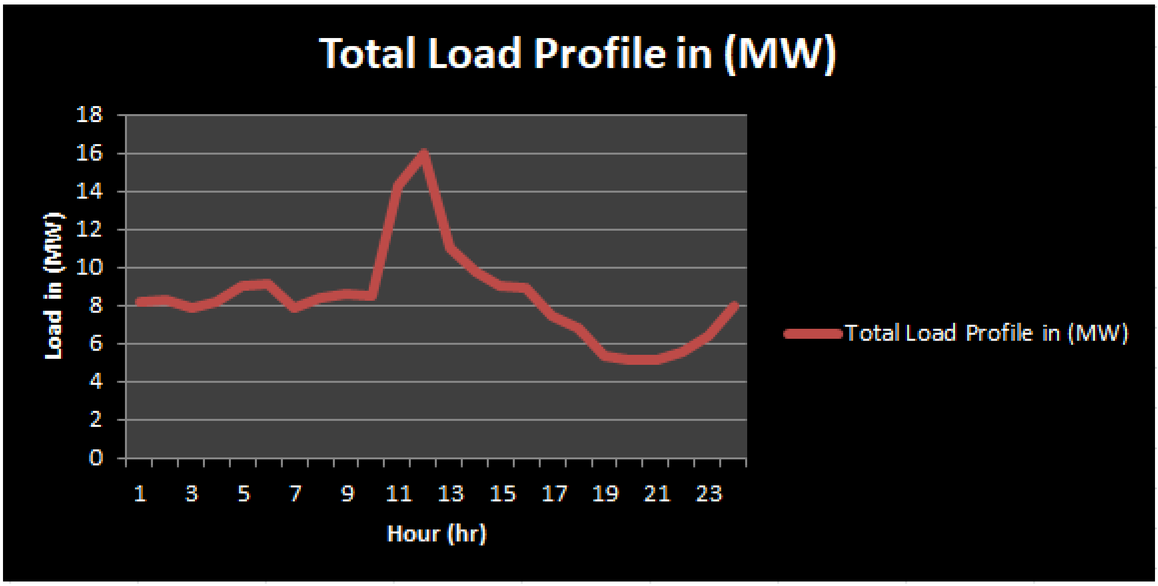

Figure 3.5 Total Load Profile (MW) of Dire Dewa Substation

Figure 3.4 and Figure 3.5 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 11:00 AM to 13:00 pM day time (due to the desert area most customers, which are used to Air condition and ventilator) which is 16.01 MW.

3.4 Major Cause of Power Interruption in the existing distribution system

According to IEEE100-1992, an interruption to service is the isolation of an electrical load from the system supplying that load, resulting from an abnormality in that system. The abnormality in the system can either be a malfunction of a system component, a fault or a system operation due to maintenance or repair. Interruptions, independent from the cause, are generally undesired, as they leave energy unserved and customers without service. Most of the time, interruptions occur because the system is reacting to a fault. A fault or short-circuit is defined by IEEE100-1992 as an abnormal connection of relatively low impedance, whether made accidentally or intentionally, between two points of different potential [35],

At Dire Dewa substation, major faults occurring frequently are short circuit, earth fault, blackout, system 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 [36]. 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 [37].

There are many principal causes of electrical failure; such as dust and dirt accumulation, moisture, lose connections, and friction of moving parts, aging of conductors, clearance from trees and limbs and structures, equipment over loading, frequency and so on. An effective maintenance program should aim to minimize these effects by keeping equipment clean and dry, keeping connections tight.

Before considering observational data, it is expedient to mention various sources of interruptions in the existing substations are:

Fault: The main cause of interruption for Dire Dawa distribution network is the fault .out of interruption recorded 79.6 % is due to fault. The fault in this network is due to different contributing factor like wind condition, tree movement during wind, insulation failure on overhead line, and protection equipment failure. The fault can be reduced tree trimming, constant monitoring of insulation, cable replacements can reduce faults. Temporary faults are harder to point.

Storms and Weather: Longer circuits lead to more interruptions. Dire Dawa distribution systems consist of only six radial arranged feeder which covers several kilometer distance. Even in one radial system above one hundred transformer were installed with only one auto recloser at the initial of feeder. Due to this issue the number of interruption and duration increased.

Especially for permanent short circuit the problem become head ache since they use isolator for later section they check each isolator to identify the location of fault.

Circuit Exposure and Load density: Longer circuits lead to more interruptions. Dire Dawa distribution system consist of only six radial arranged feeder which covers several kilometer distance. Even in one radial system above one hundred transformer were installed with only one auto recloser at the initial of feeder. Due to this issue the number of interruption and duration increased. Especially for permanent short circuit the problem become head ache since they use isolator for later section they check each isolator to identify the location of fault.

Supply Configuration: The distribution supply greatly impacts reliability. Long radial circuits provide the poorest service. A distribution system can be reconfigured by changing the location of the normally open switches, effectively changing the allocation of the customers and the flow of power for the effective feeders. But Dire Dawa network is not mesh or ring so that it is no option to get power the main feeder is interrupted. According to the data collected from the Dire Dewa 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

Table 3.7 Frequency Interruptions from 2017/18 G.C to 2018/19 G.C

Feeder Name	2017/18 G.C			2018/19 G.C		
	Unplanned	Planned	Total	Unplanned	Planned	Total
F 1	351	119	470	391	87	478
F2	304	76	380	300	53	353
F3	531	128	659	433	62	495
F4	422	199	621	505	57	562
F5	280	101	381	245	69	314
F6	23	15	38	26	10	36
Total	1911	638	**2549**	1900	338	**2238**

Table 3.8 Duration Interruptions from 2017/18 G.C to 2018/19 G.C

Feeder Name	2017/18 G.C			2018/19 G.C		
	Unplanned	Planned	Total	Unplanned	Planned	Total
F1	166:70	44:49	211:19	140:52	32:20	172:72
F2	59:38	43:51	102:89	97:45	12:05	109:5
F3	274:87	87:50	362:37	207:54	35:95	243:49
F4	247:56	67:83	315:39	210:304	27:08	237.38
F5	132:55	54:25	186:80	86:91	25:46	112:37
F6	96:50	33:70	130:2	185:63	8:79	194:42
Total	977:56	331:28	**1308:84**	928:35	141:53	**1069:88**

Table 3.9 Average Frequency Interruptions and Average Duration Interruptions Per Year

Feeder Name	Frequency Interruption (Int/Year) 2017/18 G.C to 2018/19 G.C			Duration Interruption (Hour/Year) 2017/18 G.C to 2018/19 G.C		
	Unplanned	Planned	Total	Unplanned	Planned	Total
F1	371	103	474	153:61	38:35	191:96
F2	302	64.5	366.5	78:42	27:78	106:2
F3	482	95	577	241:21	61:73	302:94
F4	463.5	128	591.5	228:93	47:46	276:39
F5	262.5	85	347.5	109:73	39:86	149:59
F6	24.5	12.5	37	141:07	21:25	162:32
Total	1905.5	488	**2393.5**	952:97	236:43	**1189:4**

Table 3.10 Average Interruption duration and frequency of different faults of 2017/18 to 2018/19

Feeder Name	PEF		TEF		PSC		TSC		OP	
	FER	DUR	FER	DUR	FER	DUR	FER	DUR	FER	DUR
F1	45	45.85	103.5	2:64	76.5	101:41	146	3:74	103	38:35
F2	48	43:97	147.5	3:80	63.5	29:52	43	1:15	64.5	27:78
F3	88	119:40	185	5:14	86	113:06	123	3:14	95	61:73
F4	121.5	143:05	147	5:27	89	76:70	106	3:62	128	47:46
F5	57.5	64:17	83.5	3:02	40	39:87	81.5	2:71	85	39:86
F6	8.5	70:98	5.5	2:29	6	67:39	4.5	0:12	12.5	21:25
Total System	368.5	487:42	672	22.16	361	427:95	504	14:48	488	236:43

In Table 3.10, where; PEF is a distribution permanent earth fault, PSC 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 3.11 Percentage of the cause of average duration and frequency of interruption of different faults

Feeder	PEF		TEF		PSC		TSC		OPR	
	%FER	%DUR	%FER	%DUR	%FER	%DUR	%FER	%DUR	%FER	%DUR
F1	10.61	23.88	21.84	1.38	16.12	52.82	30.8	1.95	21.73	19.97
F2	13.10	41.40	40.25	3.58	17.33	27.79	11.73	1.08	17.60	26.15
F3	15.25	39.48	32.06	1.70	14.91	37.38	21.34	1.04	16.46	20.41
F4	20.54	51.81	24.85	1.91	15.05	27.78	17.92	1.31	21.64	17.19
F5	16.55	42.89	24.03	2.02	11.51	26.65	23.45	1.81	24.46	26.64
F6	22.97	43.81	14.86	1.41	16.22	41.59	12.16	0.07	33.78	13.12
Average	15.4	41	28.1	1.9	15.1	36	21	1.2	20.4	19.9

Table 3.12 and Table 3.13; shows as the percentage of each of the cause of fault in Dire Dewa Substation.

Table 3.12 Percentage Average Interruption Frequency of each type of faults

Causes	PEF	TEF	PSC	TSC	OPR
% Frequency (Int/Year)	15.4	28.1	15.1	21	20.4

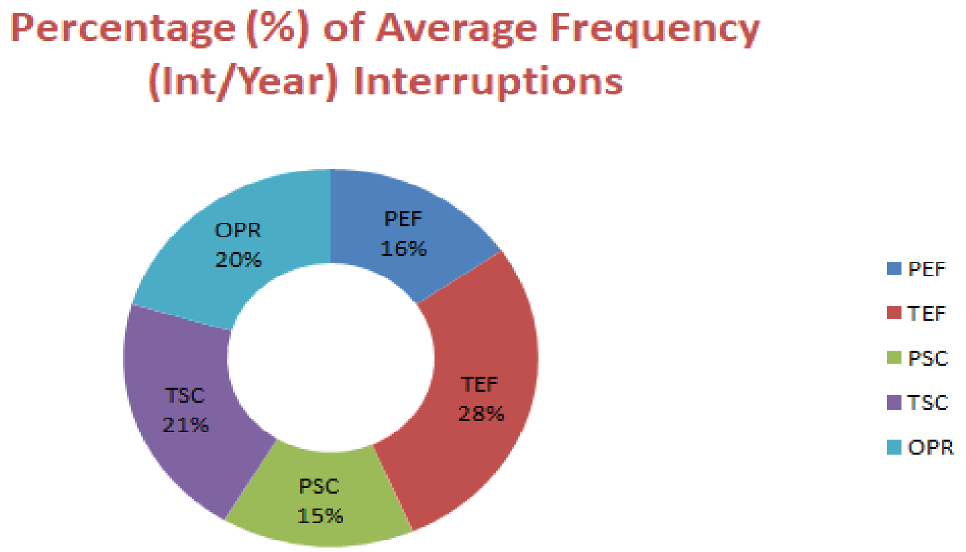

Figure 3.6: Percentage of Average Frequency Interruptions of overall system of Dire Dewa Substation.

From the above Pie chart in Figure 3.6 shows that 28% of the interruption frequency is due to the temporary earth fault, and 21% are due to a distribution temporary short circuit fault, 20% a distribution operation and maintenance, 15.1% is permanent short circuit fault.

Table 3.13: Percentage Average Duration Interruptions of each type of Fault

Causes	PEF	TEF	PSC	TSC	OPR
%Dur(Hr)	41	19	36	12	19.9

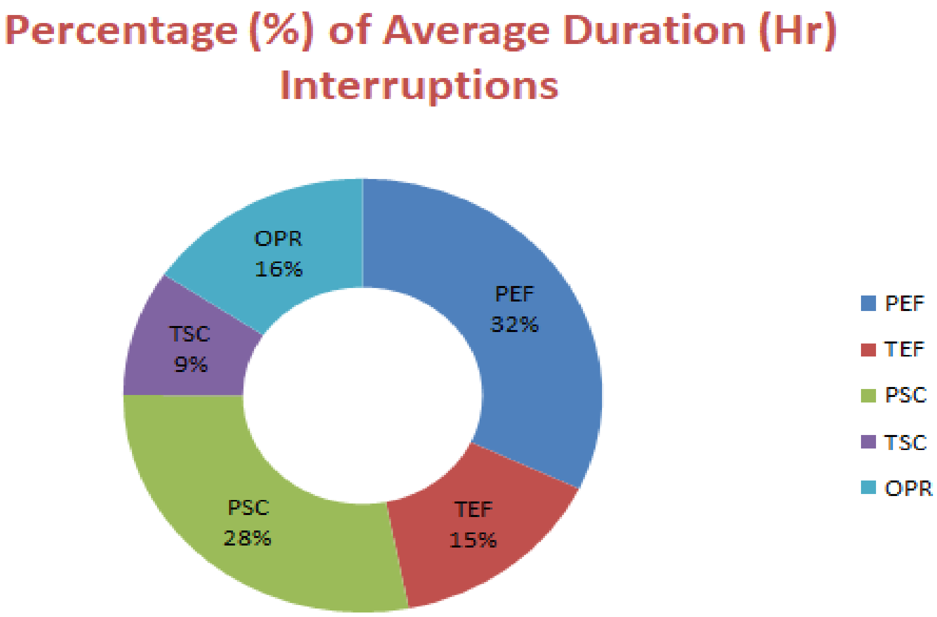

Figure 3.7 Percentage of Average Duration Interruptions of overall systems of Dire Dewa Substation

3.5 Distribution Reliability Indices Calculation

As one object of this study is to provide a more adopted method for determining distribution network reliability, this part of the study used IEEE1366 indices [38] to evaluate the reliability indices of Dire Dawa distribution system. The availability of power for customers from this substation is performed on the medium voltage side of the customer transformers (15kV). The reliability is highly affected by outages occurred on the customer side secondary distribution lines which unable to collect data for analysis due to lack of resource, lack of organized data and advanced technology at the substation to view the performance of the customer side secondary distribution network. The utilities commonly use the following reliability indices for frequency and duration to quantify the performance of their systems [39]. 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 recorded data given in Table 3.7 and 3.8 we can calculate the reliability indices for 2017/18 to 2018/19 G.C and the average of the two years. Hence, the results are shown in Table 3.14, Table 3.15 and Table 3.16 respectively.

Table 3.14: Computed Reliability Indices of 2017/18 Dire Dewa Substation I

Feeder	SAIFI	SAIDI	CAIDI	ASAI	ASUI	EENS(MWh)	AENS
F1	470	211	0.45	0.98	0.02	1263.89	0.121
F2	380	103	0.27	0.99	0.01	595.34	0.059
F3	659	315	0.55	0.96	0.04	1799.14	0.208
F4	621	362	0.51	0.96	0.04	3049.20	0.181

F5	381	187	0.49	0.98	0.02	837.76	0.108
F6	38	130	3.42	0.99	0.01	70.2	0.074
Average	424.8	218	0.51	0.98	0.02	1269.26	0.125

Table 3.15: Computed Reliability Indices of 2018/19 Dire Dewa Substation I

Feeder	SAIFI	SAIDI	CAIDI	ASAI	ASUI	EENS(MWh)	AENS
F1	478	173	0.36	0.98	0.02	889.22	0.085
F2	353	110	0.31	0.99	0.01	495	0.049
F3	495	237	0.49	0.97	0.03	1129.72	0.131
F4	562	244	0.42	0.97	0.03	2204.1	0.130
F5	314	112	0.36	0.99	0.01	604.8	0.078
F6	36	194	5.39	0.98	0.02	44.62	0.047
Average	373	178.3	0.48	0.98	0.02	894.58	0.087

3.16: Computed Reliability Indices the average of two years at Dire Dewa Substation

Feeder	SAIFI	SAIDI	CAIDI	ASAI	ASUI	EENS(MWh)	AENS
F1	474	192	0.41	0.98	0.02	1076.56	0.103
F2	366.5	106.5	0.29	0.99	0.01	545.17	0.054
F3	577	276	0.52	0.965	0.035	1464.43	0.170
F4	591.5	303	0.47	0.965	0.035	2626.65	0.156
F5	347.5	149.5	0.43	0.985	0.015	721.28	0.093
F6	37	162	4.41	0.985	0.015	57.41	0.061
Average	398.9	198.2	0.50	0.98	0.02	1081.92	0.106

In this thesis, focus is given only on Dire Dewa substation I, the city feeder line four (F4) has more frequency and duration interruptions than other feeders in the existing substation.

Table 3.17: Computed Reliability Indices of Dire Dewa City Feeder Line Four (F4) for year 2017/18-2018/19 G.C.

Feeder Name (F4)	Reliability Indices	2017/18 G.C	2018/19 G.C	Average
	SAIFI	621	562	591.5
	SAIDI	362	244	303
	CAIDI	0.51	0.42	0.465
	ASAI	0.98	0.97	0.975
	ASUI	0.04	0.03	0.035
	EENS	3049.20	2204.1	2626.65
	AENS	181	0.130	90.565

3.5.1 Comparison of the calculated values of reliability indices with benchmarks

Reliability benchmarks are the standards against which analyzed or measured reliability is judged. The purposes of reliability benchmarks are to define minimum average reliability performance, by feeder type, for a distribution network and provide a basis against which a distribution network service provider's reliability performance can be assessed.

The benchmarks were calculated using the IEEE Guide for electric power distribution reliability indices – IEEE Standard 1366-2003. The standards are given in order to provide a justification and give acceptable margin for the reliability performance of distribution networks. Based on IEEE Guide, reference [40] highlighted the benchmarks for nine countries computed for power distribution reliability as shown in Table 3.18 while the authors included the results from this work in the table too.

This thesis also focuses on the customer oriented reliability indices and energy oriented indices.

Table 3.18: Comparisons of SAIFI and SAIDI values with different countries [41]

Countries	SAIFI(Int./Year/Customer)	SAIDI(Hr./Year/Customer)
United iStates iof iAmerica	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 iKingdom	0.8	1.5
Germany	0.5	0.383
Netherland	0.3	0.55
Ethiopia	20	25
D.D iSubstation I Feeder 4(F4)	591.5	303

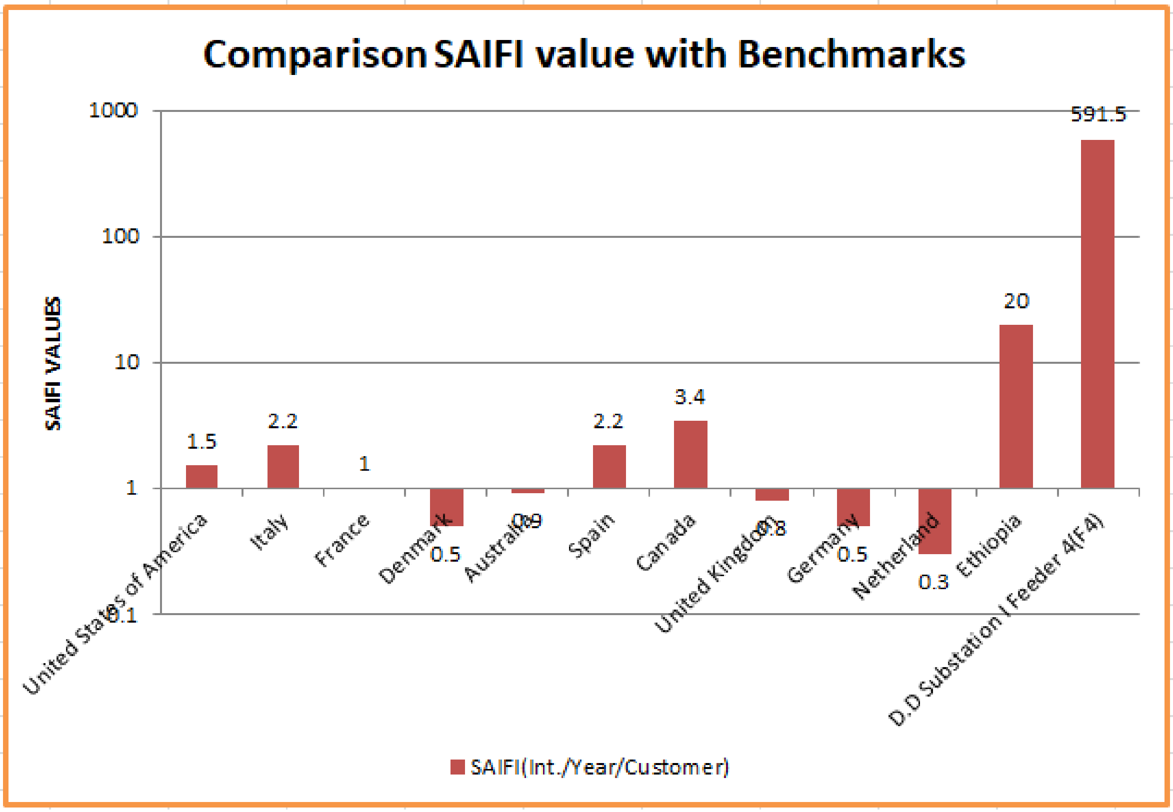

Figure 3.8: Comparison of SAIFI values with different countries standards

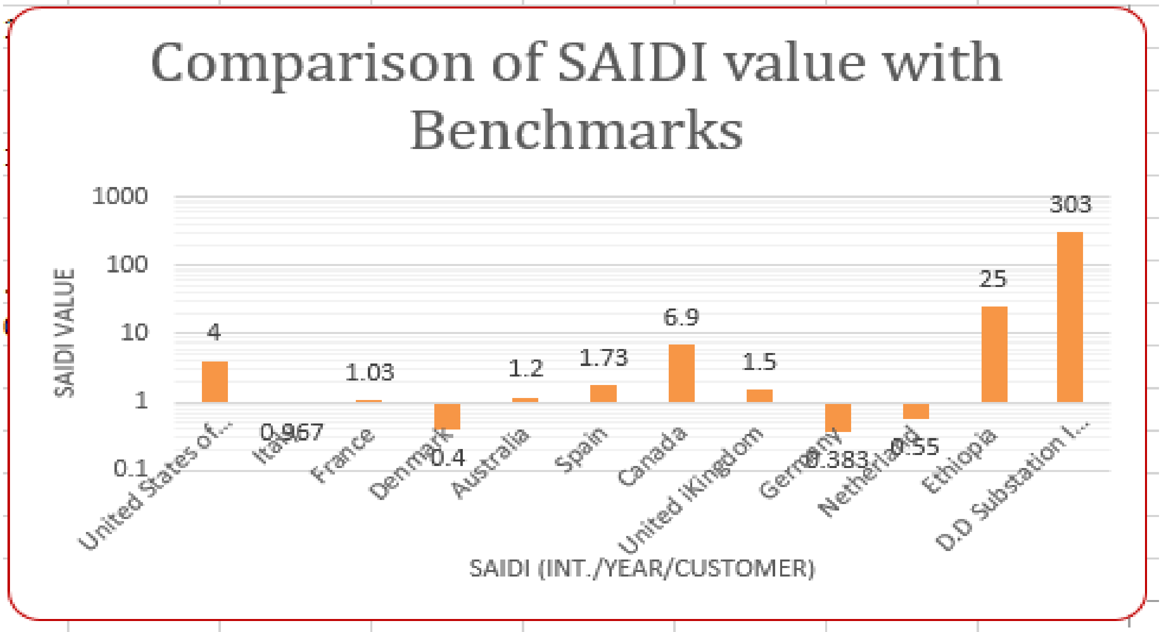

Figure 3.9: Comparison of SAIDI values with different countries standards

3.6 Outage Cost Evaluation of Dire Dawa Substation I Feeder Line

Common approach used in quantifying the worth or benefit of electric service reliability is to estimate the customer costs associated with power interruptions 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 Dire Dawa city are approximately broke up 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, Dire Dawa 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 3.19: Ethiopia Electricity tariff (Birr/KWh) Energy Tariff amendment study according to consumers class

Tariff amendment		As of Dec. 18 onward	As of Dec. 19 onward	As of Dec. 20 onward	As of Dec. 21 onward
Tariff Category	kwh/month	Birr/kwh	Birr/kwh	Birr/kwh	Birr/kwh
Residential tariff block					
1st block	Up to i0 ikwh	0.2730	0.2730	0.2730	0.2730
2nd block	Up to 100 ikwh	0.4591	0.5617	0.6644	0.7670
3rd block	Up to 200 ikwh	0.7807	1.0622	1.3436	1.6250
4th block	Up to 300 ikwh	0.9125	1.2750	1.6375	2.0000
5th block	Up to 400 ikwh	0.9750	1.3833	1.7917	2.2000
6th block	Up to 500 ikwh	1.0423	1.4965	1.9508	2.4050
7th block	Above 500 kwh	1.1410	1.5877	2.0343	2.4810
General Tariff					
Flat Rate		1.0352	1.3982	1.7611	2.1240

Low Voltage Industry Tariff				
Flat Rate	0.8161	1.0544	1.2927	1.5310
Demand Charge irate	50.0000	100.00	150.0000	200.0000
Medium Voltage Industry Tariff. 15kv & 33kv				
Flat Rate	0.6047	0.8008	0.9969	1.1930
Demand Charge rate	36.8850	73.7700	110.6550	147.5400
High Voltage Industry Tariff. Above 66kv				
Flat Rate	0.5174	0.6540	0.7911	0.9280
Demand Charge rate	21.9100	43.8200	65.7300	87.6400
Street Light Tariff				
Flat Rate	1.0352	1.3982	1.7611	2.1240
Bulk Supply Tariff				
Demand Charge rate perikw	39.2908	78.5815	117.8723	157.1600
Generation Tariff. Monthly per kwh	0.2218	0.4435	0.6653	0.8870

Based on Table 3.19, the interruption cost in the study area that is in Dire Dawa substation can be calculated using the formula below;

Interruption Cost = Unsupplied Energy (in KWh) X 0.4409 ETB\KWh (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 [42]. For Dire Dawa city feeder (F4) in the year 2017/18 has 3049.20 MWh unsupplied Energy from Table 3.17; then, Interruption cost is calculated as:

$$Interruption\ Costs = 3049.20KWh \times 1000 \times 0.4409\, {}^{ETB}/_{KWh} = 1{,}344{,}392.28ETB$$

By the same procedure the interruption cost for the 2 years, that is, from 2017/18 to 2018/19G.C is calculated and summarized in Table 3.20. Based on the exchange rate of the Commercial Bank of Ethiopia (CBE) on 23 April 2020, (l USD = 33.353 ETB).

Table 3.20: Summary of estimated interruption cost from 2017/18 to 2018/19 G.C in Dire Dawa City substation I feeder line four (F4)

Year	EENS(MWh)	Interruption Cost (ETB)	Interruption Cost (USD)
2017/18 G.C	3049.20	1,344,392.28	40305.343
2018/19 G.C	2204.1	971,787.69	29136.44
Average	2626.65	1,158,089.99	34722.21

As shown from the table 3.20, the average of two year's interruption cost due to the unsold energy of the Dire Dawa city substation I feeder line four (F4) is 1,158,089.99 ETB or 34,722.21 USD per year.

3.7 Data Analysis

Based on the data collected from Dire Dawa substation I we can summarize the power reliability indices of the Dire Dawa city feeder line F4 in the following manner:-

SAIFI of the overall system as shown in Table 3.17 is 591.5 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 Germany standard, it is much greater than the maximum limit [43]. This clearly indicates that there is serious reliability problem in the existing Dire Dawa city feeder line, F4.

SAIDI of the overall system from Table 3.17 is 303 hours per customer per year. This shows that every customer experiences 303 Hr. interruption per year. This indicates that there is great reliability problem in the existing Dire Dawa city feeder line, F4. As per the Ethiopian Electrical Agency's (EEA), the SAIDI value should not exceed 25 hours per customer per year [41]. The permissible SAIDI value in Germany is 0.383 hours per customer per year [41].

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 3.17 the power supply of the overall system for Dire Dawa city feeder, F4 is 0.965 (96.5%) available. However, this value is still not good enough since the ASAI value should be greater than 99.98% as per Ethiopian Electrical Agency's standard [41].

ENS: It shows the unsupplied energy or unsold energy of each feeder. From the Table 3.20 The average unsold energy for Dire Dawa city feeder, F4 was 2626.65 MWh per year. AENS: This index shows the average energy not supplied per customer by the system. From the Table 3.17 the overall system for Dire Dawa city feeder, F4 has an AENS value of 0.156 MWh per customer. Due to power interruption per year for the Dire Dawa city feeder, F4 the average cost of unsold energy is 1, 159,089.99 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 Dire Dawa city feeder line, F4 does not meet the requirements set by the Ethiopian Electric Agency (EEA). The power reliability indices of Dire Dawa city feeder line, F4 is not a good performance as compared to the international reliability indices of best-experienced countries. In the study area of city feeder line, F4 has high unavailability of services in the system. The impact of planned and unplanned outages in the existing power grid of Dire Dawa city feeder line, F4 has more loss of unsupplied energy.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 INRTODUCTION

This chapter presents the explanation of the modeling and simulation of the existing system with different mitigation alternative cases to improve the system reliability of the Dire Dawa city feeder line (F4) at a reasonable cost. Different cases have been analyzed by ETAP 16 Software simulation. The simulation focuses on evaluating the impact of using reclosers and reconfiguration of the feeder on the reliability of the system.

These are acceptable for simple radial systems and more extended indices have to be used for general distribution systems. In this thesis, the following alternatives which may enhance reliability of Dire Dawa City distribution system (feeder four, F4) shall be considered:

I. Assessing of the DD distribution network

II. Change in the network configuration or reconfiguration of the distribution

III. Use of additional switches and protective devices

From the Beginning of existing system of Dire Dawa distribution (Substation I) design and calculating of the reliability indices in two years, this thesis has evaluated different mitigation technique to enhancement of system reliability at low cost. Many cases have been analyzed by computer simulation. The simulation focuses on evaluating the effects of using reclosers and reconfiguration of the feeder on reliability of Dire Dawa distribution system. The recloser increases for utilities to implement automatic back feed restoration, fault finding and fault isolation. Automatic reclosers are designed for uses both overhead distribution lines as well as distribution substation application for different voltage classes like 15KV, 27KV and 38KV [44].

4.2 Procedure for Distribution Reliability Analysis by ETAP Softwear.

The simulation output of reliability analysis is obtained by performing the following steps in ETAP12.6.0 software.

- Single line diagram of the existing system (DD City distribution at feeder four) has been designed on the working plane of the software.
- DD distribution (feeder four) reliability calculations has been specified and

entered.

- All switches and protection devices has been specified based on type and operation.
- Then run the reliability assessment of exiting network.

4.3 System Modeling by ETAP

The Electrical Transient Analysis Program (ETAP) is totally graphical Enterprise package that operates on different Microsoft Windows operating systems. It is the most Comprehensive analysis tool for the design and enhancement of power systems available.

Figure 4.1 shows the project editor view, with the reliability page open. The parameters used in designing, assessment analysis and enhancement for reliability of any system are those shown on this page. Using its standard offline simulation modules, ETAP can utilize real-time operating data for advanced monitoring, real-time simulation, optimization, energy management systems and high speed intelligent load shedding. ETAP can be combining the electrical, logical, mechanical and physical attributes of system materials in the similar database.

To predict the reliability indices of Dire Dawa city feeder line four (F4) distribution system, values of failure rates and mean time to repair for each component of static loads are necessary. To estimate the failure rate of the line per kilometer, the total number of outages should be divided by the feeder length (kilometers) as indicated in equation (4.1). The average mean time to repair (MTTR) each failure is computed using equation (4.2).

$$\lambda = \frac{Total\ number\ of\ Interruptions}{(Total\ feeder\ length)(Number\ of\ years)} \qquad \left({}^{Int.}/_{Km.\,year}\right) \qquad (4.1)$$

$$MTTR = \frac{Total\ Repair\ Time}{Total\ number\ of\ Interruption} \qquad \left({}^{Hr.}/_{Int.}\right) \qquad (4.2)$$

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

$$\lambda = {}^{591.5}/_{182} = 3.25 \left({}^{Int.}/_{Km \times year}\right)\ and\ MTTR = {}^{303}/_{591.5} = 0.5123\left({}^{Hr.}/_{Int.}\right)$$

To estimate the failure rate of a component ETAP 12.6.0 uses a combination of active (λ_A) and passive (λp) 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 (λp) 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, λp is assumed as zero in the model.

Based on reliability assessment result place and number of automatic re-closers are chosen by considering

I. Number of customers of the feeder

II. Total lengths of feeder four(F4)

III. Sensitivity of the area like industrial, commercial and offices

IV. Economic benefits as much as possible low cost both utility and customers

Reliability indices SAIFI, SAIDI and cost benefits would be the main drivers for comparison of the alternatives using heuristic technique. For this thesis, Nu-Lec 15kv outdoor pole mounted, automatic circuit recloser, is selected because it is available on the ETAP software library, allows protection coordination with other devices also it is applicable in the real world. Nu-Lec industries are Schneider electrics core business unit for recloser technology [45].

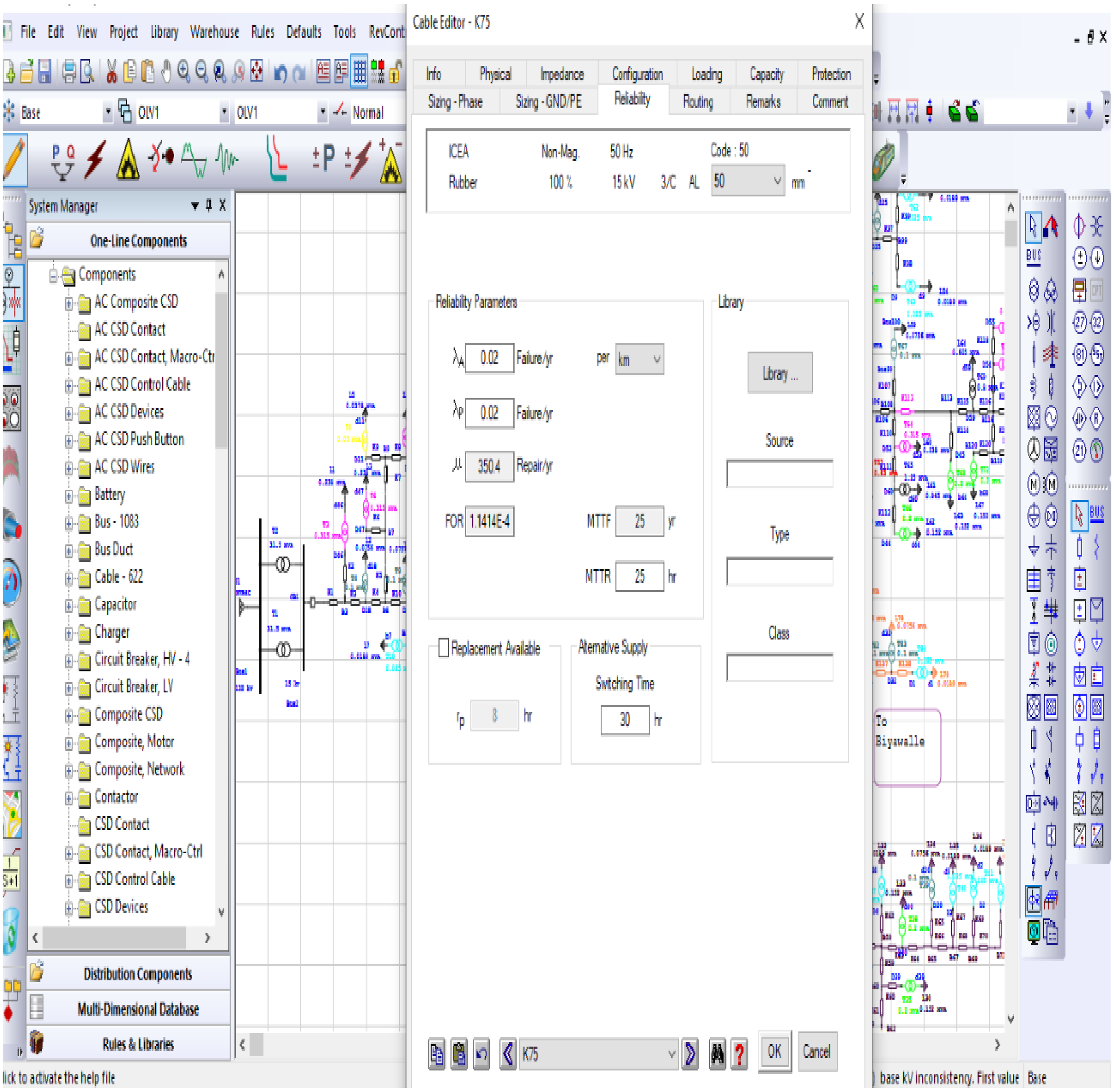

Figure 4.1: Window of ETAP 16.0 Software existing system of reliability page opened.

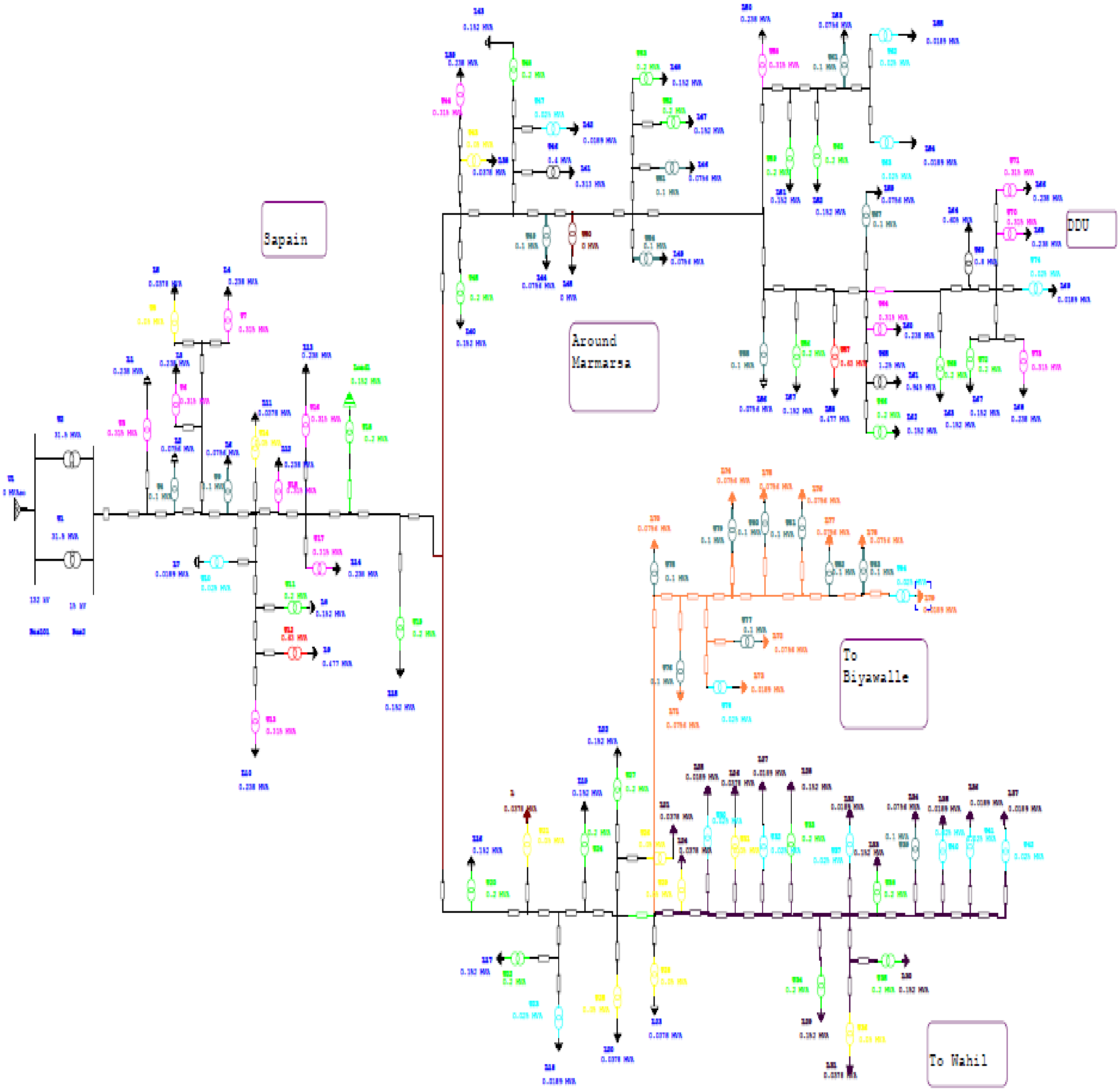

Figure 4.2: Single Line Diagram of the Existing System.

Table 4.1: Simulation result of reliability indices for existing system.

Reliability Indices	Simulation Result
SAIFI(fr/customer.yr)	591.5
SAIDI(hr/customer.yr)	303
CAIDI(hr/customer Interrupion)	0.465
ASAI (pu)	0.975
ASUI (pu)	0.035
EENS (Mwhr)	2626.65
ECOST (USD/yr)	34722.21

4.4. Simulation and Result analysis of feeder reconfiguration for Dire Dawa substation feeder line four (F4)

4.4.1. Case I: By Using One Recloser

When placing one recloser at line K27 or between two buses (B27-B29) the output or the reliability indexes (SAIFI, SAIDI, ENNS…) of DD distribution had reduce. Always when we insert recloser and other protection device, we consider different factors like length of conductor, type of load, sensitivity of area and compare the reliability index value.

As can be seen from the table 4.2, 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 591.5 to 343.03 (42% system reliability has improved), the annual outage duration has been reduced from 303 to 220.28 hours (27.3% reduction in outage duration) as compared with the existing system. In Case-1 the reliability of Dire Dawa city substation feeder four (F4) is improved by 42%, 27.3% and 58.19 % for SAIFI, SAIDI and EENS respectively. And also the interruption energy cost for (Case-1) can be calculated as, Interruption cost =1098.2 KWh x 1000 x 0.4409 ETB/ kWh = 484196.38. Therefore the interruption energy cost has been decreased from 1, 158,089.99 to 484, 196.38 ETB per year.

4.4.2. Case II: Using Two Recloser

Table 4.2 (Case -2), shows the reliability improvement of using two Reclosers in the feeder. As can be seen from the Table 4.2, 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 591.5 to 275.48 (53.5% SAIFI has been improved), and the annual outage duration has been reduced from 303 to 166.65 hours (45% SAIDI and 68% EENS) has been improved as compared to base years' average. The interruption energy cost for (Case-2) can be estimated as;

Interruption cost = 840.528 MWh x 1000 x 0.4409 ETB/ kWh = 370, 588. 795.

Therefore the interruption energy cost has been decreased from 1, 158,089.99 to 370, 588.795 ETB per year.

4.4.3 Case III: Using One Tie Switch and New Substation

In this Case, Dire Dawa 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 Dire Dawa city feeder four (F4) 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 Dire Dawa city feeder line (F4). The capacity of Dire Dawa diesel generator substation is assumed to be 28 % (9.68/35*100%=28%) of the peak demand of the Dire Dawa city. Furthermore, increasing power reliability on the city feeder line the recloser R1 has been placed on the outgoing line of the Dire Dawa city to Biyawalle Woreda and this has been reduced the impact of transient faults on the distribution reliability of the system.

In case-3 network reconfiguring of the feeder with the new substation and normally open tie switch has been added. The normally open tie switch separate the feeder load (based on number of customers) almost in to two equal parts, and using the tie switch paves the way to transfer the load from old substation to the new substation during outage condition. This has solved the problems related with overloads. So based on such condition the reliability indexes, as shown clearly in Table 4.3 the expected number of outages per year is reduced from 591.5 to 177.45 (70% SAIFI has been improved). And also the annual outage duration has been reduced from 303 to 86.325 hours (71% SAIDI and 83.4% EENS) has been improved. The interruption energy cost for (case-3) can be estimated as, Interruption cost =436.024 MWh x1000 x 0.4409 ETB/ kWh = 192, 242.981. Therefore the interruption energy cost has been decreased from 1, 158,089.99 to 192, 242.981 ETB per year.

4.4.4. Case IV: Using One Tie Switch, Two Reclosers and with New Substation

In Case-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 Dire Dawa diesel substation. The same thing considered for Recloser (Rec-1) which has been placed at 15KV feeder line side.

As can be seen from the Table 4.2, 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 591.5 to 106.47 (82% SAIFI has been improved), and the annual outage duration has been reduced from 303 to 51.51 hours (83% SAIDI and 91.91%) has been improved as compared with the selected base years.

In the same case the interruption energy cost for (case-4) can be estimated as, Interruption cost = 212.416 kWh x1000 x0.4409 ETB/ kWh = 93,654.21ETB. Therefore the interruption energy cost has been decreased from 1,158,089.99 to 93,654.21 ETB per year.

Table 4.2: Summary of the results of reliability improvement for all Cases

Reliability Indices	Cases				
	Existing	Case I	Case II	Case III	Case IV
SAIFI(fr/cus.yr)	591.5	343.07	275.048	177.45	106.47
SAIDI(hr/cus.yr)	303	220.28	166.65	86.325	51.51
EENS(Mwhr/yr)	2626.65	1098.2	840.528	436.024	212.416
ECOST(USD/yr)	34722.21	14517.326	11111.108	5763.889	2807.969
% imp SAIFI	-	42%	53.5	70	82%
%imp SAIDI	-	27.3%	45%	71%	83%
%imp EENS	-	58.19%	68%	83.4%	91.91%
%imp ECOST	-	58.19%	68.%	83.4%	91.91%

4.5. 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 Cases. For Case -1, annual average unsold energy is reduced from 2626.65 to 1098.2 MWh per year as shown in Table 4.3. Therefore, the revenue saved due to reliability improvement can be estimated as follows.

The Revenue loss before improvement due to unsold energy is:

2,626,650 KWh/year x 0.4409 ETB/KWh = 1, 158, 089.99 ETB/year

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

$$\frac{[2626650-1098200]KWh}{year} \times 0.4409\, {ETB}/_{KWh} = 673893.605\, ETB$$

The investment cost can be calculated by using the cost of one outdoor high voltage recloser used to design the system in Case-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 23-April-2020, (l USD= 33.353 ETB), the cost of one 15 KV, 800A pole mounted outdoor Recloser is: 15, 000 x 33.353 = 500 295 ETB.

The Payback period is used as an important factor to evaluate the economic competiveness of the respective Cases. 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.

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

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

$$\text{Payback period} = \frac{500\ 295\ ETB}{673893.605\ ETB/year} = 0.742\ years\ payback\ time$$

Hence, the payback period indicates that it takes 0.742 years to get back the investment cost. In this Case-1, the reliability indices SAIFI and SAIDI have been reduced by about 42% and 27.3% respectively.

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

$$= \frac{[2{,}626{,}650 - 840528]KWh}{year} \times 0.4409 \frac{ETB}{KWh} = 787{,}501.19\ {}^{ETB}/_{year}$$

Investment Cost $= 2\ \times 15{,}000\ \times 33.353\ = 1{,}000590\ ETB$

$$\text{Payback period}\ = \frac{1{,}000{,}590\ ETB}{787{,}501.19\ {}^{ETB}/_{year}} = 1.27\ years\ payback\ time$$

In Case-2, the payback period shows that it takes 1.27 years to get back the investment cost and the reliability indices SAIFI and SAIDI have been reduced by 53.5% and 45% respectively.

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

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

$$= \frac{[\ 2{,}626{,}650\ - 436{,}024]KWh}{year} \times 0.4409\ {}^{ETB}/_{KWh} = 965847.0034\ {}^{ETB}/_{year}$$

In Case-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 2,601 KW when the power factor is 0.85.

Hence, the diesel generator operates for emergency case has fuel capacity 963.7 Litter/hr. For the price of diesel, which is equal to 0.56 USD/Litter (Petro prices in Ethiopia, June-18-2020). Then, 963.7 x 0.56 USD = 538.29 USD. According to the exchange rate of Commercial Bank of Ethiopia (CBE) on 23-April-2020, (l USD= 33.353 ETB), the cost of diesel generator operates per hour is; 538.29 x 33.353= 17,953.59 ETB. In Case-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 33.353= 1,000,590ETB) because of the cost of Tie- Switch similar to the Recloser cost. Then the total investment cost is: 17,953.59 ETB + 1,000,590 ETB = 1,018,543.59 ETB.

$$\text{Payback period} = \frac{1{,}000{,}590\ ETB}{965{,}847.0034\ ^{ETB}/_{year}} = 1.04\ years\ payback\ time$$

Hence, the payback period is 1.04 years. In this Case-3, the reliability of the system has been improved by 70%, 71% and 83.4% for SAIFI, SAIDI and EENS respectively.

For Case-4: The new 2.5 km feeder line cost mainly consists of material cost, labor cost, and transportation cost. The line should be 15 kV, 12 meter concrete pole, and three phase 95 mm2 AAC conductor with overhead triangular configuration. By dividing the total length (2500 meter) to the span length (50 meters) the total number of concrete poles are estimated to be about 50 (50 Concrete poles for 12 meters).

Table 4.3: Labor and Transport cost of MV line construction (EEU price list, 2011 E.C)

Distance	Labor Cost(ETB)	Transport Cost(ETB)	Total(ETB)
For 1 Km line construction	10, 725.12	1, 643.76	12, 368.88
For 2.5 Km line construction	26812.80	4109.40	30, 922.20

From the Table 4.3, the sum of labor and transport cost to construct 2.5 km medium voltage line is 30, 922.20 ETB.

Table 4.4: Summary of materials needed to construction the new line and their costs (EEU price list, 2011 E.C).

Stock No.	Materials	Unit	Unit Price	Amount	Total Cost
03-01-000	Insulator HT 18/5 mm^2 15KV	Each	439.30	204	89, 617.2
03-01-200	Insulator pin 18/5 for HT 15 KV	Each	510.82	204	104,207.3
04-04-920	AAC, All Aluminium Conductor 95 mm^2	MT	50.31	10, 200	513,162
09-01-680	Concrete Pole 12m	Each	4574.13	68	311,040.8

09-03-030	Cross arm type 4-48/202	Each	142.54	68	9, 692.72
09-03-430	Collars Big	Each	131.08	272	35653.76
09-09-670	15 KV Tie strap	Each	442.71	136	60,208.56
12-04-860	Long Bolt Galvanized 5/8" 40 Cm	Each	185.37	4	741.48
	Total Material Cost				**1, 124, 324**

As per the Ethiopian Electric Utility price List version 2011 E.C, the total materials cost needed to construct the new MV line (2.5 km) as shown in Table 4.5, is 1,124,324 ETB.

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

$$= \frac{(2626650 - 212416)\ KWh}{year} \times 0.4409\ ETB/KWh\ = 2{,}414{,}234\ ETB/year$$

$$\text{Payback period} = \frac{2{,}223{,}865.38\ ETB}{2{,}414{,}234\ ETB/year} = 0.92\ year$$

Table 4.5: Summary of estimated payback period for all cases

Cases	EENS (MWh)	Interruption Cost (ETB)	Investment Cost (ETB)	Annual RevenueSaved (ETB)	Payback period (year)
Existing	2626.65	1, 158, 089.985	0	-	0
Case 1	1098.2	480, 228.28	500, 295	673, 893.605	0.7424
Case 2	840.528	370588.795	1, 000, 590	787, 501.19	1.27
Case 3	436.024	192, 242.982	1, 018, 589.68	965, 847.0034	1.1
Case 4	212.416	93654.2144	2,674, 130.88	2, 414, 23	0.92

Table 4.5, clearly shows that the payback period of Case-1 (0.7424 year) is smallest compared with the other Cases, but as clearly shown in Table 4.3, the percentage reduction for SAIFI (42%) and SAIDI (27.3%) compared with the selected base years is minimum. In Case-2 (53.5% for SAIFI) and Case-3 (70% for SAIFI), the system reliability enhancement is not good enough as compared to Case Four (82% for SAIFI). But Case-2 and Case-3 the payback periods are more compared with Case-4. Case four has a bit better reliability indices but the payback period is only 0.92 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 Case-4 as the optimum one.

Table 4.6 below shows the comparison of the most commonly used reliability indices (SAIFI and SAIDI) of Dire Dawa substation feeder four, with the requirements of the Ethiopian Electric Agency (EEA) and the best-experienced countries in the world. As it is observed from Table 4.6, the SAIFI and the SAIDI have been improved by 82% and 83% respectively as compared with the base year's values.

Table 4.6: 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
United Kingdom		0.8	1.5
Germany		0.5	0.383
Ethiopia		20	25
	Existing	591.5	303
	Case 1	343.07	220.28
	Case 2	275.048	166.65
	Case 3	177.45	86.325
	Case 4	106.47	51.51

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATION

5.1. Conclusions

In this thesis work, evaluation of power reliability and improvement techniques for Dire Dawa city feeder line four (F4) 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 DD city substation feeder does not meet the requirements set by the Ethiopia Electric Agency (EEA). The average frequency of the interruptions the city feeder is 591.5 interruptions per customer per year (SAIFI). And also the average duration of the interruption is 303 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 2626.65 MWh per year. This results in a loss of around 1,158,089.99 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 DD city feeder line four F4 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 Cases have been proposed and analyzed for the implementation of reliability improvement in the study area. As the simulation result shows all Cases have different reliability improvement contribution on the city feeder with 1.16 to 3 years payback period investment cost. All Cases are tolerable in terms of the investment cost. But, to improve city power reliability indices more Case-4 is highly proposed.

By implementing Case-4 the overall reliability of the Dire Dawa city feeder linefour (F4) 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.

5.2. Recommendation

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.
- As this thesis is conducted on one feeder, doing reliability assessment analysis for whole part of the city is recommended.
- For better power reliability improvement of Dire Dawa 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.
- Dire Dawa 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.
- I highly recommended for Engineers to put their hands on solving such real time problems.

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Appendix

Appendix A

Table A-1: Dire Dawa 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 A-2: Reliability Parameters of Distribution System Components

Components	Failure rate (failure/year)	Repair time (hrs)
Lines per KM	0.065	5
Breaker 15KV	0.006	4
Breaker 132KV	0.0058	8
Transformer 132/15KV	0.01	168
Transformer 15/0.4 KV	0.015	200
Bus bars 132 KV	0.001	2
Bus bars 15 KV	0.001	2

Table A-3: Ethiopia Electric Utility Tariff for Electricity (ETB/KWh) Energy Tariff amendment study according to consumers class

Tariff amendment	As of Dec. 18 onward	As of Dec. 19 onward	As of Dec. 20 onward	As of Dec. 21 onward
Tariff Category kwh/month	Birr/kwh	Birr/kwh	Birr/kwh	Birr/kwh

1. Residential tariff block				
1.1 1st block Up to 50 kwh	0.2730	0.2730	0.2730	0.2730
1.2 2nd block Up to 100 kwh	0.4591	0.5617	0.6644	0.7670
1.3 3rd block Up to 200 kwh	0.7807	1.0622	1.3436	1.6250
1.4 4th block Up to 300 kwh	0.9125	1.2750	1.6375	2.0000
1.5 5th block Up to 400 kwh	0.9750	1.3833	1.7917	2.2000
1.6 6th block Up to 500 kwh	1.0423	1.4965	1.9508	2.4050
1.7 7th block Above 500 kwh	1.1410	1.5877	2.0343	2.4810
2. General Tariff				
2.1 Flat Rate	1.0352	1.3982	1.7611	2.1240
3. Low Voltage Industry Tariff				
3.1 Flat Rate	0.8161	1.0544	1.2927	1.5310
3.2 Demand Charge rate	50.0000	100.00	150.0000	200.0000
4. Medium Voltage Industry Tariff. 15kv & 33kv				
4.1 Flat Rate	0.6047	0.8008	0.9969	1.1930
4.2 Demand Charge rate	36.8850	73.7700	110.6550	147.5400
5. High Voltage Industry Tariff. Above 66kv				
5.1 Flat Rate	0.5174	0.6540	0.7911	0.9280
5.2 Demand Charge rate	21.9100	43.8200	65.7300	87.6400
6. Street Light Tariff				
6.1 Flat Rate	1.0352	1.3982	1.7611	2.1240
7. Bulk Supply Tariff				
7.1 Demand Charge rate per kw	39.2908	78.5815	117.8723	157.1600
7.2 Generation Tariff. Monthly per kwh	0.2218	0.4435	0.6653	0.8870

Appendix B

Apendix B-1: Line Data for the selected Feeder (F4)

Line Name	Length of Line			Line Name	Length of Line		
	From	To	KM		From	To	KM
K1	B3	Bus 2	0.41	K50	B51	B49	1
K2	B4	B3	0.2	K51	B52	B51	0.05
K3	B5	B3	0.1	K52	B53	B51	2.1
K4	B6	B5	0.4	K53	B54	B53	1.3
K5	B7	B6	0.3	K54	B55	B53	4.45
K6	B7	B8	0.2	K55	B56	B55	0.65
K7			0.45	K56	B57	B55	1.6
K8	B10	B9	0.25	K57	B57	B58	0.15
K9	B9	B11	0.25	K58	B59	B57	0.35
10	B12	B6	1	K59	B59	B60	0.25
K11	B13	B12	0.2	K60	B61	B60	0.05
K12	B13	B14	0.15	K61	B60	B62	0.55
K13	B14	B15	0.05	K62	B63	B59	2.8
K14	B14	B16	0.3	K63	B64	B59	1.65
K15	B17	B16	0.2	K64	B65	B64	2.55
K16	B16	B18	0.25	K65	B66	B65	0.2
K17	B19	B18	0.05	K66	B67	B65	0.25
K18	B18	B20	0.1	K67	B68	B67	0.05
K19	B21	B13	0.4	K68	B69	B67	1
K21	B22	B13	0.45	K69	B70	B69	0.35
K22	B23	B22	0.25	K70	B71	B69	8.7
K23	B24	B23	0.4	K71	B72	B71	0.6
K24	B23	B25	0.4	K72	B74	B73	0.1
K25	B26	B23	0.05	K73	B75	B74	0.2
K26	Bus 7	B26	0.25	K74	B73	B76	0.3
K27	B27	B26	0.4	K75	B77	B73	0.25
K28	B27	B28	0.35	K76	B78	B77	0.35
K29	B29	B27	0.1	K77	B79	B78	0.2
K30	B73	B29	0.35	K78	B80	B78	0.15
K31	B29	B30	0.5	K79	B81	B80	0.05
K32	B31	B30	0.35	K80	B82	B80	0.05
K33	B32	B31	0.15	K81	B83	B77	0.05
K34	B33	B31	0.2	K82	B84	B83	0.1
K35	B33	B34	0.3	K83	B85	B84	0.45
K36	B34	B35	0.05	K84	B86	B85	0.1
K37	B34	B36	0.15	K85	B87	B86	0.05
K38	B37	B33	0.05	K86	B88	B86	0.3
K39	B38	B37	0.15	K87	B89	B88	0.15
K40	B39	B37	0.15	K88	B90	B88	0.15
K41	B39	B40	0.25	K89	B85	B90	0.2
K42	B41	B39	0.2	K90	B92	B85	0.15
K43	B44	B41	0.1	K91	B92	B93	0.05
K44	B45	B41	0.1	K92	B94	B93	0.05
K45	B46	B39	2.85	K93	B94	B95	0.05
K46	B46	B47	0.15	K94	B96	B94	0.3

K47	B48	B46	2.05	K95	B96	B97	0.15
K48	B49	B48	0.15	K96	B96	B98	0.7
K49	B50	B49	0.05	K97	B99	B98	0.1
K98	B99	B101	0.15	K118	B118	B117	0.35
K99	B100	B99	0.15	K119	B116	B119	0.2
K100	B92	B102	0.49	K120	B119	B120	0.2
K101	B102	B103	0.1	K121	B121	B119	0.2
K102	B104	B102	0.05	K122	B122	B116	0.1
K103	B104	B105	0.05	K123	B123	B46	4.2
K104	B106	B104	0.55	K124	B124	B123	4.2
K105	B106	B107	0.05	K125	B124	B125	0.15
K106	B108	B106	0.2	K126	B126	B124	0.4
K107	B109	B108	0.05	K127	B126	B127	2
K108				K128	B128	B127	0.1
K109				K129	B127	B129	2.45
K110	B108	B110	0.3	K130	B131	B126	5.4
K111	B110	B111	0.2	K131	B132	B131	0.25
K112	B111	B112	0.2	K132	B133	B131	0.95
K113	B113	B108	0.2	K133	B134	B133	0.1
K114	B113	B114	0.2	K134	B135	B133	1.8
K115	B115	B113	0.15	K135	B136	B135	0.4
K116	B116	B115	0.05	K136	B137	B135	0.6
K117	B117	B116	0.1	K137	B138	B137	5.2
				K138	B139	B138	0.2
Total			19.45Km	Total			64.85Km

Table B-2: Sample Interruption Data for DD Substation I

2011e.c interruption data								
FEEDER NAME		TEF	PEF	TSC	PSC	OP	SOL	SHADING
F1	F	108	43	162	78	84	0	0
	D	2.747	43.35	4.06	90.36	32.197	0	0
F2	F	161	44	38	57	53	0	0
	D	4.23	38.4	1.07	53.75	12.05	0	0
F3	F	160	88	101	84	62	1	0
	D	4.18	112.5	2.74	88.12	35.95	0.1	0
F4	F	130	139	138	98	57	1	0
	D	6.147	125.957	4.11	74.09	27.08	0.1	0
F5	F	71	57	83	34	69	1	0
	D	2.34	48.06	2.05	34.46	25.46	0.1	0
F6	F	5	9	4	8	10	1	0
	D	0.09	69.88	0.08	115.58	8.79	0.1	0
F1(33)	F	3	6	0	0	9	0	4
	D	0.116	182.38	0	0	111.75	0	96.0
F2(33)	F	0	6	0	0	14	0	0
	D	0	84.21	0	0	35.45	0	0
F3(33)	F	20	127	0	0	54	0	4
	D	1.15	1105.42	0	0	93.93	0	147.57
132	F	8	12	0	1	4	22	0
	D	0.38	10.43	0	0.1	3.31	12.96	0
230	F	3	6	0	0	3	25	0
	D	0.15	4.28	0	0	23.03	38.03	0